Food Packaging Technology

Food Packaging Technology provides a comprehensive foundation in food packaging concepts, materials, and innovations critical for preserving food quality and ensuring consumer safety. Designed to bridge academic knowledge and industry application, the book explores conventional and modern packaging methods, the science behind modified atmosphere and active packaging, and the rising role of biopolymers in sustainable packaging. It serves as a core resource for students, researchers, and professionals involved in food science, food technology, and packaging industries.

Key Features

- Explains core packaging principles and their importance in food safety and shelf-life extension
- Covers modern advancements including modified atmosphere, active, and intelligent packaging
- Details sustainable packaging with a focus on biopolymers and ecofriendly solutions
- Explores packaging design, machinery, testing protocols, and safety standards
- Includes real-world insights into regulatory, functional, and industrial perspectives

Structured to align with academic curricula and industrial requirements, this book blends theoretical knowledge with practical relevance. It is an ideal reference for food technology students, packaging professionals, researchers, and quality assurance personnel looking to enhance their understanding of packaging's critical role in the food supply chain.

Food Packaging Technology

Edited by

M. Sukumar

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Preface

This book, titled *Food Packaging Technology*, is designed to provide a comprehensive and structured understanding of food packaging for students, researchers, and professionals involved in the food technology, food science, and packaging industries.

The book covers all essential concepts in a clear and organized manner, aligning with the needs of academic curricula and industrial applications. We confidently believe that this book will serve as an effective study material, especially for students pursuing advanced studies and training in food packaging and safety.

Each topic is explained in simple English with easy-to-understand illustrations and diagrams to support better comprehension. The language and presentation are kept student-friendly to suit both self-study and classroom use.

Step-by-step explanations, eye-pleasing layout, and logically arranged chapters make this book suitable for learners at various levels. Emphasis is laid on both theoretical concepts and practical insights, which are essential for bridging the gap between academia and industry.

This book primarily deals with:

- Basics of food packaging principles
- Packaging materials and their functional roles
- Modified atmosphere, active, and intelligent packaging
- Sustainable packaging, with a focus on biopolymers
- Packaging machinery, testing protocols, and quality standards
- Regulatory and safety aspects in food packaging

The book aims to give learners a holistic view of the role packaging plays in ensuring food safety, extending shelf life, and meeting modern consumer and environmental demands.

M. Sukumar
Editor

Editor

M. Sukumar is a senior academic and an esteemed expert in the field of food technology, currently serving as the director of the Centre for Food Technology at Anna University, Chennai. With a strong foundation in research and academic leadership, he has played a pivotal role in advancing food processing and packaging technologies in India and abroad.

He has over 100 research publications in reputed national and international journals and has contributed to four book chapters in the area of food science and technology. His academic mentorship is equally noteworthy, having successfully guided 15 doctoral students, and he is currently supervising 11 PhD scholars in diverse areas of food technology.

His research interests span food preservation, functional foods, food safety, and sustainable packaging solutions. As the editor of *Food Packaging Technology*, he brings extensive knowledge and a comprehensive understanding of current industry trends and scientific innovations. His editorial leadership in this volume reflects his dedication to promoting high-quality research and fostering collaboration between academia and industry for the advancement of food packaging systems.

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1 Packaging Concepts

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1.1 IDEA

So the questions remain: How did they enter into the world? How do marketers, package designers, output designers, merchandising experts, and the ad team come up with all of their ideas surrounding the package? What program do they use? Is it directed to them from the future as they attend waiting? Is it conceived by breakthroughs because they are the creative accumulation and intend to fulfil their action to exhibit their destiny? Do they function with hands out, eternally drawing and crumpling unsolicited ideas on paper, throwing the ball somewhere, so dozens of these inadmissible ideas sit in the ground, a mound of paper balls and discarded ideas (Moskowitz et al., 2009)?

1.1.1 Novel Ideas

In the first place, let us see the situation today. Numerous people who have substantial familiarity with the insights of employment, appear to believe that there is a standard expected procedure for developing an idea. These standard methods are instructed to every single person who is striving for a masters of business administration (MBA) degree. Also, numerous individuals trust that when a recently minted MBA comes into the company, they carries with them these dressed-to-the-teeth techniques, which are positively embraced by each organization. What's more, normally the activity continues forever. The achievement is, for all intents and purposes unique. There are no best practices for ideation. Each group has its star techniques. These techniques vary. Besides, a company will change its basic point strategies over time, so that the transformation over time implies cross-sectional (crosswise over organizations) and longitudinal (crosswise over a time, within an organization) changes. Astonishing as this oversight sounds, it originates from the fact that organizations like to hit the battlefield in a presence that continually moves. This plunge from issues to opportunities, then from strength of outstanding power to survival and continuation, produces Schumpeter's so-called 'innovative rack and destroy'(Plehwe & Slobodian, 2019) in the survival of ideation we are inquiring about. Organizations handle delightful techniques. The newly derived method works for a period of time, and in time it advances as a sustained life form to address new issues. The temperate condition encourages expressions and state-of-the-art techniques over an extended period of time. Using the same old methods resembles a house ablaze; the evolution of strategies is at times like a house ablaze, and the outcome is that each blend receives its own particular techniques for rapidly

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changing timeframes, misusing those techniques at the same time they backfire. At that point, when the need emerges in such a manner, the firm looks more effectively for the past 'battle' that will indicate solid thoughts (Coles et al., 2003; Paine & Paine, 1992).

1.1.2 Follow-Up of Ideas

The old axiom 'need is the mother of innovation' is particularly valid in the business universe of consumer items. The exceptional rivalry among brands you find in the grocery store is the noticeable result of gigantic endeavors behind the scene. Even though, 60 years ago, shoppers were glad to get any item that was adequately nutritious and reasonably priced, today customers are bombarded by the side effects of having numerous products. It is evaluated that more than 20,000–25,000 items are developed for the store racks each year, only for the vast majority of them to come up short. Some of these items flop gradually, others bomb rapidly, and some burn out (Moskowitz et al., 2009; Robertson, 2010).

Our inquiry is not about the items as such, however, but about the packaging. How do the packaging ideas come to fruition? Do the packages spring full-grown from the psyche of the package architect, as does Athena does from the head of Zeus in Greek folklore? Or then again, are the packages painstakingly made, scientifically created, and tested to within an inch of their lifeless lives by steady, proficient, and famously skilled economic specialists who investigate every possibility to find exactly how well the package will perform? Or on the other hand, more probably, does reality lie some place in the middle (Robertson, 2010)?

Packaging, not at all like the item itself, consolidates craftsmanship, designing, customer science, and a touch of acting flair. There is a creative angle to packaging. Packaging requires a comprehension of how to function in space and how to make the package remarkable, appealing, functional, and visible to the barraged, promoted-to eye. The package originator is a craftsman—maybe a business craftsman, yet a craftsman in any case. Packaging is like a newly created building. The package must perform to its potential. It is not like advertisement or promotion, where you only guarantee the outcome. It has to work in the intended way for customers to believe in the product, which is in the package. Packaging needs to convey critical information such as product identity, freshness, safety, nutritional value, functional benefits, and sustainability attributes, thereby influencing consumer trust and purchase decisions. Without other saving graces, the package must store, secure, and even publicize the item that lives inside it (Coles et al., 2003).

So how does the package creator get thoughts? What strategies do planners use in organizations to make the new packages? Are these thoughts basically about the structure of the package (most likely difficult to do and once in a while requiring leaps forward)? Or are these thoughts principally about the illustrations (simple to do and requiring a flair for the configuration of illustrations, but not really the mechanical properties of materials and shapes). In this part we center on the wellspring of the thoughts. We will take a look at strategies that organizations use, keeping in mind the goal to make new thoughts regarding items. Since this book discusses packaging, we will extract from the outcomes some illustrative thoughts regarding packages.

Remember that in most corporate activities of the Information Age, packaging is just one focus among several competing priorities. More often than not, the new product development process regards packaging as one component of a much broader and integrated innovation effort (Paine & Paine, 1992).

1.1.3 Observing the World of the Market

Thoughts for packages frequently originate from basically watching individuals adapting to the issues, focuses, and even delights of their day-to-day life. Simply take a look at a youngster endeavoring to open a bottle of heart pills or sedatives. An overdose could be destructive. Or then again, think about a child endeavoring to tip the juice container to get more squeezes, spilling the substance over the table, the floor, and soiling the greater part of their recently cleaned garments. Or then again think about the more seasoned individual, say one's grandma, age 75, not so old but rather not youthful, adapting to the very firmly shut jug. How can she get that darned container open (Robertson, 2010)?

The package architect takes in a considerable measure just by strolling around. It doesn't take the virtuoso craftsman to perceive that the package of pills must be childproof, that the container must be easy to open for a mature individual, and that the print on a package in the store ought to be clear, particularly when it is going to have health data on it. On the other hand, envision the package planner strolling the store, taking a look at the variety of items on the racks, for instance, tea. One most loved product is the unavoidably well-known chai tea. A couple of years ago, customers could try new tea products, settle on a choice, and after that can go back to the stores later to restock. Those awesome, straightforward days are finished. The tea section is congested, similar to a yard of weeds with a polluted stream running close it (Coles et al., 2003). With weeds, or for this situation teas, as magnificent as they may be, a single specific product cannot consistently give satisfaction to the consumers; thus it becomes tedious to find delight in consumption of same type of product over time. How does the package planner manage this issue, to make an item critical and find capability 'in what is ending up being a wilderness' (Moskowitz et al., 2009)?

Over a century ago, anthropologists considering different societies started to distribute monographs on the social orders in which they lived. They called their strategies 'ethnography', covering a wide region of methods. The thought was that one could best find out about another culture by drenching oneself in that culture. Ethnography, customarily an exploration technique for anthropologists, uncovered parts of regular day-to-day existence in different societies that couldn't be generally observed.

It should not shock anyone that the business group received their attention. A whole school of business anthropologists arose, some basing their methodologies on the customary human sciences like sociology. Others constructed their anthropological undertakings with respect to a change of subjective methodologies in statistical surveying. Today, as this book is being composed, anthropological methodologies are extremely popular as approaches to comprehend the shopper (Robertson, 2010).

Where does this have an effect on package architects? It is certain that a decent observation of customers can disclose a great deal. With regard to different preferences, researchers examining human conduct find that it is the overall effect that quickly comes to the fore and command what we consider about the item. We don't regularly discuss loving or despising the package, yet we quite often discuss the flavor of the item, regardless of its composition or quality, whether it tasted incredible or unpleasant, regardless of whether it was excessively solid or excessively frail, and so on. In an exceptionally common sense, this prepotency or instantaneousness of the overall effect implies that we have to try to utilize better techniques, and be set up for harder inquiries, when we endeavour to comprehend packaging.

Today's world is competitive to the point that organizations can't sit tight for the after-effects of ethnography to demonstrate their openings. They should make these doors open. In some cases, opportunity creation originates from shrewd perceptions of day-to-day life. Realizing that it is hard for more seasoned purchasers to open packages implies that one can watch these customers to perceive how they adapt. Or again, in studies, one can inquire of purchasers whether they have any issue, and find what are the chances for them to have potential problems. By doing so companies can evolve and find solutions to adapt to and rectify the issues. The remainder of this section deals with managing two distinctive ways to making new thoughts, both done in general and for packaging.

The main general approach utilizes coordinate cooperation among individuals. Strategies, for example conceptualization, fit into this first approach. Through conceptualizing, individuals think of thoughts, and every person in the session may endeavor to enhance the thought, by and large withholding feedback in the meantime. This first approach depends on the immediate association of individuals to start new thoughts. The second approach utilizes innovation to encourage the improvement of thoughts. Innovation doesn't essentially think of thoughts. Or maybe, innovation helps the cooperation among individuals, records their thoughts, and presents the thoughts in new structures to different respondents, maybe isolated from each other. From the cooperation of individuals and innovation, new thoughts rise. These new rising thoughts are cleaned by people who may live a large number of miles from each other, who surely don't have any acquaintance with each other, but who team up to make the new thoughts (Coles et al., 2003).

Purchasers frequently have great instincts about what's required, particularly with regard to packaging and to tackling a specific issue. Frequently purchasers looking at packaging issues concoct innovative arrangements that, in the hands of a package builder, can make absolutely new, exceptionally solidly performing packages. Ideation for new thoughts in the customary strategies happens either in a gathering, in a discussion, or even with paper and pencil separately. Every one of the three techniques is utilized broadly, each having its own particular advocates and its own spoilers (Moskowitz et al., 2009).

At the point when ideation is directed in a gathering, the goal is for a person to concoct thoughts, and afterward to have different people expand on these thoughts. There are various sorts of such strategies, for the most part conversationally called conceptualizing. The members might be urged to do homework early and acquire thoughts, and to expand upon the thoughts of others, and even to alter the thoughts structurally (e.g., what is the inverse?). Basic to these methodologies is the utilization of the individual or gathering as the developer of a total thought. The goal of the session is to think of as many thoughts as can be allowed, generally unedited, with the acknowledgment that many of these thoughts are fragmented, infeasible, excessive, and so on (Paine & Paine, 1992).

It isn't strange for organizations to contract specialists to encourage these ideation sessions. These specialists may not really know a great deal about packaging or other particular themes that are the focal point of the sessions or about the present needs of the business. A couple of preparation reports are for the most part required for huge numbers of these better facilitators to bounce directly into the activity and start working with customers. The specialists are called 'specialists' in light of the fact that they know the procedure. The particular substance is left to the customer who procures the specialists and to the members who give the data. Obviously it is the key for specialists to tune in with the 'third ear' to know when they have hit 'pay earth' and to know when they are revealing new things.

The facilitator is frequently remunerated for this capacity by getting new assignments, not really in the same topic area, since as we simply noticed, the master knows and encourages the procedure, not the particular theme. Center gatherings (i.e., individual-to-individual or peer-to-peer contact) are well known today among facilitators as an approach to create thoughts. It is significant that a great part of the assistance improved the organizations' situation, in light of the fact that the objective is to create item and administration thoughts, instead of as a scholarly exercise to build the entirety of our insight.

This situation holds around the world. By far most of the ideation sessions are controlled by experts, for organizations, under command to think of new thoughts. Scholastic research is left to watch and remark on the procedure (i.e., compose articles about the procedure of ideation, as opposed to ideation itself as an issue). At times, scholarly research may utilize ideation in a restricted manner to manage generally small-scale connected issues, the sort given to colleges to resolve as a major aspect of a research grant or through an agreement. One noteworthy outcome of the connected idea of ideation is the absence of writing on outcomes. A few journals in item advancement (i.e., *Journal of Product Innovation Management*) manage ideation as a business procedure to be contemplated. There are likewise subjects – particular journals, for example those addressing food – that incidentally highlight an observational article about a connected issue, in which packaging research also comes in. The connected idea of ideation and the relative scarceness of research, unadulterated and connected, about packaging imply that there is moderately little in the logical writing yet substantially more in the exchange writing (Coles et al., 2003).

1.2 NEW PACKAGE – DERIVATION OF CONCEPT-LEVEL PACKAGING

Packaging is only one player in the new item. Advertisers get a kick out of the chance to talk about the five Ps: Product, price, place, position, and obviously packaging. *Product* incorporates the physical item that is being purchased, *price* is what is being charged, *place* is the means by which the organization discusses the item in promotion and advertising, *position* is the place on the rack the item is situated in the store, and obviously *packaging* is the thing that holds the item. It's an uncommon case that the focal point of any undertaking remains entirely on packaging. However, frequently, new item research includes packaging, and a considerable measure of the emphasis might be on the highlights of the new package. With the trial plan of thoughts, it is conceivable to work with packaging as a storehouse or set of storehouses, containing diverse components or choices. There will be different storehouses, obviously, for themes beyond packaging.

On account of this presentation, and perceiving that packaging is only one player in another process, let's perceive how one maker managed to open the doors for fluid margarine. Though the thought of fluid margarine isn't especially progressive today, it was when organizations understood that the very idea of 'fluid' indicated well-being and that they could get an additional 'something' by offering a fluid margarine as opposed to a strong margarine. Center gathering after a focus group proposed that 'fluid' hinted at 'stimulating,' maybe in light of the fact that there was an unexploited association between oil (particularly olive oil) and well-being. Oil is fluid, and fluid is well-being. Conversely, individuals have an inclination that the strong margarine item is some way or another 'counterfeit', a concoction, 'and in this way not all that empowering'. Like most 'early-organize' extensions in the new item plan, the fundamental need was not especially engaged. That is, at the point at which we started the task, the team truly didn't focus on any one subject. Converting from a strong to a fluid margarine was new, yet not absurdly so. You may feel that with organizations being in the business for many years, they would know the things to say with regard to the fluid margarine, what they should guarantee in the method for better well-being, and since the margarine is fluid, what sort of package is generally reasonable.

Nothing could be further from the truth. Indeed, there was an open door, and as it turned out, a major open door in numerous nations. It turned out that in spite of the fact that there were loads of reports from little, detached tests about individuals' inclinations for packaging, there was no far reaching database about what the package could be. Besides, it again turned out that this venture would need to make its own database, with a huge number of various thoughts, each fighting against the others, to drive extreme acknowledgment (Coles et al., 2003).

Because of this story, let's perceive how the organization tackled the issue, identified what the item ought to be, and obviously in doing so identified the specifics of the packaging. We can see the expansiveness of data that can be generated and after that quantified through today's research strategies.

In the mid-1990s, the organization had created fluid margarine. It rapidly turned out to be evident that this item could give extra and most likely quite noteworthy income to the organization, particularly in Europe. The inquiry was essentially what to do with this item. Around then the utilization of a test configuration to make new item concepts was winding up progressively acknowledged. Organizations in the 1990s perceived that they would need to contend on learning, not on basic expectation. It wasn't adequate to have experiences alone. In the food business, particularly, rivalry was warming up. We see a considerable measure of a similar circumstance today, after 15 years. The cost of passage is low. It doesn't take much cash to put another margarine on the rack, on the off chance that you can pay the 'opening charges' that the stores ask (nearly a lease for their space, to be possessed by your item). On the off chance that the item can be made to appear to be sensibly novel and buyer-worthy, at that point you have an opportunity to get onto the swarming racks and fight it out with contenders, at any rate for a brief period (Robertson, 2010).

By the day's end, the item engineer, package architect, advertiser, and promoting office need to concur on the item, its highlights, its packaging, and alternate Ps. Obviously, the undertaking is entirely clear when one is compelled to one of a couple of item frames, a couple of shapes, a couple of compartments, and a couple of lawfully affirmed messages. Such is the situation with the pharmaceutical business, where the greater part of the work focuses on informing, not on item shape and positively not on packaging. Turn that arrangement of imperatives firmly on its head with regard to products in another shape. Positively there are a set number of fundamental packages; however, the number of elective thoughts can be stunning. The inventive package architect can work with various essential compartments, and for these holders the architect can work with the same number of diverse highlights on the holder. Ultimately, only creative energy confines the opportunities. Researchers who work with item ideas need to settle on decisions in what they do, particularly when they work in a business situation that requests choice and activity. At the point when there are numerous viewpoints on an item, for example, the fluid margarine we address in this part, the scientist can choose some encouraging thoughts, and after refining these thoughts in center gatherings, the scientist can test the thoughts for claim and for conceivable market achievement. In such a case the exploration purposely centers on a couple of promising thoughts. Testing the ideas for potential execution resembles running a 'wonder challenge' (Moskowitz et al., 2009).

As analysts, package architects, item engineers, and advertisers, we are accustomed to our own classifications or methods for isolating data. One of these routes is by nation. It is a normal learning (albeit once in a while inferable) that individuals contrast in their inclinations by nations. It's clear that there are contrasts in nations and societies in light of the fact that the world isn't yet homogenous in its entirety. However, individuals of various nations need distinctive things, for example, packages: Each individual finds convenience in different types of packages, which makes us wonder about individuality with respect to particular needs. We can test the theory that there are distinctive nation-to-nation inclinations.

1.3 PACKAGES IN MARKET VERSUS PACKAGING CONCEPTS

Let's audit for a minute the contrast between item ideas and package outlines. Item ideas enlighten the engineer or shopper regarding the item. Item ideas come in two structures: ideas that tell the engineer what is available in the item and ideas that explain to the buyer the reason to get it.

We see here a significant astonishing advancement from a traditional foundation saturated with religion and moral values to an all-time most loved tidbit found on the racks of grocery stores, school cafeterias, and candy machines. Thus we picked this intriguing prevalent nibble food. Let's take a look at thoughts regarding pretzels versus what you can really appear on a package–and what's more, most critically, what works! In spite of the fact that that technique for package creation is a distant memory, we are as yet faced with a similar issue; in particular, what do planners say on the package, and how would they outline an item's package that would persuade buyers to purchase? What do you see about pretzels, and what do you show on packages? Before we outline the package, be that as it may, let's consider how ideas for items vary from ideas for packages. Ideas for items are to some degree wealthier. Ideas paint word pictures in the brain. Individuals can add in all the missing pieces in an idea. Interestingly, package configuration is constrained to specific pictures that can be set on a package. Obviously, you may state that a person fills in the spaces' with his psyche, notwithstanding, when they see a package. By the day's end, nonetheless, the psychological picture we get from an idea is frequently wealthier than the psychological picture we get from a package, essentially in light of the fact that there are such huge numbers of subtleties in dialect.

Let's now move to the corresponding scene, this one around the package plan of pretzels. We will move out of dialect and portrayal, where mental pictures are made, into the universe of quick impressions. We are moving from a universe of depictions that may make an author glad to the universe of masterful style, where toning it down would be best, where affect is basic, and where there isn't sufficient space to exhibit one's message in the most expressive frame. But then, we move to a world where everybody fights, with restricted consideration. Genuinely we move from the universe of Shakespeare and masterworks to the universe of Malthus and Darwin (Moskowitz et al., 2009).

1.4 CONCEPTS FOR CONTAINER

The vast majority of what we cover in this book addresses the different parts of a plan. Be that as it may, shouldn't something be said about the real package itself, the three-dimensional holder, stripped of pretty plans and basically a useful item? Would we be able to apply the strategies systematically to comprehend what highlights individuals need? Also, much more essentially, would we be able to do this in an effective way, with the goal of on-time planning, to manage the need of consumers using packaging concepts? In this section we will do just that. We will take the standards of the test plan that we utilized for illustrations and apply them to the portrayal of packages with compartments to hold food. The outline components that we address contain highlights that are useful, yet in addition some that are utilized for reasons of style (Robertson, 2010).

Today's PC innovation enables the originator to show a wide range of highlights of packages to purchasers. At the beginning, the packaging work should be possible in the virtual universe of the two-dimensional PC screen. After this underlying work is done, the information from the investigation should point toward the specific items that the three-dimensional compartment ought to involve. It winds up plainly essential to make the physical package in three measurements, utilizing the best possible materials manufactured for the final packaging (Paine & Paine, 1992).

Let's now move out from the universe of unadulterated package outline into the more utilitarian universe of plastic compartments for food. When we discuss plans in this world, we are discussing the way the holder works, and in addition how much the compartment satisfies. In different parts we have discussed the plan as an apparatus to help offer the item. Here we discuss plan as the contribution to making the package really play out its activity.

The vast majority of people know about clear plastic holders into which one can put scraps. These have diverse physical highlights. Orderly investigation can enable us to recognize what works and what doesn't. As we advance through this section, we should remember that the criteria for winning thoughts is not simply 'love'. Rather, the respondent must assess the outlines on various distinctive characteristics. Beyond intrigue, the principal evaluative credit is how much the item would play out its capacity. The item might be appealing, yet if it doesn't seem to guarantee that it will be a decent stockpiling compartment, chances are that it won't be obtained (Moskowitz et al., 2009).

This issue of 'vital storehouses' isn't a hypothetical one. It produces particular steps in both the test plan, which lays out the particular mixes, and the examination, which recognizes the commitment of every component to the rating. We will probably make a model that relates the nearness/nonattendance of the distinctive components to the relevant variable.

The presence of a storehouse—containing elements from which at least one must be included in each idea—is addressed in a straightforward, though not entirely exhaustive, manner. Here are the means: ("Silo" or "storehouse" means a container for designing an experiment to test consumer preferences.)

1. Place every component into its appropriate storehouse.
2. Distinguish the storehouse or storehouses where there are 'genuine zeros' (i.e., the storehouse can be authentically truant from the idea).
3. Recognize the storehouse or storehouses that *must* be in the test idea or visual outline. Call these storehouses the 'constrained storehouses'.
4. Code the greater part of the components as 1 or 0 for the diverse boosts, with 0 meaning missing and 1 signifying present.
5. For the greater part of the storehouses that have a genuine 'zero' condition, let the greater part of the components be indicators in the relapse display.
6. For the majority of the storehouses that are 'constrained storehouses', intentionally pick one component from every storehouse to let well enough alone for the condition. It doesn't matter which component is going to be forgotten, as long as one and only one component is chosen to be missing from the model.
7. In our undertaking here on the compartment, we have three storehouses that must be constrained in. We can pick whichever component from the storehouse we wish to 'forget'. That arrangement of left-out components will appear consistent in the added substance, as we see subsequently.
8. The three constrained-in storehouses are visual appearance (forget shading – see through), visual shape (forget square), and visual conclusion (forget standard seal).
9. Presently run the review on the information. You will get the outcomes in the traditional arrangement, including an added substance constant, and effect or utility values corresponding to the components that were used as indicators.

10. The added substance constant in traditional research all through this book compares to the assessed utility or effect if no components are available. Normally this 'no components introduced' would be the situation for these holder's information also. Three of the storehouses can be missing (Silo D: visual seclusion; Silo E: fittingness and activity in fridges, coolers, and microwaves; Silo F: cleaning). Three of the storehouses can't or ought not to be missing (Silo A: visual appearance; Silo B: visual shape; Silo C: visual conclusion).
11. The added substance constant relates to the zero cases for each of the six storehouses. For three of the storehouses (D, E, F), there are genuine zeros. For the remaining three storehouses, the zero cases are particular conditions 'left out of the model'. Keep as a primary concern that it doesn't truly matter which specific component in each storehouse is forgotten.
12. When we choose among obvious zeros and constrained components, we can appraise the effect or utility estimates for all components. The effect estimates have genuine, total significance for those storehouses that permit genuine zero (i.e., those three storehouses that can be truly truant from the package idea without influencing the truth of the package).
13. Conversely, the utility estimates are in respect to the specific component that is chosen as the reference for those storehouses that we choose to be in the project. Change the component, and the effect estimates change. Nonetheless, the distinctions among components never show signs of change; just the effect estimates do.

1.4.1 Producing the Container Package (According to Consumer Preference) from Results

How would you make an ideal holder from this information? Maybe the least difficult path is to distinguish the components that win. Begin with the added substance constant (which relates to a specific package that is 'see through appearance', 'square shape', 'standard seal'. Then look at each of the storehouses and distinguish components that perform well. In the event that the component has an obviously high utility (>5), at that point by all means incorporate this winning component. If the component does not have a considerably high utility (0–5), you might need to incorporate it. It's a choice. The best thing is that the fundamental item is now dealt with by the added substance constant. The utility or effect estimates are substitutes for the fundamental components incorporated into the added substance constant.

1.4.2 Packaging Concept from Market Requirements for Attracting Consumers

We encounter packaging in a universe of three measurements, in a universe of activity, and in a universe of outcomes. Researchers and economic scientists are keen on the well-tempered laws of reality. This emphasis on strong outcomes regularly drives agents to influence the packaging to be consistent, regardless of whether the experience is content ideas, illustration outlines, or genuine packages themselves. We weren't fundamentally considering the package in real life, or in the event that we do, at that point as a rule we abandon some of that reasoning to the originator. All things considered, the thinking goes, researchers endeavor to gauge what is and attempt to make sense of the 'rules' of reality. It is up to the creator to coordinate these guidelines into the package or its illustrations.

Lately, specialists have started to understand that it is imperative to catch the package's involvement. In one of the most on-point cases of the use of video, Mike Gadd in Toronto built up an Apple QuickTime reenactment of the shopping knowledge, for which he won a well-merited honor at an ESOMAR conference on development. Gadd's work forecasted a portion of the later work on the shopping knowledge. Through re-creation, he could catch a portion of the genuine video of a shopping background and bring that recording into an investigation where respondents could 'go shopping' in what might end up being a virtual situation.

Scholastics and after that specialists soon perceived the value of video, or maybe it would be more right to state that while Gadd was doing his work in Toronto, others in the scholarly world were taking a look at the capability of video to give further information about the shopping background. Beginning in the mid-1990s, for instance, Professor Raymond Burke and his associates at Harvard and after that at Indiana University began to think about how customers reacted to the rack. As opposed to furnishing the purchaser respondents with straightforward 'rack shots', which are static, Burke gave the respondents racks loaded with items, speaking to what might be seen at a store. By utilizing the PC, respondents could then pick out an item, turn it around, zoom in, investigate it, and select it if wanted (Moskowitz et al., 2009).

The managing viewpoint is the individual–package connection. It was immediately acknowledged by everybody that depicting the activity of utilizing the item may deliver a response; however, would it be the response to a photo, or would it be better from a genuine encounter? Another issue, less critical yet at the same time an issue, was that it is hard to get some of these new packages in adequate amounts for individuals to study their involvement in utilizing them. A final issue, constantly imperative in organizations, was secrecy. It was one thing to discuss a package, another to demonstrate a video of a package, yet it was impossible to let the package outside of one's coordinate control. Workers in organizations perceive these distinctive levels of concern, in some cases all the more seriously in specific ventures (Coles et al., 2003).

With the advancement of video abilities in the PC program combined with high-determination screens, we discovered it was conceivable to present video and pictures as 'visual components' into idea assessment. It didn't matter to the respondents who were watching the screen whether they were looking at content alone, at content in addition to picture, or content in addition to video. One of the storehouses was a visual storehouse, which was introduced on the screen for around 5 s if a video, or present for the whole idea assessment if a basic picture. The respondent could replay the video by a straightforward keystroke.

1.5 INFORMATION IN PACKAGE LABELS FOR MARKETING

In organizations, the planner doesn't simply go off, willy-nilly, to make the package configuration, regardless of how skilled the fashioner might be or how energized the outer plan organization says they feel. Perhaps a considerable measure of what can be said needs to spur the client to purchase the item. Just precisely how would you find what persuades? All things considered, the appropriate response can be gotten either by speculating (which happens more regularly than you may want to accept), by guarantee testing ('Which of these announcements do you like?'), or by tentatively composed ideas where the messages are blended and coordinated. We're going to outline the homework by taking a look at tentatively planned ideas for grain. We'll find that the fashioner has a considerable measure to browse once the trial is run, and that the triumphant thoughts 'float to the top' (Paine & Paine, 1992).

A great deal of what we will introduce originates from the universe of idea testing. We will concentrate this section on getting the correct dialect before we go to the plan viewpoint. As you will learn, the right dialect doesn't simply mean the right points to put on the package. The right dialect implies the correct method for saying what you need to state, effectively and influentially (Moskowitz et al., 2009; Paine & Paine, 1992).

1.5.1 Discussing Cereal

Where did this so-prevalent staple found in our cabinets begin? All things considered, it has a place profoundly inserted in our history. For instance, in Eurasia, remains of domesticated grains (grain, einkorn, and emmer wheat), sickles and hand axes have been dated at different locales to 8000 years BCE. Oats have been around quite a while, and from all the business movement around it, it would seem that grain is staying put. The word 'grain' itself originates from Ceres, the Roman goddess of the harvest and farming. Oat grains are developed in more prominent amounts worldwide than some other harvest. In some growing countries, oat grains constitute almost a person's whole eating routine.

An anecdote about a now famous item paints a pleasant foundation for our undertaking. There are such huge numbers of varieties of oat items that knowing 'what to state' requires some experimentation. Grains give more food to human utilization than do some other yields. We're all comfortable with the now basic cereals produced using rice, wheat, grain, oats, maize (corn), sorghum, rye, and certain millets, with corn, rice, and wheat being the most critical. Another grain, triticale, adds to the rundown, yet triticale is a man-made, genetically modified item. Triticale originates from the intersection of wheat and rye, subsequently multiplying the quantity of chromosomes. Today, chilly oat, likewise called RTE or ready-to-eat, is a rapidly growing industry, always developing to stay aware of the ever-changing requests of today's shrewd purchasers. More recently, the industry gave purchasers discernibly fewer decisions. Customers normally didn't request much. Observational research, so-called 'customer bits of knowledge', uncovered that buyers by and large honed in instantly on what they needed.

They regularly went specifically to the recognizable area on the rack to find and select their family's cereal. Presently, a stroll down the oat aisle can be very different than it was in the past, loaded with offerings, astonishing in the assortment to be found. Thus taking a look at how organizations showcase their oat items gives us a decent report point to acquaint with our universe of plans. Be that as it may, first, let's manage the thoughts – the hot takes that the creator should finally fuse in the package.

With such a history and family, grains have loads of things that can be said with regard to them. Every single oat grain has high-vitality esteem, coming mostly from the starch portion and in addition from the fat and protein. As a rule, grains are low in protein content, although oats and certain millets are special cases. Whole-grain foods are profitable wellsprings of supplements that are inadequate in the American eating regimen, including dietary fiber, B vitamins, vitamin E, selenium, zinc, copper, and magnesium. Whole-grain foods additionally contain phytochemicals, for example phenolic aggregates, which together with vitamins and minerals may assume imperative parts in infection avoidance.

The rule developing experimentation (RDE) apparatus works in a direct way. To repeat two or three striking thoughts:

1. Individuals don't realizes what they need until the point when they see it.
2. You get more sensible outcomes when you introduce mixes of thoughts together. That's the way nature works in any case; so let us reproduce nature instead of presenting individuals with one thought at any given moment.
3. If you deliberately change the blends or vignettes so the respondent sees an arrangement of these mixes, you can recognize what each grain component 'conveys to the gathering'. You utilize regression analysis, a standard statistical method found as a highlight in most spreadsheet programs, yet quite often accessible in like manner in statistical software packages.

Luckily, scientists have perceived the way that individuals significantly contrast from each other in what they like; however, these distinctions may not show themselves in how individuals portray their conduct. These distinctive gatherings are mindset portions. We have seen the power of such division over and over in these sections, and we will keep doing so. These sections are genuine, and significantly not the same as each other.

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2 Importance of Packaging

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2.1 INTRODUCTION

Packaging plays an important role in the field of marketing the targeted product. Technological and scientific upgrades have brought revolutionary change in packaging. In the old days, people use to buy their products in bottles or gunny bags. But currently, due to the upgrades in technology, neatly packed, branded grocery items are available in the market.

Main aspects are as follows:

1. *Protection*: The designed package will be based on the nature of the product matrix in such a way as to encounter the damage from climatic hazards and mechanical hazards. Climatic hazards include the atmospheric moisture, oxygen, heat, cold, and microbial attack. Mechanical hazards include impacts, vibrations, and compressions during the packing, storing, transportation, and distribution of the products.
2. *Preservation*: Packaging materials are designed under circumstance to enhance the shelf life of the targeted products. The packaging design helps to maintain the quality of the product till it is consumed. The better the packing, the better the preservation of the qualities of the products. Proper intactness of packaging is an assurance of the product qualities and infuses confidence among consumers to prevent spurious items and cheap imitations.
3. *Promotion*: The packages of products are the silent salesperson and tend to attract the consumers toward the products. Manufacturer can cut the advertisement costs by using proper packages. The artful packages of confectionery and bakery products tempt the customer to buy the products. Good packaging may not save a bad product, while bad packaging can definitely derail a good one. Figure 2.1 explains the packaging concepts and their application in the food industry.

2.2 NEED FOR PACKAGING

1. Protects from the microbial spoilage
2. Prevents the leakage during transportation
3. Uniqueness
4. Marketing

Packaging materials are designed to play an important role in protecting the products till they are consumed by consumers. They also provide us with important product

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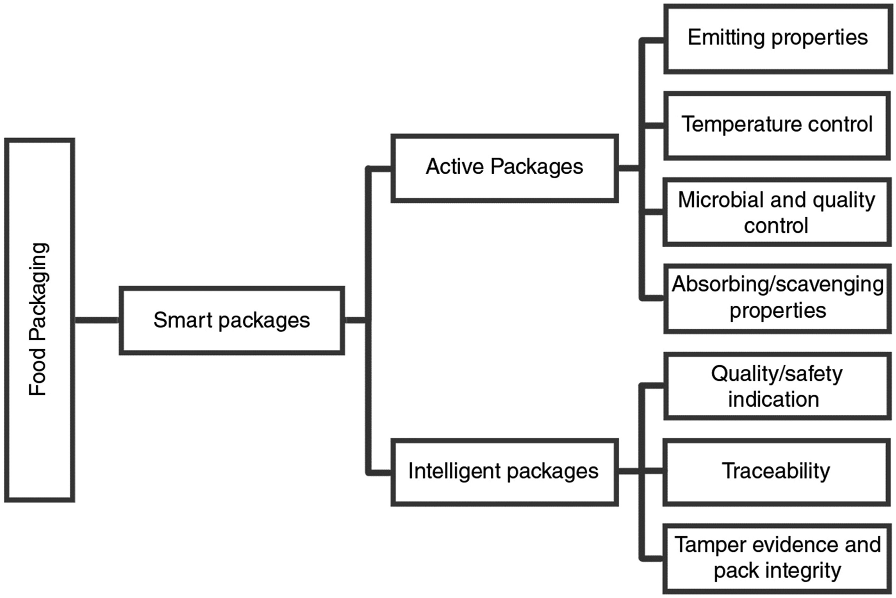

FIGURE 2.1 Process flow – role of packages and their importance in food industry.

information about nutrition and storage, for example. Currently, the usage of nonbiodegradable materials as food packaging units been significantly increased. The nonbiodegradable materials are usually produced from petroleum crude and increase complexity during disposal (Avella et al., 2005). In order to overcome this, development of bio-packaging (biopolymer) materials would be one of the most promising approaches and would play an ecofriendly role due to its biodegradability (Tang et al., 2012). Bio-packaging is mostly derived from biopolymers; these polymers are developed from the monomeric units with covalent bonds to form chain-linked molecules. The term *bio* denotes that these polymer-based materials are degradable. Due to its biodegradable properties, biopolymers are regarded as alternative materials to nonbiodegradable materials like plastics made from petroleum crude. The common biopolymer-packaging units have been developed from starch, cellulose, carbohydrates, whey protein, alginate, and so on.

Currently, the recent upgraded techniques led to the production of synthetic biopolymers, which include polyvinyl alcohol (PVA), polylactic acid (PLA), polycaprolactone (PCL), and polyglycolicacid (PGA) (Rhim et al., 2013). Benefits of synthetic biopolymers are increased physico-chemical properties such as flexibility, durability, clarity, and tensile strength.

2.3 ACTIVE PACKAGING

Active packaging is an innovative packaging technique, where the targeted product is highly exposed to a safe environment to extend the shelf life and maintain the quality of targeted food products (Ahvenainen, 2003). Active packaging involves

TABLE 2.1
Active Packaging's Role in the Food Industry

Type of Active Packaging	Role in the Food Industry
Releasing/emitting properties	Antimicrobial, antioxidants, preservatives, flavor, carbon dioxide, etc.
Temperature monitor	Heat-sensitive package, insulator-based packages, auto temperature sense modifier packages
Microbial and quality control	UV- and surface-treated packaging materials
Absorbing/scavenging properties	Taints, moisture, oxygen, carbon dioxide, ethylene, flavors, etc.

packaging units that protect the food from contamination or degradation by means of a barrier to control the internal and external atmosphere within the package (Ettinger, 2002). The European Union Guidance to the Commission Regulation (EUGCR) No 450/2009 defines active packaging as a type of food-packaging technique with an added function of providing a protective barrier against external influence. The packaging absorbs food-derived chemicals from the food or the environment within the packaging surrounding the food, or it releases substances into the food or the environment surrounding the food such as preservatives, antioxidants, and flavorings (EU, 2009). The packaging units alter the conditions of the packed foods to enhance its shelf life and ensure its safety and sensory properties by maintaining the quality of packaged food (Ahvenainen, 2003). The active packaging also includes freshness enhancers that can participate in a host of packaging applications and also enhance the preservation function of the primary packaging units (Table 2.1).

2.3.1 Releasing/Emitting Properties

2.3.1.1 Antimicrobial Activity

Antimicrobial packaging was developed using the following concepts (Apeendini & Hotchkiss, 2002; Coma, 2008; Cooksey, 2001):

- *Development of packaging film and units along with the direct incorporation of antimicrobials agents*: The packaging films can be developed by admitting the conventional heat treatment (co-extrusion of packaging films with the antimicrobial activity), with a chance of losing the activity of bioactive compounds), and by nonheating methods, such as solvent compounding, electrospinning, and casting, which can be used to maintain the maximal activity of active compounds in the packaging films (Sung et al., 2013). The antimicrobial compounds will be gradually released from the packaging films to the surface of the food and inhibit the microbial growth.
- *Sachet or pad incorporated with the active antimicrobial substances developed along with the packages*: These active compounds get released from the sachet or pad to play an antimicrobial role (Otoni et al., 2016). Antimicrobial packages are developed mostly for perishable products to inhibit or arrest the growth of microorganisms.

- *Coating the packaging material with a carrier matrix*: The matrix possesses the activity and release of antimicrobial agents to the surface of the food through evaporation into the headspace (volatile substances) or migration into the food (nonvolatile substances) through diffusion. This matrix can be a plastic film or any food-safe material such as wax or polysaccharides incorporating antimicrobials directly coated on the food.
- *Use of polymers that are inherently antimicrobial*: Chitosan and poly-L-lysine have a good range of antimicrobial activity. The charged amines of the polymers interact with negative charges on the microbial cell membrane, which causes leakage of intracellular constituents and then cell death (Goldberg et al., 1990). Calcium alginate films have also been reported to reduce the growth of the natural flora and coliform inocula on beef, and the antimicrobial mechanism is probably due to the ionic and toxic effects of calcium chloride on bacterial cells (Williams et al., 1978). Generally, bacterions, antibiotics, ethanol, Ag ions, chlorine dioxide, essential oils, carbon dioxide, organic acids, and spices are frequently tested for their activity against the bacterial growth in the foods (Suppakul et al., 2003; Zhou et al., 2012). Comparatively, plant extracts such as peptides and nisin are frequently used as antimicrobial agents (Arvanitoyannis & Stratakos, 2012). The antimicrobial active packaging materials available in the market are listed in Table 2.2.

TABLE 2.2
The Antimicrobial Active Packaging Materials Available in the Market

Active Compounds	Industry	Products
Glucose oxidase	Bioka, Bioka Ltd., Finland	Sachets
Allyl isothiocyanate	WasaOuro, Lintec Corp., Japan	Sheets
Wasabi extract encapsulated in cyclodextrin	Wasapower, Sekisui Plastics Co., Ltd., Japan	Coated PEF and tablets
Silver [Ag]	Zeomic, Sinanen Co., Ltd., Japan	Films, paperboard cartons, wraps
Sulphur dioxide	Uvasy, Grapetek, South Africa	Laminated sheets and pads
Allyl isothiocyanate	Wasaouro, Mitsubishi-Kagaku Foods Co., Japan	Antibacterial and antifungal sheets, labels and films
	Natamycin	Sanico, Laboratories STANDA
Silver zeolite	Aglon, Agion Technologies, USA	Films, paperboard cartons, wraps
Ethanol vapour emitting	Ethicap, Freund, Japan	Sachets
Ag	Biomaster, Addmaster Ltd., UK	Masterbatch
Ag	Biomaster, Linpac Packaging Ltd., USA	Trays and films
Ag	d2p, Symphony Environmental Ltd., UK	Trays and films

Source: Adapted from Coma (2008), Realini and Marcos (2014), and Sung et al. (2013).

2.3.1.2 Antioxidant Active Packaging

A higher level of O_2 in the packaging matrix facilitates lipid oxidation and maximizes the off flavors and off odors. This also leads to microbial growth, color changes, and nutritional losses. Development of rancidity and potential formation of toxic aldehydes occur due to lipid oxidation. Polyunsaturated fatty acid (PUFA) degradation leads to nutritional quality (Gomez-Estaca et al., 2014). For example, in meat packaging, the control of environmental oxygen levels determines the rate of deteriorative and spoilage reactions. The compounds with the higher activity of antioxidants infused with the packaging matrix improve the quality of products and extend its shelf life. Antioxidant active packaging systems are grouped into two categories: (1) oxygen scavenging systems and (2) antioxidant packaging materials (Gomez-Estaca et al., 2014).

2.3.1.3 Oxygen Scavenging Packaging

Packaging matrix like sachets and labels tend to contain some oxygen scavengers. These scavengers are developed in a sandwich concept to avoid surface contact with the food. Minute and well-pulverized powders of ferrous and iron oxides are frequently used oxygen scavengers. Apart from this, ascorbic acid, ligands, sulphites, and glucose oxidase have also been under consideration in developing the packaging matrix (Brody et al., 2008). The scavenging reaction has been triggered by specialized mechanisms. For example, in an iron-based scavenger packaging matrix, the humid atmosphere is required to activate the oxygen removal (Lopez Rubio et al., 2004). The uses and applications of O_2 scavenging packaging have been extensively reviewed (Rooney, 2005; Suppakul et al., 2003). Available O_2 scavengers are listed in Table 2.3.

TABLE 2.3
Currently Available Active Antioxidant Packaging

Product Activity	Industry
Film coated with antioxidant	ATOX, Artibal SA, Spain
Film suitable for high temperature	OMAC, Mitsubishi Gas Chemical Inc., Japan
Resin	Oxbar, Constar International Inc., Plymouth, USA
Sachets	OxyGuard, Clariant Ltd., Switzerland
Sorbents	Desi Pak, Sorb-It, Tri-Sorb, Getter Pak, 2-in-1 Pak, Süd-Chemie AG, Munich, Germany
Label	ATCO, Laboratories STANDA
Barrier resins	ActiTUF, MandG Finanziaria s.r.l., Alessandria, Italy
Sachets	FreshPax, Multisorb Technolgoies, Inc., USA
Caps, closures	O2S, Bericap GmbH und Co. KG, Germany
Container suitable for high temperature	OxyRx, Mullinix Packages Inc., USA
Masterbatch	Shelfplus O_2, Albis Plastic GmbH
Sorbents, shield	Tri Sorb, Tri Shield, Tri Sorb EVA, Tri Shield EVA blue, EVA Tri-Seal, Tekni-Plex, Belgium
Sachets	OxyCatch, Kyodo Printing Co., Ltd., Japan

2.3.1.4 Antioxidant Packaging Materials

In antioxidant packaging materials, the active compounds with the higher range of antioxidant activity were incorporated within the layers of packaging film matrix. The active compounds were designed to diffuse into the surface of foods to prevent rancidity and to absorb undesirable compounds from the headspace around the product. The type of polymer and the characteristics of the antioxidant agents were taken into consideration to achieve the maximal activity of the matrix. If the antioxidant activity of the matrix is based on a diffusion process into food products, then the release of targeted active compounds should be permitted as food additives, complying with regulations in terms of their maximum allowable concentration. The active compounds were infused with packaging polymer matrix by (1) incorporating the active compounds in the molten matrix, (2) using coating techniques, and (3) immobilization of active compounds in the matrix (Gomez-Estaca et al., 2014).

2.4 INTELLIGENT PACKAGING

Intelligent packaging is designed to monitor and communicate information regarding the quality of food products. These techniques are used to trace a product and its history via critical points in the supply chain of food products. The quality of a perishable food changes as it proceeds from harvest or producer to consumer. Perishable foods are a class of foods that are active biological systems with high reaction rates of spoilage after harvest, processing, or slaughter (Van Boekel, 2009). There is a large economic and environmental loss due to expired perishables because of their limited shelf life. Perishable foods are often not or only minimally processed, and storage conditions strongly influence the quality of foods. Food manufacturers can face difficulties in ensuring the quality of perishable foods and can experience negative consequences when consumers are disappointed by the quality of their foods. If the quality of foods can be monitored during the entire supply chain, quality assurance can prevent consumer disappointment, and retailers don't need to discard food that has reached the printed shelf-life date but still has an acceptable quality. Intelligent packaging can be used, in principle, to inform all actors in the chain like wholesalers, retailers, and consumers about the quality status of foods, and it offers the possibility to take logistic actions based on dynamically estimated shelf life, thereby reducing waste of foods. The research described in this thesis investigated the possibility to use intelligent packaging for monitoring food quality, and it describes, as a case study, an approach for the development of a nondestructive sensor for monitoring quality of packed fish.

Intelligent packaging gives more information than the conventional packages. The consumer gets the knowledge of both internal and external activities of the product by means of observation and regular records. Both the internal and external conditions of the product can be monitored using intelligent packaging. Intelligent packages assess the quality of food products by means of direct contact in the headspace unit or by using indicators for the safety and quality of the packaged food products. Generally, the indicators represent the ripeness regulators, bioprobes, toxin indicators, radio frequency indicators, gas leakage signals, and time–temperature

TABLE 2.4
Intelligent Packaging Role in Food Industry

Intelligent Packaging	Role
Quality/safety indication	Pathogen detection, microbial growth, enzymatic spoilage, gas-sensing devices, time–temperature indicators
Traceability	Radio frequency identification labels, tags, chips
Tamper evidence and pack integrity	Breach of pack containment

monitors (Stauffer, 2005). The intelligent packaging concepts are used to evaluate the strength and efficacy of active packaging units (Kerry et al., 2006).

The role of intelligent packaging is to provide a detailed knowledge throughout the supply chain and regulate the food quality by means of identifying the critical points with the use of attached, incorporated, or printed labels onto packaging materials (Dainelli et al., 2008). Temperature regulators are used for regulating the self-heating and self-cooling systems. In self-heating is regulated by the heat generated by the exothermic reaction of MgO, Ca, and H_2O. The major portion of packages space is accomplished by the heating device, which is the main drawback. Self-cooling packages are available to induce the cooling effect by means of evaporating the external components (Brody et al., 2008). Intelligent packaging was developed with the presence of ethylene adsorbers and absorbers; the removal of ethylene from the packaging units helps to retain the quality level and to extend the shelf life of the food products. Potassium permanganate is used as an ethylene absorber, which oxidizes ethylene to ethanol and acetate (Table 2.4).

2.4.1 Indicators

1. Time and temperature indicators (TTIs)
2. Freshness indicators
3. Leak indicators

2.4.1.1 Time and Temperature Indicators

Temperature is the most influential environment factor that has a direct impact on safety and the quality of food products (Aung & Chang, 2014). TTIs are a tool that is developed to monitor the effect of temperature on the quality of food products (Wanihsuksombat et al., 2010). The operating principle of the indicators is based on the irreversible change due to enzymatic, chemical, mechanical, electrochemical, and microbiological causes, generally expressed as a visible color response. The colour response rate is temperature dependent; the response denotes the label storage conditions and expresses the quality of the packaged food products (Taoukis, 2008).

Two categories of TTIs are partial history indicators and full history indicators. Partial history indicators – normally, the color response expressed until some predetermined threshold temperature is exceeded. Full history indicators are the color response expressed continuously to all the temperatures. There is no direct correlation of color response with the quality of the food product (Robertson, 2013).

Properties

- Frequent changes in color response
- Ease of measurement
- Time–temperature dependencies
- Irreversibility
- Reproducibility
- Low cost
- Resistance to normal mechanical abuse
- Simplicity and clarity in conveying the desired information to the consumer

TTI packaging units are frequently proposed among all other intelligent packages (Table 2.5).

TABLE 2.5
Time and Temperature Indicators

Manufacture	Description	URL
OnVu TTI from BIZERBA North America Temperature sensitive composed adhesive label	Photochromic ink based on benzyl-pyridines that are activated by UV light, which turn them to a dark blue color.	www.bizerba.com
CheckPoint Indicator from VITSAB Visual Indicators Tag Systems AB	Simple adhesive label with the device consists of a bubble-like dot containing two compartments. The dot, initially green in colour, becomes progressively yellow as the product approaches the end of shelf life. The reaction is irreversible and will proceed faster as the temperature is increased and slower as the temperature is reduced.	www.vitsab.com
Fresh-Check Indicator from TEMPTIME Corporation	An adhesive label with the active centre circle darkens irreversibly, faster at higher temperatures and slower at lower temperatures. Indicator polymer formulated from diacetylene monomers The polymer, which starts lightly colored, gradually darkens depending on difference in the temperature.	www.fresh-check.com
eO TTI from CRYOLOG	An adhesive colorimetric indicator with the nutritive medium in the shape of the petal of a flower and a dye indicator, which is responsible for its initial green color.	www.cryolog.com

2.4.1.2 Freshness Indicators

Freshness indicators in the packaging units represent the quality of food products. Their working mechanism depends on the irreversible detection of metabolites such as amines, ethanol, enzymes, sulfur dioxide, carbon dioxide, NH_3, and toxins, which present on the upper layer of food products due to their deterioration. A profound knowledge about the metabolites, which affect the quality of food products, is an essential prerequisite for the development of freshness indicators. These types of indicators are developed from substances that possess a huge variation in color response when the previously listed metabolites occur in the food products during its deteriorations. Freshness indicators are placed inside the package and allowed to expose in the headspace atmosphere. The packaging materials should be developed accordingly for direct surface contact on the food products and also comply with strict regulations (Table 2.6).

2.4.1.3 Leak Indicators

Leak indicators focus on the package integrity during its complete distribution chain. These indicators are developed as a printed layer, laminated in a polymer film, as a label, or as a tablet. The food products are packed in the modified atmosphere packaging (MAP) condition to minimize the microbial growth rate and subsequent spoilage, where CO_2 is frequently used. Carbon dioxide can alone be used or admitted in various combinations with other available gases like oxygen and nitrogen to provide a protective atmosphere for the food products (Puligundla et al., 2012). The leakage in the MAP represents increases in oxygen concentration and decreases in the carbon dioxide concentration, leading to the presence of aerobic microbial growth. The inner atmosphere of the package was monitored by means of

TABLE 2.6
Freshness Indicators

Indicator	Application	Reference
FreshTag@ Cox Technologies Recorders	TAGS (color indicating) – attached to the outside of the packages to monitor the freshness of seafood products, and reagents were filled in a plastic chip. The volatile amines released in the headspace due to spoilage of seafood react with the reagents in the tags and turn bright pink in color.	www.coxtec.com
RipeSense@ – Jenkins Group Ltd and the Horticulture and Food Research Institute of New Zealand Ltd	Indicator – indicates the degree of preferred ripeness for fruits. The metabolites released from the fruit as it ripens are detected. Red color – initial; denotes crisp fruit Orange – firm Yellow – fruits fully ripened	www.ripesense.co.nz

internal gas-level indicators so that these indicators should be suitable for direct surface contact on the food product (Ahvenainen & Hurme, 1997).

CO_2-level indication: Normally the elevated carbon dioxide gas level is the initial indication of spoilage in the packed food under MAP conditions. Hence, a CO_2 sensor incorporated into food package can efficiently monitor product quality until it reaches the consumer. Although much progress has been made so far in the development of sensors monitoring CO_2, most of them are not versatile for food packaging applications and suffer from limitations such as high equipment cost, bulkiness, and energy input requirement, including safety concerns. Therefore, the development of efficient CO_2 sensors that can intelligently monitor the changes in the gas concentration inside a food package and specific to food packaging applications is essential. The present review discusses progress in the development of different types of CO_2 sensors such as optical sensors, polymer opal films, and polymer hydrogels, which can be readily applicable to food packaging applications.

2.4.2 Traceability

2.4.2.1 Radio Frequency Identification

The radio frequency identification (RFID) tag is a technique in which the product information and details are encoded in electronic tags and embedded with packaging materials for data transformation. Rather than barcodes, RFID tags are intended to carry more data (up to 1 MB for high-end tags) for the identification of items with various unique characteristics (Mennecke & Townsend, 2005). Comparatively, RFID tags are more expensive than barcodes and require a high-power electronic information network.

Nevertheless, the RFID tag is not considered as a replacement for the barcode mainly because of its relatively higher cost and need for a more powerful electronic information network (Yam et al., 2005). The basic concept of RFID tags includes a smaller transponder and antenna that possess a unique number or alphanumerical sequence for food products; the receivers send radio waves to collect the data or information from the RFID tags, and the data are allowed to pass through a real-time server database from a host system for product analysis (Want, 2004). These tags were grouped into passive tags and active tags. The passive tags are designed without batteries and require energy supply from the readers, but the active tags are developed with the addition of a battery and do not require energy from external means. The more expensive active tags were developed with a reading range of more than 50 m, and the passive tags are developed with a reading range of up to 5 m. The reading range may vary according to the reader power, frequency of operation, and interference from metal objects (Yam et al., 2005). The tags with low frequency (~125 kHz) are more economic, require less power, and can easily penetrate nonmetallic objects. These tags are frequently recommended for the betterment of perishable products like meat and seafoods. They are generally suitable for close-range scanning of objects with a higher level of water content (Kerry et al., 2006). The top-level manufacturing companies like Wal-Mart, 7-Eleven, and Marks and Spencers are already making use of this technology for their products' improvement;

		20012345678909	0 22334 54545 3
417 barcode	**Aztec code**	**RSS barcode**	**UPC barcode**

FIGURE 2.2 Types of barcode.

due to the frequent utilization, the unit cost of RFID tags is rapidly decreasing. Currently, the costs of a passive tag are between USD 0.3–1. Due to a higher level of competition between the manufacturers, the cost of the tags is expected to become less than USD 0.05 or even USD 0.01 (Mennecke & Townsend, 2005; Want, 2004). Currently, RFID tags are available with reprogramming capabilities for more than a thousand times. RFID tags tend to possess additional benefits in the production, distribution, and retail chain of the food products and also offer traceability, inventory management, labor-saving costs, security, and promotion of quality and safety (Mousavi et al., 2002).

2.4.2.2 Barcodes

The Universal Product Code (UPC) barcode was commercialized in the year 1970, and now it facilitates the inventory control, stock reordering, and check out in grocery stores (Manthou & Vlachopoulou, 2001).

In UPC barcodes, manufacturer identification number and item number have been represented by a unique pattern of bars and spaces with 12 digits of data (Yam et al., 2005). Currently, the barcodes are designed with a two-dimensional, composite symbology, reduced space symbology, and GSI Data Bar Family (Uniform Code Council, 2014). The barcodes are encoded with sufficient information that includes batch number, nutritive information, websites address of product manufacturer, package weight, product expiration data, and packing date. The barcodes reduce the inconvenience experienced by both retailers and consumers. Current barcodes can be easily readable by means of smartphones. The different types of barcodes are shown in Figure 2.2.

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3 Types of Packaging

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3.1 INTRODUCTION

Packaging is of vital significance in the food industry, as it can be a key in expanding the food business. The basic functions of packaging are preservation, protection, containment, information, and convenience. A decent package is essential not only to preserve the food quality but also to significantly contribute to business profit. It also has secondary functions such as sales and promotion. Without packaging, material handling would be a chaotic, disorganized, and exorbitant exercise, and the mode of consumer marketing would be virtually impossible. The packaging division speaks to around 5% of gross national product (GNP) in developed nations, and in the packaging industry about half of all packaging is used for food products.

Packaging technology has attempted to reduce the volume and weight of materials in efforts to minimize resources and costs. Thus, there is a constant challenge to give financially savvy packaging that fulfils the necessities and needs of the customer, with well-being and security being of fundamental significance. In the meantime, it is also critical to limit the ecological effects. This challenge is persistently fortified by various key drivers – most remarkably there is a drive to diminish the amount of packaging utilized and packaging waste to be discarded. This is a problem in package development that may confront us in the future (Soroka, 2008). Food packaging has evolved from traditional preservation methods to convenient point-of-purchase marketing, tamper proofing, and environmental issues (Paine & Paine, 1983). Food technologists are keen on revising packaging systems and package designs to increase food safety and security. Currently intelligent/active packaging and edible packaging are commercially being developed for the security and safety enhancement of food products. Consequently, it is declared that those associated with packaging need to build up a coordinated perspective of the impact of packaging that comprises safety and quality, designing, marketing, food innovation R&D, sales promotion, legal issues, finance, the production network, and finally the environmental issues (Mudgil & Mudgil, 2015).

3.1.1 The Value of Packaging to Society

The societal benefits of packaging may include the following:

- Prevents or lessens product damage and food deterioration
- Generates much less solid waste disposal
- Lowers the cost of food through economies of scale in mass production

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- Reduces or eliminates the risk of tampering and adulteration
- Presents food in a hygienic and often aesthetically attractive way
- Communicates important information about the food and helps consumers make conscious purchases
- Provides functional convenience in use or preparation
- Promotes goods in a competitive marketplace and increases consumer choice
- Extends the shelf life with the benefit of prolonged product use, thereby reducing wastage
- Saves energy through the use of ambient packs that do not require refrigeration or frozen conditions and storage

The food industry is aware of current public concerns related to packaging, which include:

- Packaging litter and the volume of packaging waste in municipal waste
- Cost of disposal and recovery of discarded packaging in municipal waste
- Pollution associated with methods of disposal, that is, landfill and incineration; for example, biodegradation of low-density polythene (LDPE) is done by *Pseudomonas* species (Kyaw et al., 2012)
- Perception of over-packaging due to apparently excessive free space resulting from product settlement
- Reliability of information on labels
- Contamination of food due to the packaging itself
- Accidents involving packaging

The public's interest for prepackaged food keeps on expanding in cutting-edge economies; thus the developing worldwide populace is equally fueling the demand. Quick urbanization is being encountered because of the advancement of changing consumer lifestyles, extensive retail groups, and food service enterprises (Soroka, 2009). Their prosperity has included a profoundly competitive assortment of logistical, trading, marketing, and customer service expertise, thereby creating a sensational development in the scope of products accessible, empowered by technological innovations in food science, processing, and preservation techniques, which have been applied in a variety of ways to ensure the safety of the consumer and integrity of the product. However, the realization of successful growth of both packaging and food technology in this regard is indicated by the fact that umpteen packages are being safely consumed every day.

3.2 DEVELOPMENTS IN FOOD PROCESSING AND PACKAGING METHODS

Looking back, the packaging industry has seen the development of packaging from being a container for the product to an imperative component of the total product plan – for instance, the advancement of packing tomato ketchup in glass bottles to squeezable co-extruded multilayer plastic containers or sachets with oxygen barrier

TABLE 3.1
Trends in the Evolution of Food Packaging

Period	Functions and Uses
1960s	Convenience, point-of-purchase marketing
1970s	Lightweight, source reduction, energy saving
1980s	Safety, evidence of tampering
1990s	Environmental impact (e.g., solid waste)
2000s	Safety and security
2010s	Carbon footprint reduction
2020s	Sustainable food sources, biodegradable and edible packaging

material for longer shelf life. Most developments have been aimed at processing food products more conveniently, more efficiently, at lower cost, and with higher quality and safety levels as the important criteria were the functions and uses of packaging mentioned in Table 3.1.

Traditional thermal processes have offered tremendous developments in the modern food industry; these include commercial sterilization, quality preservation, shelf-life extension, and safety enhancement (Soroka, 2006). Shelf-life stable products manufactured by retorting or aseptic processing do not require refrigeration and are available in any grocery store. Thus, these types of products are convenient to handle, benefiting the producers, distributors, retailers, and consumers. The major function of these shelf-stable products is to provide a barrier against the invasion of microorganisms. Beyond the simple barrier function, research and development efforts have been focused on creating new roles for food packaging systems, including active packaging, modified atmospheric packaging (MAP), edible films and coatings, and packaging that addresses environmental issues.

The packaging area has seen demanding growth, for example the invention of food canning and the increased use of paper-based containers due to the shortage of tinplate for steel cans during the First World War (Ranganna, 2000). The historical growth for prepackaged foods and food-service packaging since then has diversified the range of materials and packages used. These have all been made possible by developments in food science and technology and engineering, packaging materials, and machine technology. An outline of some developments and inventions in packaging from the past is given in Table 3.2.

Since the dawn of food cans, the major drivers for the developments in packaging were protection, hygiene, product quality, and convenience. Recently, there has been a rising demand for packaging that offers both ease of use and high-quality food to consumers with busy lifestyles. The second half of the nineteenth century saw the widespread adoption by the grocery trade of innovations such as gas barrier plastic materials utilized in aseptic form–fill–seal (FFS) plastic containers for desserts, soups, and sauces (Paine, 1987); plastic retail tray packs of premium meat cuts in

TABLE 3.2
Developments and Inventions in Food Packaging

Year	Developments/Inventions
1809	Nicolas Appert produced the means of thermally preserving food in hermetically sealed glass jars.
1810	Peter Durand designed the soldered tinplate canister and commercialized the use of heat-preserved food containers.
1852	Francis Wolle of the United States developed the paper-bag-making machine.
1871	Albert L. Jones in the United States patented the use of corrugated materials for packaging.
1874	Oliver Long patented the use of lined corrugated materials.
1879	Robert Gair of New York produced the first machine-made folding carton.
1884	Quaker Oats packaged the first cereal in a folding box.
1892	The Crown cap for glass bottles was patented by William Painter.
1899	Michael J. Owens of Ohio conceived the idea of fully automatic bottle making.
1903	Owens commercialized the industrial process for the Owens Bottle Machine Company.
1906	Paraffin-wax-coated paper milk containers were found by G. W. Maxwell in the United States
1910	Waxed paperboard cartons were used as containers for cream.
1912	Regenerated cellulose film (RCF) was introduced.
1915	John Van Wormer of Canada commercialized the paper bottle, a folded blank box called Pure-Pak, which was delivered flat for subsequent folding, gluing, paraffin wax coating, filling with milk, and sealing at the dairy.
1923	Clarence Birdseye commercialized the use of frozen foods in retail packs using cartons with waxed paper wrappers.
1927	Du Pont perfected the cellulose casting process and introduced their product, cellophane.
1935	A number of American brewers began selling canned beer.
1938	Fresh carcass meat was exported under controlled atmosphere storage (CAS).
1939	Ethylene was first polymerized commercially by Imperial Chemical Industries (ICI) Ltd. Later, polyethylene (PE) was produced by ICI in association with Du Pont.
1946	Aerosol can was developed for dispensing food products such as processed cheese and spray dessert toppings.
1948	The system for cans was pioneered by W. M. Martin.
1950	The retort pouch for heat-processed foods was developed originally for the US military. Commercially, the pouch has been most used in Japan. Aluminum trays for frozen foods, aluminum cans, and squeezable plastic bottles were introduced. The first commercial aseptic filling machine was commissioned by the James Dole Corporation in California for soups.
1951	Fresh chicken meat was exported under the application of MAP.
1956	Tetra Pak launched its tetrahedral milk carton that was constructed from LDPE extrusion-coated paperboard.
1960	Cans were developed in the United States for carbonated drinks and beers by the drawn and wall-ironed (DWI) method; the welded side-seam was developed for the tinplate food can; a tamper evident bottle neck shrink sleeve was developed by Fuji Seals in Japan, eventually leading to the development of the shrink sleeve label; an aluminum roll-on pilfer-proof (ROPP) cap was used; tin-free steel (TFS) can was developed.
1962	Wisconsin manufacturer Geuder, Paeschke and Frey produced the first licensed character lunch box – a lithographed Mickey Mouse on an oval tin with a pull-out tray inside. Plastic was first used for the handle and then used to make the entire box.

(*Continued*)

Table 3.2 (Continued)

Year	Developments/Inventions
1967	Tetra Pak launched its rectangular Tetra Brik Aseptic (TBA) carton system for long-life ultra-heat treated (UHT) milk, consequently becoming one of the major pack forms for a wide range of liquid foods and beverages; the ring-pull type of opener for canned drinks was developed.
1968	Robert W. Vergobbi patented zipper storage bags. Ziploc bags were introduced as food storage bags; sandwich bags on a roll were introduced.
1970	The barcode system for retail packaging was introduced in the United States; methods were introduced to make food packaging tamper evident; boil-in-the-bag frozen meals were introduced in the UK; PVC was used for beverage bottles and frozen foods in microwaveable plastic containers; MAP retail packs were introduced; bag-in-box systems and a range of aseptic form, fill, and seal (FFS) flexible packaging systems were developed successfully.
1972	Two-liter plastic beverage bottles and the 1-gallon plastic milk jug appeared on the market.
1973	Du Pont developed the injection stretch blow-molded PET bottle, which was used for carbonated drinks.
1977	Bacon, fish, and shellfish were exported under MAP.
1983	Co-extruded plastics integrating oxygen barrier plastic materials for squeezable sauce bottles, as well as retortable plastic containers for ambient foods that could be microwave heated, were developed.
1984	The Society of the Plastics Industry (SPI) introduced an identification coding system for identifying plastic resins that were used in packaging containers.
1987	PET-coated dual-ovenable paperboard for ready meals was developed.
1991	Digital printing of the graphics on carton sleeves and labels for food packaging was introduced in the UK; shrink-sleeve plastic labels for glass bottles were rapidly adopted by the liquid industry; canning technology was more widely adopted in the United States and Europe as drinks companies sought ways for differentiating their brands.
1993	Fresh and chilled foods were exported under MAP.
1995	Salad-in-a-bag packaging (metallocene-catalyzed polyolefins) was introduced, helping to reduce food waste and making it easier to purchase fresh produce.
1997	Use of noble gases for packaging in MAP was introduced.
2000	Flexible plastic tubs for read-to-eat snacks like yogurt became available, making it possible to enjoy a tasty nutrient-rich snack on the go.
2010	Metallite films were introduced to help keep food items like coffee beans, grains, and noodles fresher by reducing packaging tears. The new films are also lighter than foil-based designs. Heinz Dip & Squeeze, the first new ketchup packaging in the last 42 years, offered two ways to use the ketchup – peel back the lid for easy dipping or tear off the tip to squeeze the ketchup onto your food.

a modified atmosphere; and reheatable plastic containers for ambient storage ready meals that can be microwave heated. Technological developments often need to combine in order for a packaging innovation to be adopted. These have included developments in transportation, post-harvest technology, new retail formats, and domestic appliances such as refrigerators, freezers, and microwave ovens. For example, the development of the microwave oven hastened the development of convenience packaging for a wide range of foods (e.g., ready-to-eat foods).

3.2.1 Packaging Situation in the World

- It is estimated that the food packaging market will reach more than USD 305,955.1 million by the year 2020.
- Asia-Pacific is projected to be the largest market.
- The main packaging materials used in the world are flexible materials (36%), paper and board (24%), and rigid plastic materials (20%) (Levy, 1993).
- The most used types of packaging are bags and sachets (875.59 billion units), bottles (810.32 billion), and cans (412.95 billion).
- Rigid plastic packaging should continue its growth, according to a compound annual growth rate (CARG) of 4.4% until 2020 to USD 222.5 billion.
- Glass packaging is forecasted to drop by 0.27% due to decreasing demand from the food and especially drinks sector, which currently consume 61.70% of glass packaging in Europe.
- Demand for rigid metal packaging in European countries will record moderate growth of 1.44 to 1.88% between now and 2018.
- The world packaging industry is growing at a rate of 2–4% per year. (Natarajan et al., 2014).

3.2.2 Packaging Situation in India

- The Indian market is estimated to be the second fastest growing market.
- The Indian packaging industry itself is growing at 14–15% annually. This growth rate is expected to double in the next two years (Thapliyal et al., 2024).
- The Indian packaging industry is estimated to be USD 14 billion and growing at more than 15% per year according to the Indian Packaging Institute.
- Laminated products including FFS pouches, laminated tubes, and Tetra Paks are growing at around 30% per year.
- There are approximately 700–800 packaging machinery manufacturers, 95% of which are in the small and medium sectors, located all over India.
- Italy and Germany are the latest suppliers of packaging machinery to India, but the focus is now shifting to Taiwan, Korea, and China.
- Indian packaging machinery imports are estimated to be USD 125 million.
- Indian packaging machinery exports are rapidly growing.
- India's per capita packaging consumption is less than USD 15 against a worldwide average of nearly USD 100.
- The large growing middle-class organized retail sectors are the catalysts to the growth in packaging.
- Food and pharmaceutical packaging are the key driving segments (Park, 2013).

3.2.3 Developments in Indian Packaging

Although substrates like plastic have gained vast acceptability, the attractiveness of paper and paperboard consumption remains. Currently, India is ranked fifteenth in the world for its paper and paperboard consumption and is expected to improve its rank in the future. Paper is the fastest growing substrate segment with a growth rate of 6–7%. At present the total demand for paper is estimated to be around 6 million tonnes, of which about 40% is consumed by the packaging industry. If the demand for paper continues to grow at the same rate, total paper consumption is expected to reach 9.5 million tonnes by 2020.

Increasing investments by both domestic and foreign companies in the Indian food processing sector, especially in beverages, dairy products, processed food, edible oil, and marine products, have expanded the market for packaging machinery. According to the Indian Institute of Packaging (IIP), only 2% of India's total processed food is packaged compared with 70% in Western countries. This forecasts large growth in this sector.

Tetra Pak packaging, especially for processed food, is very popular in India. The primary reason for the popularity of Tetra Paks is convenience and longer shelf life. Also, Tetra Paks address distribution hurdles in India where distributors face transportation difficulties and extreme climate conditions.

3.3 TYPES AND FUNCTIONS OF PACKAGING TECHNIQUES

Primary packaging is the main package that holds the food that is being processed. It is the one that is in direct contact with the contained product. It provides the initial and usually the major protective barrier. Examples include metal cans, paperboard cartons, glass bottles, plastic pouches and bottles, cushioning envelopes, and skin packs.

A secondary package contains a number of primary packages. It is outside the primary packaging perhaps used to group primary packages together. It is recognized as the physical distribution carrier and is sometimes designed so that it can be used in retail outlets for the display of primary packages. Examples include corrugated cases and boxes.

A tertiary package is made to accommodate a number of secondary packages; hence it is used for bulk handling. An example is a stretch-wrapped pallet of corrugated cases.

A quaternary package is used to facilitate the handling of tertiary packages. The so-called supply chain management is done by a metal container that can be transferred to or from ships, trains, and flatbed trucks by giant cranes. There are advanced containers that are able to have their temperature, humidity, and gas atmosphere controlled for the transportation of frozen foods, chilled meats, and fresh fruits and vegetables.

3.3.1 Functions of Packaging

Packaging comprises primary and secondary functions. Under primary functions there are four main functions as follows.

3.3.1.1 Containment

Without containment, product loss and pollution would be widespread. Small items are typically grouped together in one package to allow efficient handling. As an example, liquids, powders, and granular materials need containment.

Single-serving packaging has a precise amount of contents to control the usage. Bulk commodities (such as salt) can be divided into packages that are a more suitable size for individual households to serve as a portion control. This makes a huge contribution to protecting the environment from the myriad of products that are moved from one place to another. Faulty packaging (or under packaging) could result in major pollution of the environment (Bässler & Lehmann, 2013).

3.3.1.2 Protection

This is often regarded as the primary function of the package: to protect its contents from outside environmental effects such as water, moisture, gases, odors, micro-organisms, dust, shocks, vibrations and compressive forces. The various types of protection are as follows.

- *Physical protection*: The food in the package requires protection from shock, vibration, compression, temperature, microbes, and so on.
- *Barrier protection*: A barrier from oxygen, water vapor, dust, and so on is often required. Some packages contain desiccants or oxygen absorbers to help extend shelf life since permeation is a critical factor in package design. Some foods are packaged by modified atmospheres, keeping the product fresh and safe for the intended shelf life.
- *Security*: Packaging plays an important role in reducing the security risks of shipment. The advancement in packages is to deter tampering and can include tamper evident features to help indicate tampering. For example, vacuum packaged meat will not have their best shelf life if the package permits oxygen to enter through the packs. Overall, when the integrity of the package is breached, the product is no longer preserved. Packages are engineered to help reduce the risks of pilferage, like having authentication seals to help indicate that the package and contents are not counterfeit, whereas some packages also include RFID tags that can be activated or detected by devices at exit points and even deactivated, thus preventing retail loss.

3.3.1.3 Convenience

The trend toward grazing (i.e., eating snack-type meals on the run) and the demand for a wide variety of food and drink at outdoor functions such as sports events and leisure time has created a demand for greater convenience in household products. The products designed around principles of convenience include foods which are pre-prepared and can be cooked or reheated in a very short time, preferably without removing them from their primary package. Sauces, dressings, and condiments that can be applied simply through aerosol or pump-action packages minimize mess. Thus, packaging plays an important role in meeting the demands of consumers for convenience, with features that add convenience in distribution, handling, stacking, display, sale, opening, reclosing, use, and reuse. One of the convenience aspects is the apportionment function of packaging.

In this situation, the package functions to address the desirable consumer-sized product. For example, a batch of ice cream is apportioned into 2 L plastic tubs, or a churn of butter is apportioned by packing into 25 mL packets.

An associated aspect is the shape and proportions of the primary package with regard to consumer convenience (e.g., easy to hold, open, and pour as appropriate) and efficiency in building into secondary and tertiary packages. Also, the primary packages are condensed into secondary packages while being placed inside a corrugated case, and secondary packages are condensed in a tertiary package like a stretch-wrapped pallet. Thereby handling is optimized since only a minimal number of packages or loads need to be handled.

3.3.1.4 Communication/Information Transmission

A package functions as a "silent salesman" and does the job of self-marketing. The modern methods of consumer marketing would fail were it not for the messages and information communicated by the package. Nutritional information on the outside of food packages has thus become mandatory. They also contain marketing communications and graphic design as well as directions of usage, transport, recycling, or disposal of the package or product, which are also mentioned in the package serving as the point-of-sale display.

Today the widespread use of modern scanning equipment at retail checkouts relies on all of the packages that display an UPC that can be read accurately and rapidly. But it is not only in the supermarket that the communication function of packaging is important. Warehouses and distribution centers would become chaotic if secondary and tertiary packages lacked labels or carried incomplete details. During international trade the use of unambiguous, readily understood symbols on the package is imperative. Nowadays UPCs are used in warehouses where handheld barcode readers linked to a computer make for quick and efficient stocktaking. Now the use of RFID tags attached to secondary and tertiary packages is beginning to revolutionize the supply chain.

3.3.2 Packaging Environment

The packaging environments have to perform three different functions, namely physical, ambient environment, and human functions, and if designers fail to consider all three environments during package development, it will result in poorly designed packages, increased costs, consumer complaints, and even avoidance or rejection of the product by the customer.

3.3.2.1 Physical Environment

Physical damage can be caused to the product, for example, shocks from drops, falls, and bumps; damage due to transportation modes of road, rail, sea, and air; and compression, crushing, and cramping damage arising from stacking during transportation or storage in warehouses.

3.3.2.2 Ambient Environment

The environment that surrounds the package can cause damage to the product as a result of gases (particularly O_2), water and water vapor, light (particularly UV radiation) and temperature, as well as microorganisms (bacteria, fungi, molds, yeasts, and viruses) and macroorganisms (rodents, insects, mites, and birds). Air particulate contaminants such as exhaust fumes from automobiles as well as dust and dirt can also find their way into the product unless there is an effective barrier to protect the products inside.

3.3.2.3 Human Environment

This is the environment in which the function of the package is to communicate, and it is important that the messages are clearly received by consumers where the package must contain information required by the regulations such as nutritional content and net weight. To maximize its utility functions and/or convenience and handiness, the package should be simple to hold, open, and use. The package should be resealable when it is not entirely consumed when first opened and should retain the quality of the product until completely used. Moreover, the package should contain a portion size; a package that contains so much product that it deteriorates before being completely consumed clearly contains too large a portion.

3.4 PACKAGING MACHINERY

The food machineries used in packaging methods and processes require the attention of technical skills, labor requirements, worker safety, maintainability and serviceability, reliability, ability to integrate into the packaging line, capital cost, floor space, flexibility, energy usage, quality of outgoing packages, qualifications, throughput, efficiency, productivity, and ergonomics, at a minimum.

Packaging machines may be of the following general types:

- Feeding, orienting, and placing machines.
- Filling machines for liquid and powdered products
- FFS machines
- Capping, over-capping, lidding, closing, seaming, and sealing machines
- Case and tray forming, packing, unpacking, closing, and sealing machines
- Blister-, skin- and vacuum-packaging machines
- Package filling and closing machines
- Cartoning machines
- Weighing machines
- Autocoding labelers
- Cleaning, sterilizing, cooling, and drying machines
- Conveying and accumulating machines
- Inspecting, detecting, and weighing machines
- Palletizing, depalletizing, and pallet unitizing machines
- Labeling, marking and other product identification machines
- Wrapping machines

A mechanical process is thus required to protect products, which generally needs to carry out those operations efficiently to put the product into the package. The majority of the primary operations on a packaging line are concerned with the package itself such as making or forming sachets, erecting or closing cartons, feeding and seaming cans, and presenting bottles to filler heads and capping them. Secondary operations such as coding, labeling, detecting metal, weighing, and collation for dispatch are also matters of concern. The packaging line must put the product in the package economically, in the desired condition, at the required speed, and to the stated quantity. The nature of the product will have a more profound effect on the performance of the packaging line than any other factor. The machinery must be selected to accommodate the variations in dimensions and in critical properties that will inevitably occur in both product and package (NIIR Board, 2000).

3.4.1 Technology Upgradation and Cost-Effective Packaging Using Machines

No efforts have been made to provide the infrastructure for technology upgrades on the scale required to meet the current needs, such as by setting up package testing and development laboratories in distant parts of the country where there is packaging industry concentration. The food enterprises need to completely acknowledge and actively promote the positive contributions by the researchers that their packaging makes to the quality of life by fulfilling packaging needs. The modern packaging methods at a cost below the retail market price must be an eye-opener to many, and an extension of this concept to other commodities is now being examined by those who had not previously discovered the proper role of packaging (Goue et al., 2016).

3.5 FOOD SUPPLY CHAIN CONCEPTS

Transportation generally refers to the movement of practically everything from raw material to finished goods between different facilities in a supply chain. The freight transportation industry has undergone revolutionary changes during the last decade.

3.5.1 Logistics

The goods have to be moved through surface roads, railways, sea, and air. The tonnages moved across the country are enormous.

3.5.2 Merchandise Outlets

The number of shop outlets to be serviced becomes quite obvious. Self-service stores are unknown, and goods are traded across the counter.

3.5.3 Handling

The availability of manual labor coupled with the problem of unemployment provides relatively inexpensive labor, and therefore, manual handling dominates the scene.

3.5.4 Transportation

Economic operation of transport systems demands multiple numbers of transshipments involving handling and storage.

3.6 PACKAGING PROCESSES AND TYPES

3.6.1 Aseptic Packaging System

Aseptic packaging is the filling of sterile containers with a sterile product under aseptic conditions so that they are hermetically sealed as represented in Figure 3.1 (Von Bookelmann, 2009). The term “aseptic” implies the absence or exclusion of any unwanted organisms from the product and/or the package, while the term “hermetic” (strictly airtight) is used to indicate suitable mechanical properties to eliminate the entrance of microorganisms into a package and gas or water vapor permeating into (or from) the package.

There are two specific fields of application of aseptic packaging:

1. Packaging of presterilized and sterile products, for example, packaging of milk, fruit and vegetable juices, sauces, and products with particulates.
2. Packaging of a nonsterile product to avoid infection by microorganisms, for example, fermented products like yogurt or idli/dosai batter.

Aseptic filling systems must meet the following requirements:

- The container and method of closure must be suitable for aseptic filling and must not allow the passage of microorganisms into the sealed container during storage and distribution.
- The container must be sterilized after it is formed and before being filled.
- The container must be filled without contamination occurring from the equipment surface or the atmosphere surrounding the filler.
- If any closure is needed, it must be sterilized immediately before it is applied.
- The closure must be applied and sealed in place while the container is still within a sterile zone to prevent the passage of contaminating microorganisms, and also the package must retain the aroma of the product.

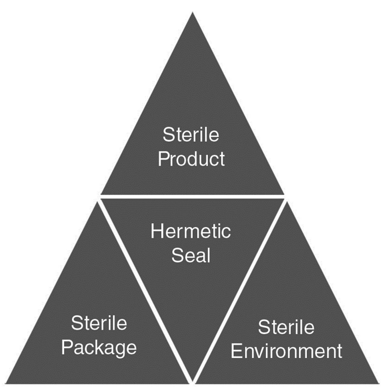

FIGURE 3.1 Diagrammatic representation of the aseptic process.

- The package material must be able to withstand sterilization and be compatible with the methods of sterilization.
- The packaging material must be compatible with the product to be packed and must comply with applicable material migration requirements. Physical integrity of the package is necessary to assume containment of the product and maintenance of sterility.

The most widespread consumer package for aseptic products is the paperboard laminate carton (Reuter, 1989). Five major categories of aseptic packaging equipment are available, and their major features and characteristics are described in the following sections.

3.6.1.1 Carton Systems

Typical structure of a paperboard laminate carton for aseptic filling is described as follows.

- *FFS cartons*: The packaging material comes in rolls already printed and lined, the latter being necessary to ease the forming process (Alec, 1967). A plastic strip is sealed at one edge, and the packaging material is sterilized using a wetting system with a deep bath or water vapor.
- *Prefabricated carton*: In this type, prefabricated carton blanks are used, with the cartons being die-cut and creased and the longitudinal seam completed at the factory by just sterilizing the inner layer of board and folding it back.

The functions of the various layers from outer to inner layer are as follows:

1. The outer polyethylene (PE) protects the ink layer and enables the package flaps to be sealed against moisture.
2. The bleached paperboard or paper is where the designs and information are mentioned and gives the package the required mechanical rigidity for stability and strength.
3. The laminated PE binds the aluminum to the paperboard.
4. The aluminum foil acts as a gas barrier and provides protection of products from light and retains flavor.
5. The two inner PE layers act as adhesions and seal in the liquid.

Advantages of aseptic packaging include the following:

- Unlike conventional canning, aseptic processing causes less thermal damage to the product.
- Products result in shelf stability at ambient conditions.

3.6.1.2 Can System

The canning process uses superheated steam up to 225°C for up to 40–50 s to sterilize the cans and can ends. The three basic types of metal cans (tinplate, electrolytically chromium-coated steel [ECCS], and aluminum) can be used in this system. After the cans are filled with the sterile product, they are sealed using a conventional can seamer modified for aseptic operation. Superheated steam is used to maintain sterilized conditions during the filling operation, and this results in a high vacuum in the can. To prevent excessive vacuum in the can that could lead to leaker spoilage, either sterile air or N_2 is blown into the headspace of the can immediately prior to seaming (Willhoft, 1993).

3.6.1.3 Bottle Systems

- *Glass*: The glass bottles are sterilized with either saturated steam under pressure or dry heat. When the latter process is used, extended cooling with sterile air is required to minimize the risk of bottle breakage from thermal shock when the bottles are filled with cool product. An example is food containing small particles, for instance baby food. In a recent development, returnable bottles are filled aseptically, which up to now were applied only for ultra-heat treated (UHT) milk. Basically, the same products can be filled into bottles and jars as glass containers, and closing is usually done by heat sealing aluminum lids. The matter of concern is to avoid the contamination of heat-sealed rims.
- *Plastics*: Blow-molded plastic bottles have been used for many years as a cheaper alternative to glass for nonreturnable containers of the use-and-throw type. High-density polyethylene (HDPE) and polypropylene (PP) are the two most common thermoplastics used; also, pigmented bottles are better protected from light.

3.6.1.4 Sachet/Bag and Pouch Systems

FFS systems and lay-flat tubing systems are available under this category. Pillow pouches are usually used for packaging of milk in a three-sided sealed pouch.

3.6.1.5 Cup Systems

FFS cups and preformed plastic cups are available under this system. They can be used either ready-made or formed in-house, and they are filled and sealed using thermoform–fill–seal machines. Two types of machines are employed, one for particulate products and another for liquid or semi-solid products, with both types filling products directly into consumer-ready packages suitable for microwave heating. Usually polypropylene-based multilayer materials with ethylene vinyl alcohol (EVOH) barriers are applied for this purpose. An example is the closing of two-piece plastic cans, or "gourmet cans." Cans and lids with easy opening features consist of PP/EVOH/PP. They are sterilized with hydrogen peroxide or UV radiation and are heat-sealed inductively. The can is presently offered for liquids only, for example, coffee.

3.6.2 Types of Packs

3.6.2.1 Tetra Paks

The Tetra Pak portfolio has Tetra Brik (TB), Tetra Aseptic (TBA), Tetra Classic Aseptic (TCA), Tetra Evero Aseptic (TEA), Tetra Fino Aseptic (TFA), Tetra Gemina

Aseptic (TGA), Tetra Recart (TRt), Tetra Rex (TRx), Tetra Wedge Aseptic (TWA), Tetra Prisma Aseptic (TPA), and Tetra Top (TT) with respective filling machines.

These packages come in various sizes and shape configurations and also a variety of openings and closures appropriate to product and consumer needs.

- *Milk*: The balance of packed milk is predominantly in tetra Pak packages, amounting to some 70 million liters. Apart from white milk, other liquid dairy products like cream, lassi, buttermilk, and flavored milk are available in Tetra Pak packages. The UHT milk segment packed in Tetra Pak packages is currently growing at 28–30% per year.
- *Juices and nectars*: The two main players in the packed juice market are Dabur's Real and Pepsico's Tropicana.
- *Juice drinks*: Popular brands of juice drinks, predominantly mango, are Frooti, Maaza, and Slice from the three major players: Parle Agro, Coca Cola, and Pepsico. Juice drinks in Tetra Pak packages account for 43%, and the rest are packaged in glass bottles.

3.6.2.2 Retort Pouches

The retort pouch is a flexible package that is hermetically sealed on three or four sides and made from one or more layers of plastic or foil. The thin profile of the package advantages the retort pouch over the metal can and also enables the number of retorting times to be reduced by up to 60%. Other main advantages are the ease of carrying, reheating, and serving, as well as weight and space saving. Finally, disposing the used pouch is much easier than for the metal can as it can be easily flattened. The major danger is that the retort pouches are susceptible to rupture or seal separation during retorting if the internal pressure exceeds the external process pressure. The shelf life of foods packaged in retort pouches is very dependent on storage temperature, whereas the zipper in the pouch makes it easier to open and reseal.

3.6.3 Trending Packaging Methods

3.6.3.1 Vacuum Packaging

Here the product is placed in an airtight pack and the air is sucked out prior to sealing, thus increasing the shelf life of food products. By removing atmospheric oxygen around the product, the level of oxygen in the packaging is depleted, which results in inhibiting the microorganisms (aerobic bacteria and/or fungi) that spoil the product and also preventing the evaporation of volatile components. The lack of oxygen also reduces the amount of spoilage due to oxidation, for example, meat turning pale and the browning of apples and bananas.

Shrink film is sometimes used to have a constricted fit to the product with flexible package forms to reduce the volume of the contents and the package. It is commonly used to store dry foods over a long period of time such as cereals, nuts, dry fruits, cured meats, cheese, smoked fish, and coffee, and it also stores fresh foods, such as vegetables like corn, and liquids because it inhibits bacterial growth.

Single vacuum chamber sealers require the entire product to be placed within the machine. Like external sealers, a plastic bag is typically used for packaging. Once the product is placed in the machine, the lid is closed and air is removed. The seal bar seals the product within the bag, after which the chamber is refilled with air by the automatic opening of a vent to the outside. Then this oncoming pressure squeezes or extrudes all remaining air in the bag. The lid is then opened, and the product is removed. This process is usually used for low- to medium-volume packaging. This style of vacuum machine is also capable of sealing liquids due to equal pressure in the chamber.

Double vacuum chamber sealers require the entire product to be placed in a plastic bag within the machine. Once the product is placed in the machine on the seal bar, the lid is closed, and the air is removed. The seal bar seals the product within the bag, after which the chamber is refilled with air by the automatic opening of a vent to the outside. Then this oncoming pressure squeezes or extrudes all remaining air in the bag. The lid is then opened and the product is removed. It is used for medium-volume packaging and also has the capability to vacuum seal liquids. Double chamber vacuum packaging machines are commonly used for fresh and processed meat, cheese, candy, and chocolates.

Automatic belt vacuum chamber sealers require the entire product to be placed in a plastic bag or flow-wrapped pouch within the machine. The product travels on the conveyor belt; it is automatically positioned in the machine on the seal bar, the lid is closed, and air is removed. The seal bar seals the product within the bag, after which the chamber is refilled with air by the automatic opening of a vent to the outside. Then this oncoming pressure squeezes or extrudes all remaining air in the bag. The lid is then opened, and the product is removed. Automatic belt vacuum chamber machines are used for high-speed packaging of large items and also have the capability to vacuum seal liquids. Automatic belt vacuum chamber packaging machines are commonly used for fresh and processed meat (large portions).

Thermoforming vacuum packaging machines are of the FFS type that forms the package from rolls of packaging film, and the products are loaded into the thermoformed pocket. Thermoforming can greatly increase packaging production speed. Some common uses for thermoforming in vacuum packaging include fresh and marinated meat, sausage, cheese, candy/chocolate, grains, and grab-and-go snacks.

Depending on the product, the shelf life of vacuum packaged products can exceed normal bagged or wrapped packages, for example, meats like beef or pork can last up to five days in the refrigerator, but in vacuum packaging it can last anywhere from four to five months in the freezer.

3.6.3.2 Controlled Atmosphere Packaging (CAP)

CAP is the enclosing of food in a gas impermeable package with respect to CO_2, O_2, N_2, water vapor, and trace gases; the gas balance is changed and is selectively controlled to increase the shelf life. The storage system consists of airtight storage chambers, O_2 regulatory unit, and CO_2 absorbing unit equipment for monitoring as well as controlling the chambers and the composition. A liquid N_2 generator is commonly installed to flush the chambers and for maintaining optimum levels of O_2. A refrigeration (chilling/freezing) unit is employed for maintaining the storage temperature.

The storage or shelf life of various fruits and vegetables can be increased by two to four times the normal life by CAS. However, CA stored products deteriorate rapidly when exposed to normal atmospheres during marketing and distribution. The building of airtight storage and continuous monitoring as well as controlling of inside storage air composition make the technology costly.

3.6.3.3 Modified Atmosphere Packaging

The food is enclosed and sealed in a pack where the atmosphere inside the package is modified to provide an optimum atmosphere for increasing shelf life and maintaining quality of the food. Modification of the atmosphere inside the package may be achieved either actively or passively (Parry, 1993). Active modification involves replacing the air with a controlled, preferred mixture of gases, while passive modification happens as a consequence of the food's respiration and/or the metabolism of microorganisms related to the food.

As in CAS, the gas composition inside the food storage is continually monitored and adjusted to maintain the optimal concentration within very close tolerances. In contrast, the common modified atmosphere storage involves some early modification of the atmospheric composition in an airtight storage room, which further changes with time as a result of the respiratory activity of the fresh food and the growth of microbes.

Advantages

1. Shelf life may increase by 50–100%.
2. Reduced economic losses due to longer stable shelf life.
3. Improved presentation – clear view of product and all – around visibility.
4. Sealed packages are barriers against product recontamination and drip from the package, thus providing a high-quality product.
5. There is no need for chemical preservatives.
6. MAP provides centralized packaging and portion control.
7. MAP creates odorless and convenient packages.

Disadvantages

1. Cost of gases is high.
2. Different gas formulations are needed for each type of food.
3. Once the pack is punctured or leaked, it is a waste.
4. CO_2 dissolving into the food may lead to collapse of the pack and an increased drip.
5. Increased volume of the pack adversely affects transport costs.

- *Gases Used in MAP*: The three main gases used in MAP are CO_2, O_2, and N_2, either individually or in a combination.
- *Carbon dioxide*: Carbon dioxide is the most important gas in the MAP of foods because of its bacteriostatic properties. It inhibits the growth of many spoilage bacteria and fungi. The high solubility of CO_2 in high-moisture or high-fat foods such as meat can result in package collapse due to the

reduction of headspace volume; however, high levels of CO_2 can also result in increased drip in fleshy food.

- *Oxygen*: Oxygen encourages several sorts of deteriorative reactions such as fat and pigment oxidation and browning reactions. Most of the common spoilage bacteria and fungi require O_2 for their growth; therefore, it is excluded or the level is set as low as possible. Exceptions occur for fruit and vegetable respiration or for the retention of color in red meat.
- *Nitrogen*: Nitrogen is an inert gas with no odor or taste, since it has a lower density than air and is also less soluble in water and other food constituents; these properties make it a filler gas in MAP to counteract the package collapse caused by CO_2 dissolving in the foodstuffs. thereby retarding the growth of aerobic spoilage microbes.
- *Carbon m*
- *onoxide*: There has been dispute regarding the use of CO in the packaging of red meat. While no risk was found in the use of low levels of CO, the point was raised that CO maintains the color of the meat, and it can hide visual evidence of spoilage. The European Food Information Council (EFIC) released a report in 2001 on the use of carbon monoxide, and since then it has been banned from food packaging all around the world.

The three major commodity types are fruits and vegetables (minimally processed fruits and vegetables), meat and meat products, and seafood for MAP. Considering the interaction of the packaging material with the product for nonrespiring products such as meat, fish, and cheese, very low gas permeability films or high barrier films are used; on the contrary, respiring products such as fruits and vegetables need a low barrier or high permeability film. Each food has its own ideal gas mixture to ensure the longest shelf life possible. For example, by reducing the O_2 level and increasing the CO_2 level, ripening of fruits and vegetables can be delayed; hence the respiration and ethylene production rates can be reduced, softening can be delayed, and various compositional changes associated with ripening can be slowed down.

3.6.3.4 Equilibrium Modified Atmosphere Packaging (EMAP)

For fresh-cut produce, EMAP is most commonly used. When packaging vegetables and fruits the gas atmosphere of package usually is a lower level of O_2 and a high level of CO_2. This kind of packaging slows down the normal respiration of the product thus extending its shelf life. Apparently other factors like the size of the product, maturity of the product, and type of tissue have an effect on the shelf life of EMA packaged produce. As long as the permeability (for O_2 and CO_2) of the packaging film is adapted to the respiration level of the product, an equilibrium modified atmosphere will be established in the package and the shelf life of the product is increased (Yam, 2009).

3.7 PACKAGING FILMS

The main characteristics required for choosing an apt packaging film are gas permeability, water vapour transmission rate (WVTR), mechanical properties, transparency, type of package and sealing reliability. Usually packaging films like LDPE, polyvinyl chloride (PVC), ethylene-vinyl acetate (EVA), and oriented polypropylene (OPP) are not penetrable enough for highly respiring products like fresh-cut produce. As fruits and vegetables are respiring products, there is a need to transmit or permeate gases through the film. Films designed with these properties are called permeable films. Other films, called barrier films, are designed to prevent the exchange of gases and are mainly used with nonrespiring products like meat and fish.

3.7.1 Some Novel Packaging Methods

3.7.1.1 Biodegradable Packaging

The current global concern around the nonbiodegradable petrochemical-based plastic materials has generated much interest in biodegradable or "green" packaging materials. According to the ASTM 2003 guidelines, a "bio-degradable plastic" is defined as a degradable plastic in which the degradation results from the action of naturally occurring microorganisms such as bacteria, fungi, and algae (Vert, 2012).

Biodegradable or green packaging must satisfy some basic requirements to be an ideal candidate for food packaging. These requirements include barrier properties (to water vapor, gases, light, and aromas), optical properties (transparency), strength, welding and molding properties, printing properties, migration resistance, chemical and temperature resistance, the ability to satisfy disposal requirements, antistatic properties, and the ability to retain sensory properties. Bio-based polymers, or biopolymers, are obtained from renewable resources. These renewable resources consist of proteins (whey protein, soy protein, collagen, gelatin, wheat protein, etc.), polysaccharides (starch, alginates, pectin, carrageenans, and chitosan/chitin), and lipids (fats, waxes and oils).

Polymers such as polylactide (PLA) have gained growing attention in the last span as the food packaging materials because they can easily be obtained from natural renewable resources, their production consumes a lot of carbon dioxide, they can be recycled and composted, and their physical and mechanical properties can be tailored through the polymer architecture.

Bio-based polymers, as the name suggests, are made from bio-based resources. Biomass used for the production of bioplastics may either be extracted directly from plants (starch, cellulose) or produced by microorganisms in fermentative processes. Biomass can either be from the first-generation feedstock (e.g., corn, sugar cane) or from nonfood crops (second-generation feedstock, e.g., lignocellulosic material). Bio-based polymers can also be produced by further chemical modifications and are not necessarily biodegradable.

Biodegradable plastics may be made from both natural and fossil resources and are biodegraded by microorganisms in natural environment. The products of this process are energy, biomass, water, and carbon dioxide or methane, depending on the presence or absence of oxygen. Oxo-biodegradable plastics are mainly polyolefins such as PE and PP, which contain more chemical additives intended to accelerate degradation. Bio-nanocomposites are biopolymers which have been stabilized using nanoparticles (Rhim, 2013). The nanoparticles enhance technical properties, such as barrier, thermal, chemical, or mechanical stability, and they include nanoclays and nanosilver (Avella, 2005).

3.7.1.2 Active Packaging

Active packaging, intelligent packaging, and smart packaging refer to packaging systems that help extend shelf life and quality of the product by monitoring freshness, displaying information on quality, and improving safety and convenience.

The functions beyond the inert passive containment and protection of the product refer to active packaging, whereas the ability to sense or measure an attribute of the product, the inner atmosphere of the package or the shipping environment refer to intelligent and smart packaging.

Methods of Active Packaging

- *Oxygen scavengers*: Packaged foods contain a certain amount of headspace gases and entrained oxygen. They offer the following advantages:
  - Prevent rancidification of fats and oils, leading to off odors, off flavors, and changes in the characteristic colors of food, as well as the loss of O_2 sensitive nutrients (such as vitamins and unsaturated fatty acids)
  - Inhibit the growth of aerobic microbes
  - Provide an economical and efficient alternative to modified atmosphere and vacuum packaging
  - Slow down the metabolism of food
  - Reduce or eliminate the need for preservatives and antioxidants by adding value
- *Carbon Dioxide Generating System*: A relatively high CO_2 level (60–80%) inhibits and suppresses microbial growth on surfaces, thereby prolonging the shelf life of packed food. Therefore, a balanced approach to O_2 scavenging involves either impregnating packaging structures with a CO_2 generating system or adding the latter in the form of a sachet.
- *Ethylene Scavengers*: The controlled release of ethylene from fruits and vegetables during storage plays a crucial role in extending the postharvest life of many types of fresh produce. Ethylene scavengers are particularly effective for preserving ethylene sensitive fruits and vegetables such as apples, bananas, mangoes, tomatoes, onions, and carrots.
- *Flavor and Odor Absorber/Releaser*: The addition of essences or odor absorbers enhances the appeal of food to consumers by improving the aroma of the fresh product itself or intensifying the flavor when the package is opened.
- *Antimicrobials*: Microbiological contamination from pathogenic or spoilage bacteria may occur due to inadequate processing or when package integrity is compromised by a ruptured seal, puncture, dents, or incomplete glass finishes. Various methods, such as heat treatment, drying, freezing, refrigeration, irradiation, modified atmosphere packaging (MAP), and the addition of salts or antimicrobial agents, preserve food against microbial growth. Antimicrobial packaging methods include adding a sachet into the package, dispersing bioactive agents in the packaging, coating bioactive agents onto the surface of the packaging material, or utilizing antimicrobial macromolecules with film-forming properties or within edible matrices. Numerous agents with

antimicrobial properties (including ethanol, carbon dioxide, silver ions, chlorine dioxide, antibiotics, organic acids, essential oils, and spices) are used to inhibit the growth of microorganisms that can lead to food deterioration (bacteria can also attack packages, affecting their functions and properties) (Gould, 1996).

- *Antioxidants*: Oxidation of fats is one of the major causes of food spoilage, second only to growth of microorganisms. The oxidation of lipids in food leads to deterioration of the texture, change in the taste and/or odor, and a drop in nutritional quality. Thereby, oxidation of food can be avoided by the use of oxygen scavengers and antioxidant agents in the packaging. Such packaging is intended to prevent or slow down the oxidation reactions that affect the quality of food (Lin et al., 2016).
- *Radio-frequency identification (RFID)*: RFID chips are becoming more common with the introduction of smart labels that are used to track and trace packages and unit loads throughout distribution and storage. Newer developments include recording the temperature history of shipments and other intelligent packaging functions (Meyers, 2007). A variety of security printing methods, holograms, and specialized labels are available to help confirm that the product in the package is not a counterfeit.

3.7.1.2.1 Microwave Packaging

Metallized films are used as a susceptor for cooking in microwave ovens. These increase the heating capacity and help make foods crisp and brown. Plastic microwavable containers are also used for microwave cooking.

3.7.1.2.2 Shock and Vibration

These detectors are attached to the package or to the product in the package to determine if an excessive shock has been encountered. The mechanisms of these shock overload devices have been spring-mass systems, magnets, drops of red dye, and several others. Recently, digital shock and vibration data loggers have been available to more accurately record the shocks and vibrations of shipment. These are used to monitor critical shipments to determine if extra inspection and calibration are required.

Other developments include engineered packaging films that contain enzymes, antibacterial agents, scavengers, and other active components to help control food degradation and extend shelf life. Food packagers take extra care with some types of active packaging. For example, when the atmospheric oxygen in a package is reduced for extending shelf life, controls for anaerobic bacteria need to be considered. Also, when a controlled atmosphere reduces the appearance of food degradation, consumers need to retain a means of determining whether actual degradation is present.

3.7.1.3 Intelligent Packaging

Intelligent packaging monitors the condition of packaged food or the environment surrounding the food by signaling changes in the internal and external environments and communicating the conditions of the packaged food product. Different from active packaging systems, intelligent packaging does not directly act to extend the shelf life

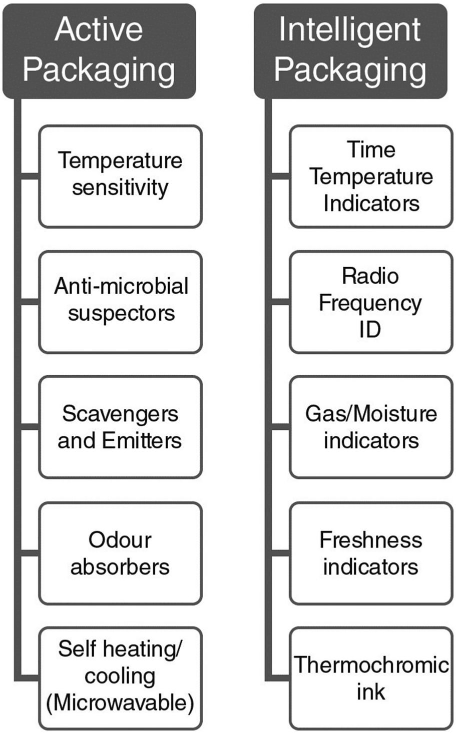

FIGURE 3.2 Variations in active packaging and intelligent packaging.

of foods; rather, it aims to convey information related to the food's quality to the stakeholders of the food supply chains (Figure 3.2). The headspace of food packages undergoes changes in its composition over time (Riva et al., 2001). Devices capable of identifying, quantifying, and/or reporting changes in the atmosphere within the package, the microbiological quality of food, or the temperatures during transfer and storage are the basis of intelligent packaging. The indicators should be easily activated and exhibit a change that is easily measurable; time- and temperature-dependent changes must be reproducible and ideally matched or readily correlated with the food quality, and also provide information regarding the status of the package.

- *Time–temperature indicators*: These are of two types: visual indicators and RFID tags. The visual indicators change color in response to cumulative exposure to temperature. The main mechanisms of action include enzymatic reactions, polymerization, or chemical diffusion. The RFID tag is an advanced form of data carrier for automatic product identification and traceability. In an RFID system, a reader emits radio waves to capture data from an RFID tag, and the data are then passed to a host computer for analysis and decision making. The RFID tag contains a minuscule microchip connected to a tiny antenna.

- *Seal and leak indicators*: The gas composition inside the package often changes as a result of the activity of the food product, leaks, nature of the package, or environmental conditions. O_2 and CO_2 can be used to monitor food quality, as seal indicators (leaks), or to verify the effectiveness of an oxygen absorber. Most O_2 or CO_2 indicators change color as a result of chemical or enzymatic reactions. A color change indicates when the oxygen concentration exceeds the limit established in a sealed food package. A major problem with such indicators is that they require storage under anaerobic conditions, since they quickly deteriorate in air.
- *Freshness and/or ripening indicators*: Freshness and/or ripening indicators provide an indication of the deterioration or loss of freshness of packaged goods. They are described as indicating different mechanisms of volatile metabolites, such as diacetyl, amines, carbon dioxide, ammonia, and hydrogen sulphide, produced during the aging of foods. Changes in the concentration of hydrogen sulphide or organic acids such as *n*-butyrate, L-lactic acid, D-lactate, and acetic acid during storage are offered as viable indicators of the formation of metabolites in meat products, fruits, and vegetables. Indicators based on color changes due to changes in pH are of great potential use as indicators of microbial metabolites and ripeness (Dainelli et al., 2008).

Products formed during microbial growth (carbon dioxide and hydrogen sulphide) and biogenic amines are of great potential use in indicating the freshness of meat and fish.

3.7.1.4 Edible Packaging

Edible packaging is the third generation of packaging materials. The need for edible packaging is such that the US Environmental Protection Agency says that every year 1.6 million metric tons of packaging waste is dumped into landfills in the United States; packaging waste is approximately 30% of municipal waste by weight, and 13% is due to plastic material that is not biodegradable. This dumped packaging includes mainly plastics, which reduce moisture and O_2 transfer rate of soil and deteriorate the quality of land. Plastics are nonbiodegradable, and they are the biggest threats to the environment in the present world. Edible package can be the solution to these environmental problems. An edible film or coating is simply defined as a thin, continuous layer of edible material formed on, placed on, or placed between the foods or food components. The package is an integral part of the food, which can be eaten as a part of the whole food product. The principles of film formation are as follows:

- *Cohesive forces between polymer molecules*: Here cohesive forces between same polymer molecules are responsible for the barrier properties of films.
- *Adhesive forces between film and substrate*: Here adhesive forces between film and substrate are responsible for the formation of an intact boundary. The functional properties are retarding moisture migration (wax coating on fruits and vegetables), retarding gas (O_2 and CO_2 permeability), retarding solute transport, retarding oil and fat migration, improving mechanical handling properties of food, retaining volatile flavor compounds, carrying food additives, and enhancing nutritive value of food.

Materials that can be used for manufacturing edible packaging materials are as follows:

- *Protein based*: Gluten – soy, collagen – casein, zein – whey protein
- *Polysaccharide based*: Cellulose – chitosan, alginate – starch, pectin – dextrin
- *Lipid based*: Waxes – acylgycerols, fatty acids

These are the main ingredients for edible packaging materials. In addition, some antimicrobial agents, plasticizers, and thickening agents are also used.

Requirements for consideration are that edible coatings should have an acceptable color, odor, taste, flavor, and texture; edible coatings should be undetectable; they must adhere to the food but not stick to the packaging materials; and they should melt in mouth but not in hands.

Advantages of edible films include the following:

- Environment friendly, as fully consumed or biodegradable and recyclable
- Reduce the waste and solid disposal problem
- Enhance organoleptic properties like color, sweetness, and so on
- Enhance nutritional values by supplementation
- Individual packaging is possible for fruits like strawberry

Film can be used as an interface between the layers of heterogeneous foods to prevent deteriorative intercomponent moisture residue and solute migration between the foods. Film can work as a carrier for antimicrobial or antioxidant agents. Film can be used for micro-encapsulation of flavoring agents. Film can be multilayer, where the innermost is edible, and can reduce the cost of utilizing byproducts, for example whey (Satyanarayana et al., 2005).

- *Ideas for the future*: Edible fruit and vegetable wraps that enhance nutrition for food products could make healthy foods more attractive to consumers. Fruit and vegetable films could also be used to cover leftovers for short-term storage in the refrigerator. Edible films could provide new flavor combinations.
- *Drawbacks of edible packaging*: The edible wraps would not be used alone where unsanitary conditions during food handling can occur. They would be used to wrap foods inside a secondary synthetic package during food distribution and storage. The new wraps are more expensive than synthetic packages. However, developers believe the nutritional and environmental advantages will justify the increased cost, despite development of off flavor and poor mechanical properties.
- *Commercialization challenges*: Edible packaging has found limited applications in the industry. Challenges to wide commercialization of edible packaging that need to be addressed include the high cost of film-forming biopolymers (with the exemption of starch and certain starch derivatives) compared to synthetic packaging materials; the need for effective, economical, and microbiologically safe methods for applying edible coatings on

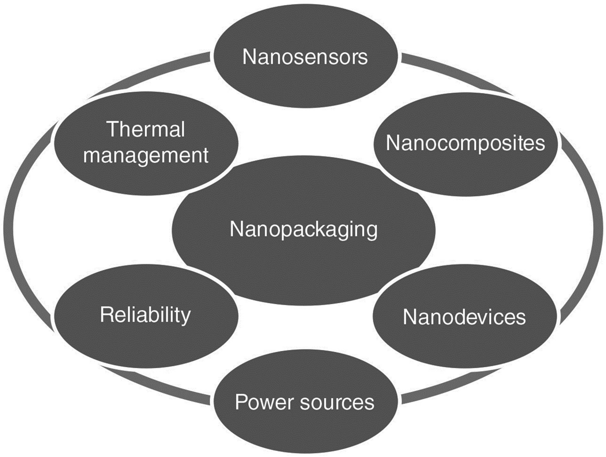

FIGURE 3.3 Principles of nanopacking.

meat products on an industrial scale; the poor barrier properties of most polysaccharide and protein-based edible films at high relative humidity environments; the possibility for adverse organoleptic effects introduced by edible coatings; and the dietary allergies and intolerances associated with various protein film-formers.

3.7.1.5 Nanopackaging

Nanoscale innovation could potentially introduce many amazing improvements to food packaging in the form of barrier and mechanical properties, detection of pathogens, and smart and active packaging with food safety and quality benefits (Brody et al., 2008). Nanotechnology enables designers to alter the structure of packaging materials on the molecular scale in order to give the material the desired properties. With different nanostructures, plastics can be given various gas and water vapor permeabilities to fit the requirements of various foods (Rhim, 2013). By adding nanoparticles, one can achieve packages with more resistance to light and fire, better mechanical and thermal performance, and less gas absorption. These properties can significantly increase the shelf life and sensory characteristics of food products and facilitate transportation and usage. The addition of nanosensors to food packages could be used to detect chemicals, pathogens, and toxins in foods (Figure 3.3).

3.8 FACTORS INFLUENCING SHELF LIFE OF FRUITS AND VEGETABLES

Several factors influence shelf life of fruits and vegetables. These factors can be conveniently categorized as internal and external factors. Internal factors relate to the type and nature of plant tissues, that is, dormant, mature, or senescent, and whether root, fruit, leaf, flower, and so on. Physiological maturity of fruits and vegetables at the time of harvesting affects the shelf life to a great extent. Hence, harvesting should be done at optimum maturity level as far as possible.

The shelf life of a properly harvested sound produce depends largely on storage as well as post storage (marketing conditions). Thus, storage as well as post-storage atmospheres (i.e., temperature, relative humidity, and the composition of air surrounding the produce) become the key factors governing shelf life. Among the various factors affecting the shelf life, factors pertaining to storage atmosphere can be manipulated to a great extent to increase the shelf life of a product.

Various metabolic processes, which continue to take place in the produce even after harvest, affect the shelf life of the produce. Among these, respiration is considered to be the major metabolic process that brings about natural aging and subsequent deterioration of the produce. In the process of respiration, O_2 from the surrounding atmosphere is taken by the produce for oxidative reduction of respiratory substrates (i.e., carbohydrates, organic acids, etc.) to CO_2 and water. Carbon dioxide evolved by the produce is given out to the surrounding atmosphere. The total amount of CO_2 produced by the commodity throughout its post-harvest life depends largely on the quantity of substrates. Hence it is constant for a given commodity. When the commodity completely gives out this constant amount of CO_2, its normal life comes to an end. It is the rate of CO_2 evolution that determines the life span. The higher the rate of CO_2 respiration, the shorter the shelf life of the product and vice versa.

3.8.1 Respiratory Metabolism

Respiration involves a series of reactions through which oxidative reduction of the substrates takes place. By storing the produce in an atmosphere having higher CO_2 concentration, the CO_2 evolution (respiration) can be inhibited to some extent. Likewise, storing of the produce at low temperature also brings down the rate of respiration. Thus, by modifying the storage atmosphere (i.e., the composition of storage air with regard to O_2 and CO_2 concentrations and the temperature), respiration of the stored produce can be decreased. Consequently, post-harvest life can be increased. CO_2 concentration levels higher than the critical level cause flesh softening and peel discoloration in the produce while temperature lower than the critical one cause chilling injury to the produce.

3.8.2 Extending Shelf Life via Packaging Methods

Shelf life is the length of time that foods, beverages, and many other perishable items are given before they are considered unsuitable for sale, use, or consumption. It is the time between the production and packaging of a product and the point at which the product first becomes unacceptable under defined environmental conditions. It is a function of the product, the package, and the environment through which the product is transported, stored, and sold.

Factors influencing shelf life include the product, the package, and the environment.

- *Product*: Products differ greatly in their susceptibility to various agents. These agents cause different charges that affect the shelf life. Examples include:
    - Aroma loss as in freshly ground pepper or roasted coffee, which results in the loss of palatability
    - Pick up of a foreign odor, for example, the absorption of onion odor by butter when these two items are placed together
    - Loss of carbonation as in the case of soft drinks or beer
    - Crystallization, for example, honey when kept cold for a long time
    - Moisture gain as in dry or dehydrated foods such as ready-to-eat breakfast cereals and snack foods, which destroys their crisp texture
    - Rancidity of snack items such as potato chips due to the oxidation of the oils absorbed during frying
    - Browning reactions as in case of freshly cut fruits
- *Package*: The critical sensitivity of the product to external agents is determined in part by the package. For example, a product such as a snack food that is susceptible to moisture gain and oxygen can be termed as moisture sensitive if texture degrades before rancidity becomes objectionable. The same product if packed in a sufficient moisture barrier would become oxygen sensitive.
- *Environment*: Product distribution through various networks causes stress on the product under a variety of climates, seasons, and shipping and warehouse conditions.

Barrier properties of the package are therefore related to the environmental conditions and are summarized in Table 3.2. Barrier properties indicate the range of properties that play a part in determining the total protective efficiency of a package.

3.8.3 Food Safety and Public Health

It is critical to maintain food safety during processing, packaging, storage, logistics (including cold chain), sale, and use. Conformance to applicable regulations is mandatory. Some are country-specific such as the US Food and Drug Administration and the US Department of Agriculture; others are regional such as the European Food Safety Authority. Certification programs such as the Global Food Safety Initiative are sometimes used. Food packaging considerations may include use of hazard analysis and critical control points, verification and validation protocols, good manufacturing practices, use of an effective quality management system, track and trace systems, and requirements for label content. Special food contact materials are used when the package is in direct contact with the food product. Depending on the packaging operation and the food, packaging machinery often needs specified daily wash-down and cleaning procedures (Opie, 1989).

Health risks of materials and chemicals used in food packaging need to be carefully controlled. Carcinogens, toxic chemicals, mutagens, and so on need to be eliminated from contact with food and potential migration into foods.

3.8.4 Manufacturing

All aspects of food production, including packaging, are tightly controlled and have regulatory requirements. Uniformity, cleanliness, and other requirements are needed to maintain good manufacturing practices.

Product safety management is vital. A complete quality management system must be in place. Hazard analysis and critical control points are one methodology that has been proven useful. Verification and validation involve collecting documentary evidence of all aspects of compliance. Quality assurance extends beyond the packaging operations through distribution and cold chain management.

3.9 PACKAGING METHODS OF VARIOUS FOOD PRODUCTS

3.9.1 Packaging of Milk Products

- *Sterilized milk*: It should be packed in glass bottles or sanitary cans properly sterilized and stocked in such a way as to protect it from contamination. Polypapers or polylaminated paper packs in tetrahedron, pyramid, or other forms may also be used.
- *Condensed milk/sterilized cream*: These products should be packed in hermetically sealed containers or LDPE-lined cartons or aseptic cartons. In the case of condensed milk, the side seam of the container may be soldered or cemented. The type of cement used should not impart any odd flavor to the milk and should also be nontoxic.
- *Fermented milk products*: They should be filled in glass bottles or any other suitable container and capped. They should not be exposed to warmer temperature as the products become too sour due to growth of microorganisms. The fermented milk products should be cooled before dispatch and maintained preferably at a temperature below 10°C to develop good flavor and texture.
- *Milk powder, cereal weaning foods*: For these products, the code has recommended that these products should be packed in hermetically sealed and clean containers in such a way as to protect them from deterioration. These may also be packed in hermetically sealed tinplate containers in N_2 or a mixture of N_2 and CO_2 gas. Another packing material that may be considered is a bag-in-box having inner layers made of polyethylene terephthalate (PET)/LDPE, which can be gas flushed. Infant milk food and whole milk powder when manufactured by the spray drying process should be packed in N_2 or a mixture of N_2 and CO_2 gas.

3.9.2 Packaging of Fruits and Vegetables and Related Products

- *Raw vegetables and fruits*: Raw vegetables may be packed loose in bulk or packed in containers for trading and transport. In the latter case, the vegetables should be packed in new loosely woven gunny bags or wooden or plastic crates or in lined or unlined corrugated fiberboard boxes.
- *Onion and garlic*: These should be packed in sound, clean, new loosely woven gunny bags, net bags, bamboo or palm leaf baskets, wooden crates, or lined or unlined corrugated fiberboard boxes or in any other suitable manner so as to allow proper aeration of the bulbs.

- *Tomatoes*: Tomatoes should be packed in baskets or wooden boxes or lined or unlined corrugated fiberboard boxes. While packing, it should be ensured that the tomatoes are not unduly pressed when the lid is closed.
- *Fruits*: They should be packed in wooden boxes or lined or unlined corrugated fiberboard boxes. The boxes should be made in such a manner as to allow for proper aeration of the fruits. A sufficient quantity of straw should be put in the container to prevent fruits from rubbing against each other. Supergrade fruit should be wrapped individually either in tissue paper or in any other suitable material before being packed into the container.
- *Juices, jams, jellies, and marmalades*: They should be packed in glass bottles or open top cans. Tomato juice can be packed in glass or tinplate containers and hermetically sealed. The containers may be either plain or lacquered; if lacquered, the lacquer should be of the acid-resistant type.

3.9.3 Packaging of Meat, Fish, and Poultry Products

- *Meat*: Meat should be wrapped in PE sheets or bags and delivered in clean, rust-free, and closed containers. If the time involved in packaging and transport is more than 2 hours, the meat should be covered with ice. If the meat has to be supplied to a distant market, it should be wrapped in PE sheets and packed in clean, rust-free, and closed containers that are sufficiently strong to withstand repeated handling. The containers should have an outlet for the flow of water resulting from melting of ice used to chill the meat. When the meat is chilled by using CO_2 or any other more effective chilling medium, the time involved for reaching the destination may be up to 1 hour. This type of packing with ice should be used when the distance involved can be covered in 6 hours from the time of packing to the time of delivery.
- *Cooked meat products*: They should be packed in butter paper or any grease-proof, clean wrapping material. All the sliced cooked meat products should be wrapped in butter paper and then put in a big PE cover. Finally, the PE container should be packed in clean, rust-free, and closed containers sufficiently strong to prevent any damage to the meat products packed. Alternatively, the meat including whole carcasses and cooked meat products may also be vacuum packed using suitable wrapping materials such as PET/LDPE.
- *Dressed chicken*: The drained and dressed birds should be packed into suitable sized PE bags or other suitable packing material. Before final sealing, the packs should be immersed into vats containing water to expel the content of air between the carcass and the bag, taking care that no water is introduced in the pack. Alternatively, vacuum packing or shrink wrapping of the packs may be adopted. After the air inside is expelled, the bag should be sealed on a sealer or should be knotted using rubber bands.
- *Egg powder*: Egg powder should be gas packed in nitrogen in suitable tinplate containers or flexible packaging materials. PET/LDPE laminate may be considered for the purpose.

- *Fish*: The fresh product should be packed in PE-lined insulated containers made of plywood, country wood, or plastic. The thickness of insulation may vary from 15 to 30 mm depending upon the storage period and the mode of transport. Thermocol or fiberglass may be used as an insulation material. Adequate drainage of melted ice may be provided.

3.9.4 Packaging of Bakery and Confectionary Products

- *Bread*: The packaging for bread should be such that it is wrapped in slice form in LDPE-coated poster paper or clean waxed paper, grease-proof paper, or any other suitable nontoxic wrapper. The loaf may be packed either in sliced form or as it is.
- *Biscuits*: The material for packing should be clean, sound containers made of tinplate, cardboard paper, or another suitable material such as cello/LDPE, biaxially oriented polypropylene (BOPP)/LDPE, PET/LDPE, paper/LDPE, or foil/LDPE in such a way as to protect the biscuits from breakage, contamination, absorption of moisture, and seepage of fat from the biscuits into the packing materials. The biscuits should not come in direct contact with the packing material other than grease-proof or sulphate paper, cellulose film, or aluminum foil laminate. The biscuits in tinplate containers should not come in direct contact with the metal walls.
- *Cakes*: The cakes should be wrapped or packed in clean waxed paper, grease-proof PE, glassine/LDPE, or any other suitable wrapper or tins. The cakes should be thoroughly cooled in a clean atmosphere before packing.

3.9.5 Packaging of Protein-Rich Foods

- *Protein-rich extruded foods*: The packaging material should be moisture proof, clean, and sound. These foods may be packed in moisture-proof paper bags (multilayered, PE-lined) or pouches made from BOPP/LDPE, glassine/LDPE, or HDPE woven bags having 300-gauge LDPE liner for bulk (i.e., 10, 15, 20, and 25 kg) or in suitable moisture-proof multiservice containers. Small quantities (i.e., 20–250 g) for consumer market may be packed in 250-gauge HDPE bags in such a way to protect them from deterioration.
- *Peanut butter*: It should be packed in wide-mouthed glass jars, polystyrene tubs, or any other suitable container of the required size and shape. The container should have an airtight seal in order to avoid oxidative rancidity and to preserve freshness.

3.9.6 Packaging of Edible Starches and Starch Products

- *Flours and starches*: The materials should be packed in either LDPE-coated jute bags or LDPE-coated raffia bags. The mouth of each bag should be either machine stitched or rolled over and hand stitched in a suitable manner.

- *Edible spray-dried potato flour*: The edible spray-dried potato flour should be packed in clean, sound, and dry tinplate containers. These should be packed in flexible materials made of HDPE or metallized polyester bags or pouches made from other flexible laminates such as BOPP/LDPE. The flexible material used should have high barrier properties against oxygen and moisture.

3.9.7 Packaging of Oils and Fats

- *Oil*: The oil should be packed in suitable well-closed containers. The packaging material used may be tinplate containers, glass bottles, rigid plastic containers of HDPE, food-grade PVC, PET, and flexible pouches made of plastic film/foil laminate. Flexible pouches of biaxially oriented nylon (BON) film/ionomer and coextruded nylon/ionomer may be considered.
- *Fat, vanaspati*: The material should be packed in suitable sealed packages, such as flexible packs and well-closed tinplate containers. The net mass of oils, fats, and vanaspati to be packed should be 500 g, 1 kg, 5 kg, and thereafter in multiples of 5 kg.

3.9.8 Packaging of Food Grains and Food Grain Products

- *Cereal grains*: Cereal gains should be packed in new, clean jute bags or LDPE-coated jute bags and raffia bags. The mouth of each bag should be machine stitched.
- *Cereal flours*: The cereal flours should be packed in 1, 2, 10, 20, 40, 65, 75, or 90 kg bags. For packages above 65 kg, the material for packaging should be either LDPE-coated jute bag/LDPE-coated raffia bags or single sound A-twill or B-twill jute bags. The bags used for smaller packs may be PE bags or PE-lined jute bags. The mouth of the bag should be either machine stitched or hand stitched. If it is hand stitched, the mouth should be rolled over and then stitched.

3.9.9 Packaging of Sugar and Honey

- *Sugar*: It should be packed in either PE-coated Hessian bags or PE-coated raffia bags or in clean, sound, and new A-twill jute bags. The bags may be lined with PE film. The mouth of each bag should be either machine stitched or rolled over and hand stitched. The stitches should be in two rows with at least 14 stitches in each row if it is hand stitched.
- *Cube sugar*: The number of cubes corresponding to a net weight of 0.5 kg should be wrapped together in butter paper or kraft paper and packed in cartons. Alternatively, these may also be packed in LDPE-coated poster paper.
- *Honey*: The packing of honey should be in hygienically clean and wide-mouthed glass containers or in acid-resistant lacquered tinplate containers or in suitable PE containers. The screwed caps of glass containers should be of noncorrosive and nonreactive material and should be provided with cork washers to avoid spilling.

3.9.10 Packaging of Stimulant Foods

- *Tea*: To maintain the flavor of tea, it should be packed in such a manner as to allow the tea to retain its freshness. Tea could be packed in flexible packaging materials or laminates such as LDPE, paper-coated LDPE, PET/LDPE, and BOPP/LDPE.
- *Roasted and ground coffee*: The product should be packed in clean, sound packing materials such as tinplate, glass containers, metal foil, plastic films or in laminated pouches of paper/LDPE, PET/LDPE and BOPP/ LDPE. The product may also be vacuum packed or packed in inert gas.
- *Chocolates*: Chocolates meant for covering purposes should be packed in clean, sound, and odor-free containers. Such containers may be either made of tinplate, plastic, grease-proof paper, aluminum foil, or laminates made of paper/LDPE, BOPP/LDPE.
- In case of other types of chocolates, each unit of chocolate should be wrapped in aluminum foil, printed or otherwise and may be lined with glassine or grease-proof paper. Such units may be over-wrapped by a decorative band. These units in turn should be collectively packed in clean and odor-free cardboard cartons. Such cartons should be finally over-wrapped with bituminized kraft paper with all joints well-sealed to ensure the prevention of entry of moisture and dust.

3.9.11 Packaging of Alcoholic Drinks and Carbonated Beverages

- *Carbonated beverages*: Carbonated beverages should be filled in glass containers conforming to IS 1107:1986 or in PET bottles. It may also be filled in cans, plastic containers, and dispensing units. The containers should be filled under strict hygienic conditions. After filling, the containers should be hermetically sealed with clean, new crown corks conforming to IS 1994:1987.
- *Beer*: Beer may be filled in 650 mL glass bottles or in PET bottles. The bottles should be properly sealed with gas-tight crown caps. Beer may also be packed in cans. Bottles or cans should be packed in wooden cases or corrugated fiberboard boxes.

3.9.12 Packaging of Spices and Condiments

- *Chillies*: Chillies should be packed in clean and sound jute bags or in pouches made from PET/EVA or BOPP/EVA or in suitably lined wooden cases. The material may also be packed in LDPE-coated raffia bags.
- *Black pepper*: It should be packed in clean and sound jute bags with or without moisture-proof lining or LDPE-coated raffia bags that do not impart any foreign smell to black pepper. The mouth of each bag should be either machine stitched or rolled over or hand stitched.
- *Cloves*: Whole and ground cloves should be packed in clean and sound airtight containers made of a material that does not affect the cloves. Packing in PET/LDPE bags may be considered. Similarly, cardamom, fennel seeds, and so on are packed.

Packaging customer products is a territory where supply and demand are continuously changing because of the advancement of a worldwide food market and adjustment to consumer, distribution, legal, and technological prerequisites.

3.10 GLIMPSE OF PACKAGING MATERIALS AVAILABLE FOR PACKAGING METHODS

Examples for traditional or natural packaging materials are bamboo basket, fiber or leaf mats, leather containers of animal skin, clay containers, gunny bags, cloth bags, and arecanut and teak leaves sheath.

The modern packaging materials can be divided into rigid, semi-rigid, and flexible materials. Examples for rigid containers are metal drums, metal barrels, glass bottles, glass jars, wooden boxes, wooden crates, plastic bottles, plastic drums, plastic crates, paper drums, are plywood containers. Examples for semi-rigid containers are aluminum collapsible tubes, plastic collapsible tubes, composite containers, and paper-based cartons.

3.10.1 Paper

Paper is widely used as a packaging material because of its stiffness and printability. The main advantages of paper as packaging material are good stiffness, good absorbent, good creaseability, good printability, low density, not brittle, biodegradable, and low cost. The main disadvantages are poor tensile strength, poor wet strength, ease of tearing, and no barrier property without coating.

3.10.1.1 Barrier Coating

In many packaging applications, a barrier may be needed against water vapor or gases such as oxygen. A water barrier can be formed by changing the wettability of the paper surface with sizing agents. Coating the paper with a continuous film of a suitable material will confer gas or vapor barrier properties. Paraffin wax applied in a molten form was commonly used to produce a water vapor barrier, but PE applied by extrusion gives a more durable and flexible coating.

3.10.2 Glass

The two main types of glass container used in food packaging are bottles (which have narrow necks) and jars (which have wide openings). Advantages of glass packaging are that they are inert, impermeable, odorless, versatility in shape and color, reusability, suitability for use in the microwave, and excellent clarity; glass containers are distinctive, convenient, and practical; and glass containers are used for premium quality foods. The disadvantages are that it is fragile, heavy, and expensive.

3.10.3 Metal

Four metals are commonly used for the packaging of foods: steel, aluminum, tin, and chromium. Tin and steel, and chromium and steel, are used as composite materials in the form of tinplate and electrolytically ECCS, the latter being somewhat unhelpfully referred to as TFS. Today, materials like tinplate and aluminum have become universally adopted for the manufacture of containers and closures for foods and beverages, largely due to several important qualities of these metals. These include their mechanical strength and resistance to working; low toxicity; superior barrier properties to gases, moisture, and light; ability to withstand wide extremes of temperature, and ideal surfaces for decoration and lacquering.

3.10.4 Tinplating

The traditional method for tinplating involved dipping or passing the steel through a bath of molten pure tin.

Tinplate has been used for preserving food for well over a hundred years. Produced from low-carbon steel (that is, black plate), tinplate is the result of coating both sides of black plate with thin layers of tin. The coating is achieved by dipping the sheets of steel in molten tin (hot-dipped tinplate) or by the electrodeposition of tin on the steel sheet (electrolytic tinplate). The benefit provided by the bare tin surface inside the can is the protection of the natural flavor and appearance of the food through oxidation of the tin surface in preference to oxidative degradation of the food.

This is also known as ECCS or chrome-oxide-coated steel. TFS requires a coating of an organic material to provide complete corrosion resistance. TFS has good formability and strength, but it is much cheaper than tinplate.

3.10.5 Aluminum Foils and Containers

Aluminum foil is a thin-rolled sheet of alloyed aluminum varying in thickness from about 4 to 150 μm. Foil can be produced by two methods: either by passing heated aluminum sheet ingot between rollers in a mill under pressure and then rerolling on sheet and plate mills until the desired gauge is obtained, or continuously casting and cold rolling. In the softest temper, aluminum foil exhibits dead fold characteristics – that is, when wrapped around an object it will assume the profile of the object with no spring back. Aluminum foil is essentially impermeable to gases and water vapor when it is thicker than 25.4 μm, but it is permeable at lower thicknesses due to the presence of minute pinholes. For example, 8.9 μm foil has a WVTR of up to 0.3 mL/m^2/day^2 at 38°C and 100% relative humidity (RH) Aluminum foil can be converted into a wide range of shapes and products including semi-rigid containers with formed foil lids, caps and cap liners, composite cans and canisters, laminates containing plastic and sometimes paper or paperboard where it acts as a gas and light barrier, and foil lidding.

3.10.6 Plastics and Polymers

Plastics have become a major packaging material, along with paper, metal, and glass. Plastics are used mainly for consumer packages in the form or wraps, pouches, cartons, bags, tubes, bottles, jars, and boxes. In transport, they are used in the form of sacks, stretch films for wrapping tray-loads, containing unit packs, or for entire pallet loads. The advent of snack foods, convenience foods, and prepared foods has been possible to a great extent due to the availability of plastic packaging materials.

Most of the plastics used in food packaging are thermoplastic, which means they can be softened by heating and hardened by cooling. The main advantages of plastic as a food packaging material are that it serves as a barrier to water vapor and gases and is light weight, with good strength, design flexibility, resistance to breakage, and machinability. It is suitable for high speed filling using FFS techniques; it is glossy and transparent, and coloring is possible; it has high tensile strength, high tear strength, high printability, high-level lamination, and low cost. The disadvantage of plastic is the disposability, that is, it is difficult to get it disintegrated into soil.

3.10.6.1 Polyethylene

Polyethylene accounts for the biggest proportion of the plastics used in packaging.

- *Low-density polyethylene*: LDPE possesses excellent resistance to most chemicals. It is a good barrier to water vapor but less so to oxygen; it has high permeability to volatile oils and swells in contact with fats and oil. It gives very good heat seals and is easily coated with other materials to serve as a laminated layer. It is used as bags, liners, bottles, and so on.
- *Linear low-density polyethylene (LLDPE)*: It is generally stronger and tougher than LDPE but has similar properties. LLDPE has higher tensile strength, puncture resistance, tear properties, and elongation than LDPE.
- *High-density polyethylene*: The chemical resistance of HDPE is superior to that of LDPE, and it has better resistance to oils and greases. The film offers excellent moisture protection and significantly decreased gas permeability compared with LDPE film but is much more opaque. Heat sealing is considerably more difficult compared to LDPE film. HDPE film has a white, translucent appearance and tends to compete more with paper than transparent films.

3.10.6.2 Polypropylene (PP)

PP has low water vapor transmission, medium gas permeability, good resistance to greases and chemicals, good abrasion resistance, high-temperature stability, good gloss, and high clarity. It can be used where a higher temperature of processing is involved and for packing readymade food that requires warming before consumption. One of the disadvantages is that the film has a tendency to become brittle at a low storage temperature, a problem that can be overcome by the addition of small amounts of ethylene into the propylene at the time of manufacture.

3.10.6.3 Polystyrene (PS)

The material is used for packing vegetables and fresh meat on trays, yogurt and other milk products in cups, and for the over-wrapping of fruits and vegetables.

3.10.6.4 Polycarbonate

It is glass-like, heat resistant, and available in the form of film, beside rigid containers, but it has very few food packaging applications.

3.10.6.5 Polyvinyl Chloride

There are two types – rigid and plasticized. The rigid form has good moisture and gas barrier properties and resistance to fats. Hence, these are used for packing butter or margarine and for making transparent bottles for mineral water, edible oils, fruit juices, carbonated beverages, and beer, as these bottles can withstand pressure.

The plasticized form is used for packing meat, fruits, and vegetables and for shrink wrapping. It is also used for the shrink wrapping of pallets.

3.10.6.6 Polyvinylidene Chloride (PVDC)

PVDC has the lowest water vapor, oxygen, and CO_2 permeability among all commercially used plastic films, besides having resistance to fats and chemicals. PVDC is used as a coating material on PE and other plastics to improve the gas and moisture barrier properties of the native plastics. It is used for packing dense materials like cheese, poultry, and so on.

3.10.6.7 Ethylene Vinyl Alcohol (EVOH)

EVOH is a widely used polymer in the manufacture of high barrier containers as in the manufacture of bulk bags used for aseptic packaging, retort pouches, and containers.

3.10.6.8 Polyethylene Terephthlate (PET)

PET is a linear, transparent thermoplastic polymer. PET bottles and films are largely amorphous with small crystallites and excellent transparency. PET film's outstanding properties as a food packaging material are its great tensile strength, excellent chemical resistance, light weight, elasticity, and stability over a wide range of temperatures. It has low permeability to moisture and gases but has poor sealing properties. Hence, it has to be laminated with PE. PET containers are used widely for packing mineral water, carbonated and noncarbonated beverages, syrups, edible oils, and liquors.

3.10.6.9 Coating and Laminating

Coating and laminating are two of the most widely used processes for transforming flexible films and sheets into products that have properties useful in food packaging. Coating is the process of applying one or more layers of a fluid or melt to the surface of a material, while laminating is the bonding of two or more webs. A laminate is defined as any combination of distinctly different plastic film materials or plastic plus nonplastic materials (typically paper and aluminum foil), where each major web is generally thicker than 6 μm.

3.11 LAWS AND REGULATIONS AVAILABLE FOR FOOD PACKAGING METHODS

Packaging laws and regulations have been introduced by the government to safeguard the interests of the consumer and the society at large. The packaging laws and regulations for food products are mainly covered under the following statutes:

1. The Standards of Weights and Measures Act, 1976, and the Standards of Weights and Measures (Packaged Commodities) Rules, 1977 (SWMA)
2. The Prevention of Food Adulteration Act, 1954, and the Prevention of Food Adulteration Rules, 1955, and its first amendment, 2003 (PFA)
3. The Fruit Products Order, 1955 (FPO)
4. The Meat Food Products Order, 1973 (MFPO)
5. The Edible Oil Packaging Order, 1998
6. The AGMARK Rule

3.11.1 The Standards of Weights and Measures Act (SWMA)

The most important rule under SWMA is that the commodities to be packed for retail should be packed in standard specific quantities as given under the rule for each commodity. However, the central government can authorize prepackaging in quantities other than those specified on technical ground.

3.11.1.1 Standard Packages

Under the Standards of Weights and Measures (Packaged Commodities) Rules, rules have been framed specifying provisions for the retail sale of packaged goods. One of the most important rules is with respect to the requirements that specific commodities are to be packed and sold only in standard packages.

3.11.1.2 Symbols for Units

The symbols for the International System of units and none other shall be used in furnishing the net quantity of the package. Symbols shall not be given in capital form except for units derived from a proper name; a period, that is, a dot after symbols, shall not be used. As far as possible, symbols shall always be written in the singular form, that is, "s" shall not be added – for example, mg, g, kg, mL, L, mm, cm, m, cm^2, m^2, cm^3, m^3.

3.11.2 The Prevention of Food Adulteration Act (PFA)

The Prevention of Food Adulteration Act was introduced by the government to prevent adulteration of food. The Adulteration Act and rules have provided standards for a large variety of food. The responsibility for adequate packaging of food and its safety falls on the manufacturer of the food product. The Prevention of Food Adulteration Act prohibits manufacture, storage, and sale of adulterated food. Violation of the law is prosecuted before a magistrate's court. The punishment is mandatory imprisonment for a minimum of three months.

3.11.3 Fruit Products Order (FPO)

The FPO is concerned with fruit and vegetable products including synthetic beverages, syrups, sharbats, and vinegar. The objective of this law is mainly to regulate the quality and hygiene of these products.

The important labeling rule under the FPO is that all labels should have the approval of the authorities concerned and carry the license number allotted. When a bottle is used as the package, it should be so sealed that it cannot be opened without destroying the license number, and the special identification mark of the manufacturer should be displayed on the top or neck of the bottle. The batch/code number along with the date of manufacturing should also be declared.

As contained in PFA, the FPO also prohibits use of any statement, design, or device that is false or misleading concerning the fruit product. Synthetic products associated with fruits and vegetables should clearly be marked "SYNTHETIC," and the word "SYNTHETIC," whenever used, should be as bold and in the same size and color as the letters used for the name of the product, and they should immediately precede such name.

3.11.4 Meat Food Products Order (MFPO)

The MFPO, similar to the FPO, regulates the licensing and labeling of all meat products. All labels have to be approved by the licensing authority, and the license number and category of manufacturer should be declared on the label. The name of the product, always a common name understood by the consumer, should be given along with net quantity. Trade names should have prior approval of the licensing authority. When any preservative or coloring agent is used, a statement to that effect should be given. When a permitted artificial flavoring agent is used, the words "Artificially Flavoured" should appear on the label in prominent letters and in continuance of the name of the product. The list of ingredients should also be given. Terms that may bear some geographical significance with reference to a locality other than in which either the factory is located or the product is manufactured can be given on the label after being qualified by the word "STYLE," "BRAND," or "TYPE," as the case may be. No statement, word, picture, or design that may convey a false impression or give a false indication of origin or quality can appear on the label.

3.11.5 Edible Oil Packaging (Regulation) Order, 1998

In order to ensure availability of safe and quality edible oil in packed form, the central government promulgated on September 17, 1998, a packaging order under the Essential Commodities Act, 1955, to make packaging of edible oil sold in retail compulsory unless specifically exempted by the concerned state governments.

Uniform methods for testing the quality of edible oil, including the thin layer chromatography (TLC) method for the detection of argemone oil, were prescribed and circulated to all state governments and manufacturers.

3.11.6 Agricultural Grading and Marking (AGMARK) Rules

AGMARK rules relate to the quality specifications and the needs of certain agricultural products to be eligible for Agmark certification. They also specify the type of packages that can be used for various products and labeling declarations that have to be given.

Some of the food products that have been covered under these rules are edible nuts, ghee, honey, pulses, spices and condiments, and vegetable oil (Heldman, 2003).

With the growth in the food industry, there is also a growing demand for packaging materials. Selection and use of the right material and the role it plays in preservation and protection of perishable products and foodstuffs has become very important. For perishables such as meat, fish, fruits, and vegetables, which are stored and transported under refrigeration or in frozen condition, proper maintenance of a cool or cold chain is imperative.

3.12 THE FUTURE PROSPECTS OF FOOD PACKAGING METHODS AND TECHNOLOGIES

The growing demand in the food packaging sector has opened ways to explore new materials with very high barrier properties. High barrier materials reduce the cost of material handling, distribution, and waste reduction, since they can reduce the amount of packaging materials. Another significant issue of the public is concern for safety and security, thus eliminating foodborne illnesses and malicious adulterations. The anxiety over public health and safety has paved the way for precut fruits and vegetables as on-the-go snacks, and also the food industry has seen the growth of minimally processed foods.

Apart from the traditional thermal treatments for the preservation of food, more thermal and nonthermal processing techniques have been developed in recent years through research. Convenience in each and every packaging operation is seen as an important parameter, from production, processing, warehousing, and marketing till cooking.

Another important trend in food packaging is that it should be natural and environmentally friendly, where many ingredients have been substituted with natural components, and designing an ecofriendly package requires biodegradable materials that are recyclable. The research in food science engineering and technology has seen huge progress in all of the aforementioned properties.

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4 Modified Atmosphere Packaging

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4.1 PRINCIPLE

Modified atmospheric packaging (MAP) is the procedure of modifying the composition of atmosphere within the package with a single gas or mixture of gases, which helps in controlling the biochemical, enzymatic, and microbial actions of the food product so as to circumvent or decrease the degradation process of the food. The shelf life of perishable foods such as milk, meat, poultry, fish, fruits and vegetables, and bakery products is restricted in the presence of atmospheric air by three prime aspects:

- The oxidation reaction of atmospheric oxygen
- The growth of spoilage aerobic microorganisms
- Moisture loss or uptake for human consumption

MAP is otherwise known as gas flushing, protective atmosphere packaging, or reduced oxygen packaging. The modified atmosphere inside the package enables fresh or minimally processed packaged food products to maintain visual, textural, and nutritional appeal. This procedure enables food packaging to provide an extended shelf life without requiring the addition of chemical preservatives or stabilizers. Processors and marketers of food products rely on MAP to ensure fresh and flavorful products that continually meet the end user's expectation for brand quality, consistency, freshness, and in-stock availability. The modification process often attempts to lessen the quantity of oxygen, moving it from 20.9% to 0%, in order to slow down the growth of aerobic organisms and prevent oxidation reactions. The removed oxygen can be replaced with nitrogen, commonly acknowledged as an inert gas, or carbon dioxide, which can lower pH and inhibit the growth of bacteria. Sometimes even carbon monoxide is used for preserving the red color of meat.

The successful expansion of shelf life of food products under MAP relies on four main factors:

1. The hygienic handling and food quality during harvest or processing
2. The gas combination used inside the package
3. The equipment used for gas flushing and subsequent packaging
4. The material used to make packaging film or bags

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The preferred atmosphere can be produced using either active or passive MAP. Active methods are based on the replacement of gases in the package or the use of gas scavengers or absorbers to establish a desired mixture of gases, while passive methods rely on the use of a specific packaging film, in which a preferred atmosphere develops naturally as a result of the respiration of products and the diffusion of gases through the film.

Storage of foods in a modified gaseous atmosphere can maintain quality and extend product shelf life by slowing chemical and biochemical deteriorative reactions and by slowing (and potentially preventing) the growth of spoilage organisms. The environment is formed from a finely balanced mix of normal atmospheric gases. The finely balanced MAP gas mix slows down the aging process of product to reduce color loss, odor, and off-taste resulting from product deterioration, spoilage, and rancidity caused by mold and other anaerobic organisms. A carefully controlled modified gaseous atmosphere achieves and maintains an optimal respiration rate to preserve the fresh, minimally processed fruits and vegetables, pasta, prepared foods, cheese, baked goods, cured meats, and dried foods throughout an extended shelf life.

Longer shelf-life MAP packages allow food processors, food manufacturers, food distributors, and food retailers to better control product quality, availability, and costs. A longer freshness cycles permit grocers to eliminate frequent product rotation, removal, and restocking, thereby reducing labor and waste disposal costs.

But it is important to ensure the pertinence and the persistence of the gas mixture at all stages of food storage and transport from harvest to end user. Incorrect oxygen levels, empty gas cylinders, and bad sealing bars can cause imprecise gas blends and poor package seals that can result in product spoilage. Routine package testing with headspace gas analyzers, online gas analyzers, and leak detectors ensures package quality and hence helps to maintain shelf life. In this chapter we discuss in detail the gas replacement method of MAP.

4.2 GAS COMBINATIONS

In MAP, mainly three types of combinations of gases are used for commercial application. The type of gas mixture chosen is mainly based on the food to be packaged. They are discussed in the following sections.

4.2.1 Inert Blanketing

The headspace of the package issolely flushed with inert gas nitrogen (N_2). This type of packaging is used mainly for powdered products, dried products, fried ready-to-eat (RTE) products, and also to retain the aroma of the products for the long term. To diminish the effect of oxidation and deterioration of flavor, inert gas can be added to the product prior to filling and closing. This can be achieved by precharging the filler containing the products with nitrogen (N_2); in this way the residual oxygen level can be reduced below 2%. Then the packaging films or bags will be preflushed with nitrogen (N_2), followed by filling with the gas charged powder.

4.2.2 Semi-reactive Blanketing

In this type of packaging the headspace gas is a combination of nitrogen (N_2) with one or more gases such as oxygen (O_2), carbon dioxide (CO_2), and so on. These types of gas combinations are primarily used for meat, poultry, seafood, and milk products. Mostly an N_2/CO_2 gas combination without oxygen is widely used to preserve fish, poultry, and milk products. This combination helps in preventing oxidation of food products and growth of aerobic microorganisms. On the other hand, for red meat preservation, mainly to retain the redness and fresh appearance of the meat, a minimum percentage of oxygen is used along with N_2/CO_2. Recently, carbon monoxide is used in the place of oxygen for meat preservation.

4.2.3 Fully Reactive Blanketing

This type of packaging is used for food products that respire, specifically fruits and vegetables. A carefully controlled gas combination of carbon dioxide (CO_2 or O_2/CO_2) achieves and maintains an optimal respiration rate to preserve fresh or minimally processed fruits and vegetables. A finely adjusted and carefully controlled gas blend is developed to meet the specific respiration needs, which helps in reducing ethylene production and ripening for each packaged fruit or vegetable product. In some cases O_2/CO_2 is also used for red meat preservation and so on.

4.3 GASES USED

The normal gaseous composition of air is nitrogen (N_2) 78.08% (volume per volume), oxygen (O_2) 20.96%, and carbon dioxide (CO_2) 0.03%, together with variable concentrations of water vapor and traces of inert or noble gases. The substitution of atmospheric air in the headspace of the food package with a different proportion of gases helps in keeping the food fresh. The gases used in MAP are generally not considered as toxic or dangerous, nor are they regarded as food additives. The various gases used in MAP are as follows.

4.3.1 Nitrogen

In MAP, nitrogen (N_2) has three important uses: for displacement of O_2 to delay oxidation, for retardation of the growth of aerobic spoilage organisms, and as a filler to maintain package conformity. Primarily it is used as filler gas either solely or along with other gas mixtures because of its inertness, low solubility, and tasteless property. Mostly dried fruits and nuts and fried foods such as chips are packed with only nitrogen in the package headspace. This not only helps in reduced oxidative rancidity of the food products but also retains the package flexibility by avoiding vacuum development.

4.3.2 Oxygen

Mostly in MAP, oxygen is either excluded or the levels are set as low as possible. This is because of the intense food deterioration caused by atmospheric oxygen, such as oxidative rancidity of lipids, rapid growth of spoilage aerobic microorganisms, reaction of oxygen with vitamins and flavors, melanosis, and so on. In some cases, oxygen is included in the package headspace especially for the respiration of fruits and vegetables, to reduce the growth of anaerobic microorganisms in fishes, and to retain the color of red meat. The redness of the meat is retained by keeping the myoglobin in oxygenated form as oxymyoglobin, which is responsible for bright red coloration. In deoxygenated form, the meat looks purplish red. In some cases of the packaging of fresh green vegetables, the application of O_2 mixtures between 70% and 100% were experimented with. This treatment is referred as oxygen shock or gas shock, and it has been found to be very effective in inhibiting enzymatic discoloration, preventing anaerobic fermentation reactions, and inhibiting aerobic and anaerobic microbial growths. High levels of oxygen can inhibit the growth of both anaerobic and aerobic microorganisms since the optimal oxygen level for the growth of microorganisms, such as 21% for aerobes and 0–2% for anaerobes, is surpassed (Jay, 2000).

4.3.3 Carbon Dioxide

The active component of MAP for most of perishable food products is carbon dioxide because of its bacteriostatic and fungi static properties. Among the major gases used in MAP, CO_2 is the only one that has a direct and significant antimicrobial effect. In general, dissolved CO_2 inhibits microbial growth, affecting the lag phase, maximum growth rate, and maximum population densities of microbes. The mode of action on bacteria is thought to be a combination of a number of effects, including changes in intracellular pH, alteration of the structure and function of microbial protein and enzyme, and alteration of the function and fluidity of the cell membrane. Owing to the antimicrobial effect of carbon dioxide, the gas is applied in the packaging along with a gas mixture, which helps in extension of the lag phase of growth and a decrease in the growth rate during the logarithmic growth phase. The inhibitory action of CO_2 is not universal; it has differential effects on microorganisms. The inhibitory effect of CO_2 and the efficiency of microbial growth retardation depend on the concentration of CO_2, the partial pressure of CO_2, the combination of gas mixture used, the type of food product packaged, the volume of headspace gas, the type of microorganism, the initial bacterial population concentration, the microbial growth phase, the growth medium used, the storage temperature, acidity, water activity, and the type of product being packaged. Various theories that clarify the antimicrobial activities of CO_2 have been summarized:

- Alteration of the function of cell membrane including effects on nutrient uptake and absorption
- Direct inhibition of enzymes or reductions in the rates of enzyme reactions
- Infiltration of bacterial membranes leading to intracellular pH changes
- Direct changes to the physicochemical properties of proteins

There are at least three general mechanisms by which CO_2 inhibits microorganisms. The first mechanism is by the displacement of O_2.

The second mechanism is a lowering of the pH in the medium or food due to the dissolution of CO_2 and formation of carbonic acid in the aqueous phase of the food in the following equilibrium (Butler, 1982):

$$CO_2 \text{ (dissolved)} + H_2O \rightarrow H_2CO_3$$

$$K_{\text{hyd}} \text{ (298 K, 1 atm)} = 2.6 \times 10^{-3} = [H_2CO_3]/[CO_2]$$

$$H_2CO_3 \rightarrow HCO^- + H^+$$

$$K'_{\text{a}} \text{ (298 K, 1 atm)} = 4.3 \times 10^{-7} = [H^+]\left[HCO^{-2}\right]/[CO]$$

$$HCO^{-2} \rightarrow CO^- + H^+$$

$$K''_{\text{a}} \text{ (298 K, 1 atm)} = 5.61 \times 10^{-11} = [H^+]\left[CO^{-2}\right]/[CO]$$

The third mechanism is a direct effect on the metabolism of microorganisms as opposed to the indirect effects of pH reduction and displacement of oxygen. Consequently, while aerobic bacteria such as the pseudomonads are inhibited by moderate to high levels of CO_2 (10–20%), microorganisms such as lactic acid bacteria can be encouraged by CO_2. Additionally, pathogens such as *Clostridium perfringens*, *Clostridium botulinum*, and *Listeria monocytogenes* are slightly affected by CO_2 levels below 50%, and there is concern that by inhibiting spoilage microorganisms, a food product may appear edible while comprising high numbers of pathogens that may have multiplied due to a lack of indigenous competition (Farber, 1991). In spite of the encouragement of the growth of certain yeast and bacterial populations in fermented foods by CO_2, it is not advisable to use CO_2 in packaging headspace. Also, it facilitates the growth of anaerobic microorganisms, so a minimal level of oxygen in maintained along with CO_2 in the packaging atmosphere of the product. Carbon dioxide is both water and lipid soluble. The absorption of CO_2 in the food packaged is highly dependent on the moisture and fat content of the food. The excessive CO_2 in the food leads to reduced water holding capacity, which leads to drip-loss-reduced total package volume, leading to snug down of the package. In some fruits and vegetables, package increased CO_2 interferes with the respiration process of the produce and results in physiological damage, ultimately reducing the market value of the produce (Dixon & Kell, 1989; Jakobsen & Bertelsen, 2006).

4.3.4 Carbon Monoxide

Carbon monoxide has little inhibitory effect on microorganisms. But in preservation of red meat under MAP, this gas greatly helps in retaining the redness by converting the myoglobin to carboxymyoglobin. The main role of low levels of CO in MAP is to give a stable cherry-red color to the meat, a result of the strong linkage of CO to the porphyrin ring of myoglobin and the formation of carboxymyoglobin. The bright red pigment carboxymyoglobin is more stable toward oxidation than oxymyoglobin, due to the stronger association of CO to the myoglobin molecule. Addition of CO at low levels counteracts undesirable color changes associated with high levels of CO_2 (Djenane et al., 2001). The commercial usage of carbon monoxide is not approved by the regulatory bodies so far in many countries, due to the hazardous effect of this gas on the people involved in the packaging environment. But in some countries like Norway this gas is approved as nontoxic for consumers when used at less than 0.5% in MAP of red meat (Sørheim et al., 1999).

4.3.5 Argon

In recent years, prospective usage of noble gases in MAP is under research. Specifically, the argon (Ar) gas is considered as a possible alternative to nitrogen due to its inert, odorless, and tasteless properties. In comparison to N_2, factors like the higher density, similarity of atomic size to molecular oxygen, and improved water solubility of argon seem to allow a more sufficient removal or exclusion of oxygen from the packages and therefore may result in lower levels of residual oxygen. Adding to this, MAP containing argon also contributes to the maintenance of typical sensory attributes during the shelf life of foods from plant and animal origin. The use of argon Ar-E 938 (European food additive code 938) is permitted in MAP of RTE foods and regulated in terms of purity in the European Union. But the commercial application is not accomplished worldwide so far (Victoria et al., 2016).

4.3.6 Other Gases

Researchers examined the usage of other gases such as helium, nitrous oxide, nitrogen dioxide, ozone, chlorine, ethylene, propylene oxide, and sulfur dioxide for MAP and also ended in successful outcomes. But their commercial use for packaging foods is unlikely to meet with approval from the regulatory authorities.

In spite of this, the selection and standardization of gas mixtures was based on the trial-and-error method with respect to the tangible quality and sensory analysis of the food to be packaged.

4.4 PACKAGING MATERIAL

Effective MAP of produce requires consideration of the optimal gas concentration, product respiration rate, and gas diffusion through the film as well as the optimal storage temperature in order to achieve the most benefit for the product and consumer. In MAP, the films used for packaging depend on the food to be packed and the gas mixture filled in the headspace. If the package headspace contains a gas mixture with little or no oxygen, then the difference in the partial pressure of oxygen in the atmosphere is higher than the oxygen partial pressure inside the package, which leads to the inflow of oxygen from outside into the package if the packaging material does not have a good oxygen barrier property. Based on the food or produce to be packaged, the following factors should be considered while selecting packaging films:

- Film permeability – oxygen transmission rate (OTR), carbon dioxide transmission rate, and water vapor transmission rate (WVTR)
- Film properties – sealing characteristics, puncture resistance, and antifogging properties

These properties should be measured and tested at different levels of packaging such as film selection, package conversion, and product fill stages, since the ability of a film to handle MAP performance characteristics may vary at each stage. In addition, when selecting an appropriate film, one has to take into account the protection provided, as well as the strength, sealability, clarity, machinability, ability to be labeled, and the gas gradient formed by the closed film.

Packaging materials with oxygen permeability lower than 100 cm^3/m^2 for 24 hours at 101.3 kPa are used in gas packaging, whereas very little stated research is available on the significance of oxygen permeability between 0 and 100 cm^3/m^2 for 24 hours at 101.3 kPa for quality gas-packed products. Vegetables and fruits differ from other products because they continue to respire even when placed in a modified atmosphere. Due to the respiration, there is a risk that CO_2 will increase to levels injurious to the packed produce. On the other hand, respiration consumes oxygen, and there is a danger of growth of anaerobic microorganisms. A number of special packaging materials intended for vegetables and fruits have been developed such as smart films, microporous film, and microperforated films. The selected films should possess the following physical properties.

- *Mechanical strength*: The packaging materials must be resistant to mechanical stresses such as tear, burst, and puncture as well as environmental stress such as humidity and temperature (frozen or chilled). If a material is of poor mechanical strength, the mechanical stresses, humidity, and low temperature during storage, transport, and handling can destroy the package and cause leakage.
- *Integrity of sealing*: An acceptable integrity of the seal is important in order to maintain the accurate atmosphere inside the package.
- *Fogging*: To advance the appearance of the packages in retail outlets, the polyethylene in the packaging laminates can be specially treated to prevent condensation of water, which fogs the package and prevents the consumer inspecting the product.
- *Microwaveability of packaging materials*: In gas packaging, particularly in the case of RTE food products, the microwaveabilty of packaging should be considered. For instance, the low melting point of polyvinylchloride (PVC) makes the PVC–low-density polyethylene (LDPE)–laminate or co-extrusion film much used as a base networking material that is unsuitable for microwave oven heating.
- *Biodegradability and recyclability*: These factors are new inclinations in the packaging business, and also a major challenge is the natural hydrophilic behavior of many bio-based polymers as a lot of food applications demand materials that are resistant to moist conditions.

- *Thermal and mechanical properties*: The mechanical properties in terms of modulus and stiffness are not very different compared to conventional polymers.
- *Compostability*: The compostability of the materials is highly dependent on the materials, for example, the first step of composting is often a hydrolysis or wetting of the material.

The amalgamated polyamide/polyethylene (PA/PE) films are increasingly presented as a multilaminate, where PA and PE layers are joined in several thin layers. The PA film possesses a good oxygen barrier property, whereas the PE film adds the moisture barrier and heat sealing property. Together these films are stronger and more resistant and offer constant barrier properties. To attain a peel quality, a special blend of the relevant PE layer is added to the existing film.

Plastic films, foils, and other packaging materials that demonstrate specified gas permeability properties and/or water vapor permeability properties are selected for use. These high-barrier substrates become modified atmospheric packages after they are formed into trays, lid stock, or bags and filled with a selected blend of oxygen, carbon dioxide, and nitrogen environmental gasses. The addition of EVOH to the film increases the gas barrier further. An absolute gas barrier can be achieved with the inclusion of aluminum.

Edible biodegradable coatings are yet another variant of the smart film technology, where a film is used as a coating and applied directly on the food.

4.5 TYPES OF MAP

4.5.1 Bulk Packaging

This type of packaging is mostly used for pallet bags and paperboard containers used in the transportation and storage of produce. These packages can be ecologically advantageous since some are returnable, and thus reuse is possible in some cases.

4.5.2 Prepackaging

Following bulk packaging and coming to the retail outlet, produce can be prepackaged by the grocer or the customer using a passive MAP. Prepackaging in the store usually involves the use of plastic film packaging such as LDPE, PVC, or polypropylene (PP) films, which help to minimize moisture loss and maintain produce quality. However, the films used often supply only a narrow range of gas selectivity, and due to its imprecise nature, this type of packaging is only appropriate to a few products.

4.6 EQUIPMENT AND METHODS FOR MAP

In MAP there are two methods to change the atmosphere in the headspace of the package:

- Vacuum generation and filling
- Gas flushing

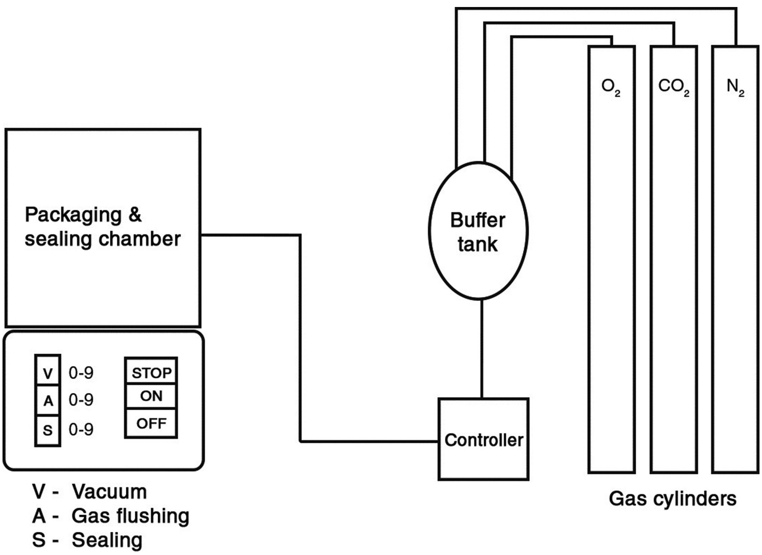

FIGURE 4.1 Vacuum generation and gas filling.

4.6.1 Vacuum Generation and Filling

In this method the air inside the package is completely removed and vacuum is created in the package. Then the desired gas mixture is filled into the package.

This method is widely used for lab scale and pilot scale packaging. The equipment used for this method is shown in Figure 4.1. It comprises different gas cylinders for oxygen, carbon dioxide, nitrogen, and so on. These cylinders are connected to a buffer tank into which the gas flushes. The desired blend of gas concentrations is adjusted using the controller. From the cylinder the gas at a pressure of 8 bar is allowed to enter the buffer tank. The desired gas mix is set along with the flow rate. From the buffer tank the gas enters at a pressure of less than 2 bar to the packaging chamber through the inlet tube. The chamber is made of stainless steel with a transparent lid, gas inlet nozzle, and heat sealer. The package containing the food or produce is placed inside the packaging chamber with the inlet gas nozzle protruded into the package mouth. The packaging chamber consists of a digital control panel. Both the vacuum and modified gas conditions are applied to the whole chamber along with the package. It also has an inclined inlet plate for packaging products like liquid or sauce. In this method we can achieve a residual oxygen level of less than 1%.

4.6.2 Gas Flushing

This method is used for commercial MAP of foods. This can be accomplished with two types of filling and sealing equipment:

- Form filling and sealing
- Thermoform packaging

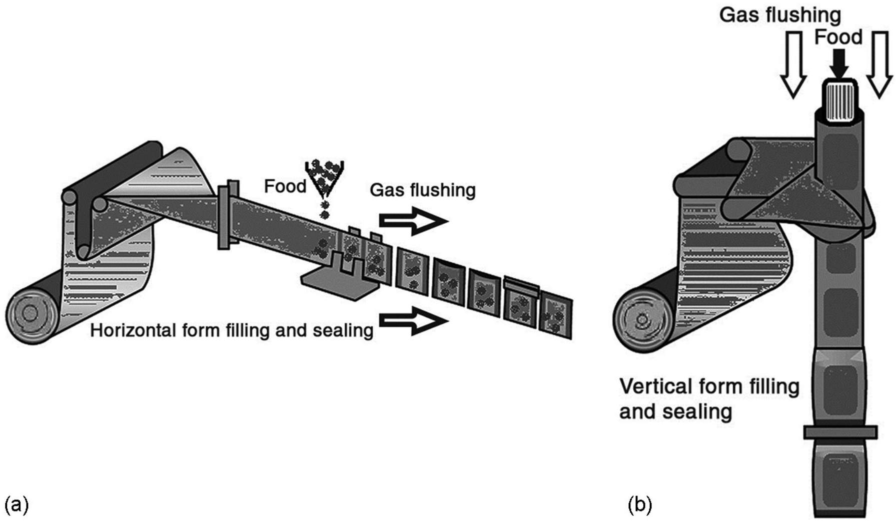

FIGURE 4.2 (a) Horizontal form filling and sealing and (b) vertical form filling and sealing.

4.6.2.1 Form Filling and Sealing

In both horizontal and vertical form filling and sealing, the atmospheric air inside the package is substituted by flushing continuous stream of gas proximate to the product filling and sealing area (Figure 4.2). This helps in dilution of the atmosphere near the food, gradually reaching our desired gas blend inside the package before sealing. The effectiveness of this packaging method is comparatively low, with a residual oxygen level of 2–5%. Hence food products that can resist this level of residual oxygen can be used for this purpose.

4.6.2.2 Thermoform Packaging

In thermoform packaging the produce or food is placed in the packaging tray; then it is taken into the gas flushing chamber. Inside the chamber a holding time is maintained based on the food packed and the package size; during this time the desired gas mixture is flushed into the chamber along with the tray. Then it is sealed. In this method the residual oxygen level can reached to 1–2%. Packaging tracks with single or multiple tracks achieve 4–20 packages per minute depending on the size of the pack and kind of product. The typical demand for the gas mixture is also dependent on package size and packaging velocity (Figure 4.3).

4.7 APPLICATIONS

4.7.1 Fruits and Vegetables

Throughout the post-harvest processing of fruits and vegetables, the cells of most of the fruits and vegetable get damaged, which leads to the release of the intracellular products. This facilitates increased bacterial growth. For fresh vegetable products,

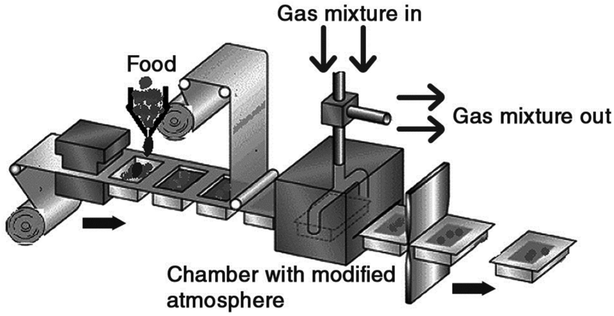

FIGURE 4.3 Thermoform packaging.

atmosphere modification in the package headspace relies on the natural interplay between two processes, the respiration of the product and the transfer of gases through packaging, which leads to an atmosphere enriched in CO_2 and poor in O_2. Fresh-cut fruits and vegetables are more prone to microbial spoilage because of the exposed internal surface and the processing methods. To reduce the risk of infection or intoxication associated with the consumption of contaminated fresh-cut fruits and vegetables, specific measures and interventions should be studied and implemented to minimize the risk of contamination. A wide variety of disinfectants such as chlorine, hydrogen peroxide, organic acids, and ozone have been used to reduce bacterial populations on minimally processed products.

Minimally processed products without preservatives deteriorate as a result of physiological aging, biochemical changes, microbial spoilage, and physical and chemical deterioration, which may result in degradation of the color, texture, and flavor. While conventional food-processing methods extend the shelf life of fruit and vegetables, the minimal processing to which fresh-cut fruit and vegetables are subjected renders the products highly perishable, requiring chilled storage to ensure reasonable shelf life and safety. But to prevent microbial growth and ensure satisfactory quality of fresh-cut fruits and vegetables, MAP may not fully guarantee microbiological safety. Therefore, MAP combined with additional inhibitory process, in the form of a hurdle technology, is considered to be an effective alternative to enhance food safety.

The major factors responsible for extending the shelf life of fruits and vegetables include careful harvesting so as not to injure the product, harvesting at optimal horticultural maturity for intended use, and good sanitation. Once these are accomplished, the execution of optimum storage conditions through modified atmospheres can be quite effective at maximizing the shelf life and the quality of the product. MAP has been widely and successfully used in combination with refrigeration to maintain the safety and the shelf-life extension of whole and minimally processed fruits and vegetables. At storage temperatures of 0–5°C, MAP is used for various types of fruit and vegetable products, and the specific mixture of gases in the packaging in each case depends on the product type, the packaging materials, and the storage temperature.

The modified atmosphere of 5% O_2, 10% CO_2, and 85% N_2, along with the chemical pretreatment of calcium chloride (1% w/v) and citric acid (2% w/v) solution of fresh-cut papaya and pineapple individually resulted in improved surface color and firmness and reduced microbial counts, and it was also effective in extending the shelf life of fresh-cut papaya up to 25 days of storage at 5°C (Waghmare & Annapure, 2013). Fresh figs packed under modified atmosphere with microperforated films increased shelf life to 14 days at 0°C. Fresh apples peeled and cut, dipped in the antibrowning solution, and packed using air or 80% argon and 20% CO_2 modified atmosphere retained the appearance and tangible quality till 15 days when stored at 4°C (Caleb et al., 2016).

Minimally processed broccoli, cabbage, and turnip indicated reduction in respiration rate of 35% when stored with 1% residual oxygen and at a temperature of 5°C. Equilibrium modified atmosphere and humidity of 97% and 95% were established in the headspace, which helps in reduced cell damage and product loss. Similarly, cherry tomatoes stored at 5°C with the atmosphere of 5% O_2 and 5% CO_2 decreased the respiration rate, ethylene production rate, weight loss, lycopene biosynthesis, and formation of red colour, consequently extending the shelf life for 25 days.

Apart from these, fresh-cut vegetables like shredded cabbage, sliced carrots, sliced leek, chopped lettuce, chopped greens, sliced mushrooms, sliced or diced onion, diced peppers, sliced or whole-peeled potato, sliced rutabaga, cleaned spinach, sliced tomato, and sliced zucchini were studied for increased shelf life and palatable quality when stored under MAP at 0–5°C. Similar retained tangible quality was achieved with MAP for minimally processed fresh-cut fruits such as sliced apple, cubed cantaloupe, cubed honeydew, sliced kiwifruit, sliced orange, sliced peach, sliced pear, sliced persimmon, arils of pomegranate, and sliced strawberry (Gorny, 1997).

4.7.2 Meat

Delightful, nontoxic, hygienic, and nourishing, chilled beef and pork meats are a foremost consumption form and have an increased global demand. However, there are many factors that affect the freshness or the shelf life of the chilled meat. Being an important external environment factor, packaging affects the diversity of the microorganism distribution and the shelf life of meat. The formation and accumulation of biogenic amines in foods result from the enzymatic amino-acid decarboxylation due to microbial enzymes and tissue activity. In the quality deterioration of meat, preslaughter handling of livestock and post-slaughter handling of meat play a primary role. The concentration of glycogen present in animal muscles is reduced when the animal is exposed to preslaughter stress, which modifies the pH of the meat to higher or lower levels, depending on the production level of lactic acid. In spite of this, other important factors throughout processing, packaging, and storage of meat may be identified, including mincing, addition of antioxidants, exposure to light, increasing temperature, and high oxygen availability, which can each affect the oxidative stability of meat and meat products negatively.

Dark cutting beef meat has been associated with a higher mitochondrial respiration rate, which helps maintain low oxymyoglobin concentrations. Minced meat is more sensitive to oxidation than whole meat because of its porous structure, and it has more susceptibility to microbial spoilage due to the grounding process. The denaturation temperature of myoglobin depends on the protein's redox state, and therefore, the relative appearance of cooked product is not necessarily a reliable indicator that beef is safe for consumption. Myoglobin redox state prior to cooking plays a crucial role in determining the color of cooked beef steaks and patties. More specifically, the redox state of myoglobin determines its resistance against heat-induced denaturation, with deoxymyoglobin being most resistant and metmyoglobin least resistant.

Lipid oxidation can be limited either by scavenging radicals using antioxidants such as hydrogen or electron donors. Another strategy to prevent oxidation is to limit oxygen access to the product; otherwise, oxygen will react with initially formed lipid radicals, producing peroxide radicals as precursors to lipid hydroper-oxides. Undesired off-odors and flavors as well as slime formation and changes in color and texture lead to the discarding of meat and economic loss.

Bacterial foodborne illnesses are due to the following seven pathogens, in descending order of concern: *Salmonella*, norovirus, *Campylobacter*, *Toxoplasma*, *Escherichia coli* O157, *L. monocytogenes*, and *C. perfringens*, and meat is among the major sources for the pathogens. Therefore, control of pathogens in meat is an important safety issue. The intervention of pathogens in meat can be accomplished through the preslaughter reduction of microorganisms in livestock and the post-slaughter decontamination of carcass and meat. Post-slaughter interventions use various physical, chemical, and combinations of both physical and chemical methods during slaughtering or processing steps.

For preservation of meat under MAP, CO_2 is usually combined with a filler gas to stabilize the package. As CO_2 dissolves in meat, the use of CO_2 alone leads to package shrinking and deformation. In some cases, oxygen is added to preserve the attractive bright red color of the meat and to inhibit the growth of strictly anaerobic bacteria like *C. botulinum*.

Increasing the concentration of CO_2 in modified atmosphere applications resulted in a decrease in oxidation stability and loss of redness due to the metmyoglobin formation, which means a decrease in the a* and b* values of samples, whereas the lightness of samples was not affected. The oxidation stability and the color of minced beef meat packaged in modified atmospheres were best preserved in atmospheres containing low CO_2 concentrations.

The gas atmosphere also creates a selective pressure on the microflora of meats. Aerobic chilled storage favors the growth of gram-negative, aerobic rod-shaped bacteria including *Pseudomonas*. Many other bacteria are present, but *Pseudomonas* spp. predominate and produce off-odors from protein breakdown and amino-acid metabolism. Under anaerobic conditions of chilled storage with elevated levels of carbon dioxide, while the slower growing lactic acid bacteria are encouraged, the growth of aerobic spoilage microflora is discouraged. In the presence of oxygen, growth of *Brochothrix thermosphacta* occurs and causes spoilage of meats. The composition of gas around 50% O_2, 30% CO_2, and 20% N_2 shows prolonged reduction of spoilage microorganisms and increased shelf life in raw meat and also in minced meat.

The effect of packaging on raw beef color stability can translate into cooked color concerns, including premature browning. For example, high-oxygen packaging (80% oxygen) increases the likelihood of premature browning, whereas packaging containing low levels of CO will decrease premature browning in ground beef. Cooked patties previously packaged with CO were visually and instrumentally more red than patties packaged with high oxygen, due to the formation of denatured CO hemochrome. This could be due to the greater heat sensitivity of metmyoglobin and oxymyoglobin present in high-oxygen patties compared with deoxymyoglobin and carboxymyoglobin found in vacuum and 0.4% CO packaging, High-oxygen and PVC-packaged patties had more lipid oxidation than patties with anaerobic CO, which meant that CO-packaged pork chops had more cooked internal redness compared with chops previously packaged with high-oxygen and PVC overwrap, even after cooking to an internal temperature of 82°C.

4.7.3 Poultry

The increased global demand for chicken and poultry products is not only due to their specific sensory attributes, relatively low cost of production, low fat content, and high nutritional value but also due to the increasing tendency of the public to consider white meat as being healthier compared to red meat. This has made the poultry meat industry to develop a diverse range of products and presentations for consumers.

Poultry meat and products are highly susceptible to microbial spoilage, and in the case of aerobic storage, *Pseudomonas* spp. are the main microorganisms prevailing. Poultry meat quality and freshness are frequently evaluated only by microbial indicators, sensorial evaluation, and also by the accumulation of biogenic amines. The quantification of biogenic amines in meat and meat products is important not only as an indicator of freshness but also from a toxicological point of view. Biogenic amines are mainly formed by bacterial enzymatic decarboxylation activity of free amino acids with the exception of physiological polyamines. The inhibition of this decarboxylase activity or prevention of bacterial growth is of great importance to its control. There are several factors that affect decarboxylase activity or bacterial growth and consequently the formation of biogenic amines. The production of biogenic amines is mainly influenced by temperature, availability of oxygen, redox potential, and pH. The presence of carbohydrates, such as glucose, also promotes the growth of bacteria and their decarboxylase activity. Apart from this, high levels of putrescine, histamine, tyramine, and cadaverine occurred during meat storage. The ingestion of high levels of tyramine and histamine can cause migraine headaches and food poisoning, respectively.

The typical gas mixtures used for retail sliced poultry meat under MAP are 20% CO_2, 70% O_2, and 10% N_2, giving a shelf life of approximately 8 days. The elevated oxygen levels saturate meat pigments with O_2 and delayed the formation of met-myoglobin on the meat surface. On the other hand, they quicken lipid oxidation, off-flavor development, and premature browning during cooking. Poultry breast fillets stored under MAP of 30% CO_2 and 70% N_2 at 4°C extended the tangible and sensory quality for up to 17 days; also low amounts of tyramine were observed.

This may be due to the absence of tyrosine-decarboxylase enzymes and/or nonexpression of this activity under the specific storage conditions.

The synergistic impact of oregano essential oil (0.1%) and MAP of 30% CO_2 and 70% N_2 helps in shelf-life extension of fresh chicken meat stored at 4°C for more days (Chouliara & Kontominas, 2006).

Fresh turkey meats packaged under modified atmosphere with a mixture containing a higher concentration of CO_2 and with CO after 25 days of storage resulted in nonaccumulation of histamine, or when present, the levels were below the limit of quantification (1.03 mg/kg). Tyramine in turkey meat under MAP was not the best amine indicator of meat deterioration, with cadaverine being suggested instead, or the sum of the amines putrescine, cadaverine, and tyramine, to characterize and quantify meat freshness.

Patties made from freshly ground turkey breasts preserved under high CO_2 97% and 3% N_2 slowed the growth of total bacteria as well as lactic acid bacteria. Also, there was a slower growth in the top meat layer exposed to CO_2 compared with interior layers.

4.7.4 Seafood

Fresh shell fishes and fin fishes are highly perishable food items, and the shelf life of such food is restricted in the presence of oxygen and the growth of aerobic spoilage microorganisms. The deterioration of fresh fish is due to bacterial and enzymatic action, and during spoilage, fish undergo color, flavor, and texture changes. The decayed fish has relatively high concentrations of histamine, which can cause poisoning or allergic reactions when consumed by some humans. Histamine is produced by microbial decarboxylation of the amino acid histidine. The importance of estimating the concentration of histamine in fish and fish products is related to its impact on human health and food quality. It was observed in sardine (*Sardina pilchardus*) when packaged under 60% CO_2 and 40% N_2 and stored at 4°C; the histamine formation is comparatively much lower than when stored in air. The shelf life of sardine was extended to 12 days in modified atmosphere. For gutted bass (*Dicentrarchus labrax*), the cross-contamination of fish during gutting procedures and also the significantly higher fish flesh surface area exposed to environmental microbial contamination leads to a shorter shelf life than ungutted bass. Atmosphere composed of 30% O_2 and 50% CO_2 helps in preserving the quality of the gutted farmed sea bass for 9 days when stored at 3°C (Ozogul et al., 2004).

The effect of MAP on the fish shelf life and the most appropriate composition of gas for a specific application depends extensively on the fish species, fat content, initial microbiological contamination, background of the fish, and treatment of the fish after slaughtering, such as handling and storage condition, ratio of gas/product (G/P), and most importantly packaging method and temperature of storage.

Among the crustaceans, shrimp have a global demand because of the high-quality protein, mineral elements, and vitamins. Nevertheless, the captured shrimp are susceptible to decomposition because of the existence of spoilage bacteria such as *Shewanella putrefaciens* and *Pseudomonas* spp. The action of autolysis by inner proteases together with melanosis results in inferior quality in shrimp at the early period of storage while bacterial spoilage makes the shrimp deteriorate during long-term storage. Melanosis is a black discoloring of the surface of shrimp, which is caused by the activity of polyphenoloxidase and occurs only in raw shell-on shrimp. Another group of significant enzymatic reactions results in the production of protein breakdown products such as ammonia, indole, methanethiol, putrescine, trimethyl amine, and other off-odor compounds that are caused by the growth of spoilage bacteria. Ice is always used to cool the captured shrimp to keep them fresh; however, the deterioration in shrimp continues due to the action of both enzymes and bacteria.

The combined effect of compound bactericide 4-hexylresorcinol with MAP with gas composition of 40% CO_2, 30% O_2, 30% N_2, and 100% CO_2 extends the shelf life of the Chinese shrimp (*Fenneropenaeus chinensis*) up to 13 and 17 days, respectively, when stored at 2°C. Apart from this bactericide, other compounds like bacteriocin and nicin are also used.

Either whole or decapitated shrimp treated after soaking with bactericide or bacteriocin and modified atmospheric packaging were effective in inhibiting melanosis, and this process is considered in shrimp as generally recognized as safe (GRAS). Its concentration is in the range of 5–50 mg/kg, which is only 125th of sulfite, also effectively inhibits the tyrosinase activities in shrimp. Shrimps packaged in CO_2 atmosphere and stored at 3°C did not permit the growth of food spoilage microorganisms for 15 days. Carbon dioxide packaging also resulted in the slowest growth of psychrotrophic bacteria and resulted in shrimp having acceptable sensory odour and appearance scores at the end of the storage.

Modified atmosphere packaged Pacific white shrimps (*Litopenaeus vannamei*) with the gas composition of 40% CO_2 and 60% N_2 facilitate the shelf life extension around 24 days under chilled storage (Lalithapriya et al., 2017).

Recently the consumption of refrigerated RTE products was found to be more convenient for the consumer. Unfortunately, even frozen RTE shrimp attracts various degrading pathogens. Two factors contribute to quality degradation in stored RTE shrimp. The first defect is melanosis, and the second is lipid oxidation. Both these processes lead to off-flavor and off-odor (Bin et al., 2015).

4.7.5 Dairy Products

Milk and dairy products are excellent growth media for pathogenic and spoilage microorganisms. The composition of most dairy products provides a favorable physical and chemical environment for the growth and propagation of a broad spectrum of microorganisms. The shelf life of unprocessed and minimally processed dairy products, including pasteurized milk, cottage cheese, and some types of yogurt and fermented milk products, is generally limited to 1–3 weeks depending upon the quality of the raw ingredients, processing conditions, and post-processing handling.

Spoilage results primarily from the growth of surviving organisms, degradative proteolytic, lipolytic enzymes surviving after pasteurization, and/or post-processing microbial contamination, and it has been estimated that 25% of all milk shelf-life problems are due to thermoduric psychrotrophs, primarily *Bacillus* spp. These organisms produce extracellular protease and lipase activities, which reduce the functionality of milk proteins and often produce undesirable aromas. Gram-positive organisms, particularly those producing lactic and acetic acids, can spoil dairy foods, but the number of organisms required is generally higher than for gram-negative bacteria, and the changes can be less noticeable.

The growth of heat-resistant lactic-acid-producing cocci is responsible for the depression of pasteurized milk pH to the point where curdling occurs. The carbon dioxide is able to interchange dynamically between the cheese material and the headspace gas. The degree of this exchange is expected to depend on material properties such as the carbon dioxide solubility in the specific cheese as well as on the product-to-headspace volume ratio and the initial concentration of carbon dioxide in both the packaging gas and the cheese material. This equilibration process is known to be relatively fast and is expected to occur within the first day after packaging, obviously depending on product geometry (Jay, 2000).

- *Raw milk*: Raw milk with increased CO_2 under modified atmospheric storage before dairy product manufacture can result in improved microbial quality with no noticeable changes to the finished product characteristics. Milk packaged in pouches with different CO_2 barrier properties showed that the presence of low levels of CO_2 inhibits the growth of psychrotrophic microorganisms and provides a moderate extension of shelf life. Lag-phase extension, growth rate reduction, and maximum bacterial counts are increased in modified atmospheric packaged whole milk directly with increasing CO_2 concentration in the package headspace. The inhibitory effect of CO_2 was greater at temperature 4°C than 7°C.
- *Pasteurized milk*: Direct addition of CO_2 to pasteurized milk for shelf-life extension has not been broadly explored, probably due to the hypothesis that added CO_2 would detrimentally affect the organoleptic quality of milk. Recent research work put forward that lower levels of CO_2 below the organoleptic threshold are inhibitory for selected microbial growth (Panjagari & Kumar, 2024).
- *Yogurt and fermented dairy beverages*: The main spoilage organisms in fermented milk products are the molds and yeasts. These develop off-odor and off-flavor in the end product if not preserved. The existence of probiotic organisms is most prominent in most yogurt products. Preservation methods that extend shelf life must therefore take into account the effect on both spoilage and desirable organisms in the product. Modified atmospheric packaging of fermented dairy products with higher level of CO_2 stored at 4°C result in reduced proteolysis and acid production. It also acts as an effective method of reducing the risk of *Bacillus cereus* contamination in the fermented milk during the prolonged incubation period. In both cases, no impact on the growth of the probiotic bacterium was identified.
- *Cheese*: MAP of cottage cheese has been reported to retard microbial growth but requires substantial changes in the form of the traditional package. In most cases, packaged dairy foods do not have sufficient headspace to serve as a reservoir for the active gases, for example, CO_2, and insufficient CO_2 may be available to retard microbial growth. In the case of dairy products, MAP may not provide sufficient control, and the shelf life of

the product may be inconsistent. However, flushing packages with CO_2 before sealing is commonly used to inhibit mold growth in certain cheeses. Sliced and grated cheeses can be pillow-packed under MAP. The gas mixture typically used is 70% N_2 and 30% CO_2 to inhibit mold growth, to keep the package from collapsing around the shreds, and to prevent shred matting. In this case, the N_2 acts as filler to prevent package collapse and formation of a vacuum as the CO_2 is absorbed.

- *Dry milk powder*: Dry milk powders packaged in cans or drums for long-term storage are commonly commercially packaged in modified atmospheres, including mixed CO_2 and N_2, 100% N_2, or reduced O_2 atmospheres. To improve the shelf life through elimination or reduction of O_2 to prevent or slow fat oxidation can cause undesirable off-flavors and off-odors, particularly in whole-fat milk powders. Quality variations in dry milk powder stored in cans or drums with modified atmospheres can occur, particularly over very long-term storage. The variability in headspace oxygen content has a direct impact on water activity, package integrity, and sensory ratings, specifically aroma, flavor, and overall acceptance.
- *Butter*: Presence of increased CO_2 in the package headspace of the container helps in reduced microbial growth. Bacterial growth was inhibited also when carbonated butter was packaged in airtight vessels. In both cases, CO_2 remain dissolved in the butter. It is generally recognized that CO_2 is highly soluble in nonpolar lipids. But the storage temperature has a direct influence on the overall solubility of CO_2 in butter products. At higher temperatures where milk fat is liquid, CO_2 solubility in the fat increases, whereas at temperatures where milk fat is in a solid phase, CO_2 solubility decreases.

4.8 COMPANIES INVOLVED IN MAP

The capability of MAP to escalate the shelf life devoid of chemical preservatives has made it more competitive in the packaging industry. Rising demand for convenient foods such as RTE and ready-to-cook foods, seafood, poultry and meat products, and dairy products has led to an improved demand for MAP. Enhanced quality of packaging has also assisted the market progression. Integrated distribution assists in the development of both retailers and consumers. Conversely, the growing prices of both the raw materials and the finished products may obstruct the growth of the global MAP market. However, cost optimization at every value addition step, particularly the input level, can resolve this problem. The top companies that predominantly increase the market growth are as follows:

- Linde AG
- Dansensor AS
- Berry Plastics Corporation
- INPAC Packaging Limited
- Hayssen Flexible Systems
- Hayssen Sandiacre

- GEA
- Multisorb
- Others

4.9 ADVANCEMENTS IN MAP

4.9.1 Equilibrium Modified Atmosphere Packaging

Equilibrium modified atmosphere packaging or EMAP is used predominantly for fruits and vegetables. In this method of packaging, either the pack is flushed with essential gas mix or the produce is sealed within the pack with no modification to the atmosphere. Equilibrium modified atmosphere contains 2–5% oxygen and 3–8% carbon dioxide, and the remaining composition is balanced by nitrogen. This defined composition is very effective in:

- Delaying maturation and softening of vegetables
- Reducing chlorophyll degradation
- Decreasing microbial spoilage and enzymatic browning
- Inhibiting undesirable pinking on prepared leafy green salad vegetables

Equilibrium modified atmosphere is influenced by the respiration rate of produce. So the effectiveness of EMAP greatly depends on the factors that affect the respiration rate of the fruits and vegetables packaged, such as temperature, produce type, variety, size, maturity, severity of preparation, packaging film permeability, pack volume, surface area, fill weight, and degree of illumination. Inside the package, an equilibrium becomes established when the OTR of the packaging film is matched by the oxygen consumption of the packaged commodity. The respiration of the living plant tissue results in the production of CO_2, which diffuses through the packaging film, depending on the CO_2 transmission rate of films. The type of packaging film selected is based on the O_2 and CO_2 transmission rate of the film, which is required to obtain a desirable equilibrium modified atmosphere:

$$\text{Produce respiration} - nO_2 + (CH_2O) \rightarrow nCO_2 + nH_2O$$

EMAP exploits the natural respiration of fruits and vegetables for regulating the in-package atmosphere. The targeted modified atmosphere develops as an equilibrium steady state composition controlled by the modified permeability of the packaging film. The required transfer rate through the packaging film is obtained by a properly designed microperforation pattern.

The permeability of the packaging and thus the extension of the shelf life of fresh produce can be controlled through microperforation. Microperforations are tiny holes in the packaging that are invisible to the human eye. Film permeability is the critical control point for the quality and shelf life of fresh produce. One perforation more or less can make the difference between 1 and 3 days extra shelf life.

The only way to make accurate holes in packaging film is by using a special laser system. A complicating factor, however, is the normal variation in film thickness, which may lead to variation in pore sizes. It is therefore important for the laser to automatically adjust itself “on the fly” to balance out any variation in film thickness.

4.9.2 Designing a MAP

Every packaging design has to be optimized for a specific crop, because the nature of agricultural products is diverse and also MAPs are dynamic systems through which respiration and permeation ensue simultaneously. Factors affecting both respiration and permeation must be considered for package designing. Food mass inside the package; storage temperature; oxygen, carbon dioxide, and ethylene partial pressures; and stage of maturity are factors influencing respiration in a package. Type, thickness, and surface area of the packaging film that is exposed to atmosphere and across which permeation of O_2 and CO_2 takes place; volume of headspace present inside the package; temperature; relative humidity; and gradient of oxygen and carbon dioxide partial pressures across the film affect permeation. In MAP design, it is required to determine intrinsic properties of the produce such as respiration rate, optimum O_2 and CO_2 concentrations, and film permeability characteristics.

4.9.3 Tools for Designing MAP

4.9.3.1 Pack-in-MAP

This is a compilation of mathematical models on product respiration rates and packaging permeability that are combined in a user-friendly web-based software tool that assists in designing MAP for fresh and fresh-cut fruits and vegetables. This software helps in finding the best storage conditions by defining the type of product, storage conditions, amount of packed product, and size and geometry of the package (Mahajan et al., 2007).

4.9.3.2 Freshline MAP Gas Selector

This was developed after carrying out plentiful trials and constructing knowledge regarding the perfect gas mixture for every food category. This online software tool was formed to support the users to recognize the accurate gas mix for the food product. This tool was designed for a variety of batch or continuous processes.

4.9.3.3 MAPAX from Linde Gas

This is a perfect MAP program developed based on the essential records concerning foodstuffs, gases, and packaging. MAPAX considers the following parameters while designing the perfect blend of gases for preservation:

- Post-harvest handling and processing of the food or produce
- Nature and magnitude of microorganisms
- Level of hygiene
- Holding time of food prior packaging
- Storage and transport temperature
- Properties of the packaging film, specifically permeability

- Free gas volume of the package
- Gases to be used in the mixture
- Residual oxygen level

4.9.3.4 Tailorpack

This is a free online assessment support system designed to support in selecting the exact packaging for fresh produce. It is mainly developed for packaging fresh fruits and vegetables. It can be operated in two modes:

- *Simulation mode*: If the package permeation properties for gases are provided, then it predicts the gas exchanges in MAP of fresh produces.
- *Optimization mode*: If the optimal storage atmosphere of the produce is provided, then it can predict the adequate permeation properties of the package.

Apart from this, the following parameters should be provided while designing:

- Respiration rate of produce
- Package geometry
- Gas permeability of the package material, particularly O_2 and CO_2 permeability
- The storage condition of produce

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5 Active and Intelligent Packaging

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In the recent past, food packaging was used to facilitate promotion of products and to provide passive protection against environmental contaminations or influences that affect the shelf life of the products. However, unlike traditional packaging, which must be totally inert, active packaging (AP) plays a dynamic role in food preservation. AP materials are successfully designed to actively maintain or improve the condition of the food by excluding undesirable components either from the package headspace and/or from the food itself either by adsorbing or by releasing active components into the food or its surroundings (e.g., oxygen scavengers, ethylene scavengers, liquid and moisture absorbers, flavor and odor absorbers or releasers, antimicrobials) (Dainelli et al., 2008) Intelligent packaging (IP) is characterized by its ability to monitor the condition of packaged food or the environment by providing information about different factors during transportation and storage, which includes time–temperature indicators (TTIs), gas detectors, freshness and/or ripening indicators, biosensors, and radiofrequency identification (RFID). This chapter provides a general overview of AP and IP. It covers the major concepts and the recent developments in AP and IP systems.

5.1 ACTIVE PACKAGING

Packaging is an obvious and essential element of the food preservation chain. The quality of packaged food is directly related to the attributes of food and packaging material. The traditional packaging merely gives mechanical support to the food and protects it from external environmental spoilage factors like chemical and microbial contamination, water vapor, oxygen, light, insects, dirt and dust particles, and so on. The basic role of packaging is rather passive and inert as one with respect to contact with foods; in other words, the traditional packaging system should be one that involves a minimum interaction between the food and packaging material (Anthierens et al., 2011). However, the increasing consumer demand for convenience foods like minimally processed foods (fresh-cut fruits and vegetables, cook-chilled and half-baked foods) and ready-to-eat “fresh” food products, the worldwide food trade, as well as the distribution from centralized processing have created major challenges for the food-packaging industry concerned with maintaining safety and quality. In order to meet the necessities, various strategies are being employed to improve

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the effectiveness of the packaging. One such strategy is AP and IP systems. Over the last two decades, these new technologies have been the focus of much research and have attracted immense interest due to their enhanced potential (e.g., increasing convenience for consumers, improved quality and safety of packaged foods, and better techniques for storage and refrigeration chains enabling longer transportation). AP involves the interaction between the product and the environment. These are systems that actively change conditions of the packed food by chemical means, extending its sustainability, significantly improving the microbiological safety and sensory properties, and thus making the packaged food shelf-stable. Whereas traditional food packages are passive barriers designed to delay the deleterious effects of the environmental spoilage factors on the food product, AP allows packages to interact with food and the environment and to play a dynamic role in food preservation. Therefore, demand for AP systems has been raised in the field of food packaging. AP has been defined as system that "interacts with the packed product, changes the condition of the packed food to extend shelf life or to improve safety or sensory properties, while maintaining the quality of packaged food"(Forsido et al., 2021).

AP represents a large and diverse group in terms of both its purpose and the solutions applied. The use of proper AP extends the shelf life of products through its impact on processes emerging in food: physiological processes (e.g., respiration of fresh fruits and vegetables), chemical processes (e.g., oxidation of fats), physical processes (e.g., staling of bread), and microbiological changes due to the impact of microorganisms. The atmosphere inside the packaging can be controlled by substances that absorb (scavengers) or release (emitters) gases (Forsido et al., 2021).

Active scavengers are designed to remove undesirable substances from the headspace of a package. Depending on the application, they may be associated with the absorption of oxygen, moisture, ethylene, or carbon dioxide. To achieve such specific effects, substances such as zeolite, cellulose, activated carbon, silica gel, iron ions, ascorbic acid, potassium permanganate, and calcium hydroxide are applied. Another group of AP systems is emitters. The operating principle of emitters is based on releasing desired substances that have a positive impact on food in the packaging environment; that is, they are intended to guarantee stable conditions during storage and should ensure extension of the shelf life. Emitters can be fragrant substances, food additives, food ingredients, humidity regulators, or biological active substances, which prevent growth of microorganisms (Table 5.1).

5.1.1 Oxygen Scavengers

The element oxygen is essential for the biological functions in plants and animals involving respiration and photosynthesis. But, in the case of foods, oxygen is a deleterious spoilage factor, which is responsible for degradation of many products either directly by oxidative reactions or indirectly by supporting the growth of aerobic microorganisms (Hotchkiss & Banco, 1992). Therefore, in order to preserve these products, oxygen is often excluded.

The presence of oxygen in food packages is mainly due to failures in the packaging process or inefficient vacuum packaging. Vacuum packaging involves

TABLE 5.1
Applications of AP in Food Industry

Types of AP	Food Products	Functions
Oxygen scavengers	Bread, cakes, biscuits, cooked rice, pizza, pasta, cheese, smoked and cured meats, fish, ground coffee, chips, nuts, dried foods, oils, fats, beverages	Prevent discoloration and flavor change in foods containing lipids, reduce microbial growth and nutritional loss, improve quality and shelf life
Ethylene scavengers	Fresh produce and fresh-cut products	Control concentration of ethylene, reduce ripening and deterioration, and extend shelf life
Carbon dioxide emitters	Roasted ground coffee, nuts, bakery products, fresh meats, fish products	Decrease microorganism growth and spoilage, reduce metabolic rate of microbes, prevent swelling of packaging
Flavour/order emitters and absorbers	Fruit juices, fried snack foods, fish, cereals, poultry, dried products	Stabilize odor
Moisture scavengers	Fish, meat, poultry, snack foods, dried products	Control excess moisture and humidity
Antimicrobial packaging	Fresh fruits and vegetables, meat products, cheese, bakery products	Inhibition of microbial growth, reduction of post-harvest decay, maintenance of storage quality
Antioxidative packaging	Cereals, milk powder	Inhibition of oxidation process

the elimination of oxygen in the package prior to sealing. However, the permeation of oxygen from the external environment through the packaging material cannot be minimized. In order to surmount this, modified atmosphere packaging (MAP) is often used as an alternative technique, which involves the reduction of oxygen levels in the food packages by modifying the product atmosphere. However, for many foods, the levels of residual oxygen that can be achieved by regular MAP technologies are too high for maintaining the desired quality and for achieving the sought-after shelf life.

The control of oxygen content is of particular importance in packages containing foods that possess high water activity (AW) because of its ability to support microbial growth (in fresh produce and meat products) as well as those containing foods rich in fat content (Anany et al., 2011) One of the most effective methods of oxygen management in packaging is the use of active packaging. More specifically, oxygen scavengers refers to a category within AP. Oxygen scavengers are packaging films or devices that chemically react with oxygen to remove it from the packaging environment. This, in turn, protects the product from degradative oxidation reactions. Oxygen scavengers exist in many forms, including sachets, films, and enzymes, all of which can be used in food systems and function in a variety of ways.

5.1.1.1 Oxygen Scavenging Sachets

Oxygen scavenging sachets are envelopes of different proportions that are confined within a food package to absorb oxygen. Any substance that reacts with oxygen can be considered an oxygen scavenger. However, when dealing with food, oxygen scavenging sachets must be harmless, effortlessly controlled, and compact in size and must not produce lethal substances or offensive odors or gases. They also must absorb a large amount of oxygen, have an appropriate oxygen absorption speed, and be economically priced.

O_2 scavenging technologies are based on one of the following concepts: iron powder oxidation, ascorbic acid oxidation, catechol oxidation, photosensitive dye oxidation, enzymatic oxidation (e.g., glucose oxidase and alcohol oxidase), unsaturated fatty acids (e.g., oleic acid or linolenic acid), or immobilized yeast on a solid material.

5.1.1.1.1 Iron Powder Oxidation

The commercial oxygen scavengers available are in the form of small sachets containing metallic reducing agents, such as powder iron oxide, ferrous carbonate, and metallic platinum. The majority of presently available oxygen scavengers are based on the principle of iron oxidation in the presence of water. A self-reacting type contains moisture in the sachet, and as soon as the sachet is exposed to air, the reaction starts. In moisture-dependent types, oxygen scavenging takes place only after moisture has been taken up from the food. These sachets are stable in open air before use because they do not react immediately upon exposure to air; therefore, they are easy to handle if kept dry.

The action mechanism of oxygen scavenger based on iron oxidation is described by the following reactions:

$$Fe \rightarrow Fe^{2+} + 2e^- \quad (5.1)$$

$$1/2\ O_2 + H_2O + 2e^- \rightarrow 2\ OH^- \quad (5.2)$$

$$Fe^{2+} + 2\ OH^- \rightarrow Fe(OH)_2 \quad (5.3)$$

$$Fe(OH)_2 + 1/4\ O_2 + 1/2\ H_2O \rightarrow Fe(OH)_3 \quad (5.4)$$

5.1.1.1.2 Ascorbic Acid Oxidation

Ascorbic acid is an additional oxygen scavenger component whose action is based on ascorbate oxidation to dehydroascorbic acid. Most of these reactions are slow and can be accelerated by light or a transition metal that works as catalyst, for example copper. The ascorbic acid reduces Cu^{2+} to Cu^+ to form dehydroascorbic acid (Eq. 5.5). The cuprous ions (Cu^+) form a complex with the O_2 originating the cupric ion (Cu^{2+}) and the superoxide anionic radical (Eq. 5.6). In the presence of copper, the radical leads to the formation of O_2 and H_2O_2 (Eq. 5.7). The copper–ascorbate complex quickly reduces the H_2O_2 to H_2O (Eq. 5.8) without the formation of OH, a highly reactive oxidant. The following reactions show the process of oxygen absorption by ascorbic acid:

$$AA + 2\,Cu^{2+} \rightarrow DHAA + 2\,Cu^{+} + 2\,H^{+} \quad (5.5)$$

$$2\,Cu^{+} + O_2 \rightarrow 2\,Cu^{2+} + 2\,O^{-} \quad (5.6)$$

$$2\,O^{-} + 2\,H^{+} + Cu^{2+} \rightarrow O_2 + H_2O_2 + Cu^{+} \quad (5.7)$$

$$H_2O_2 + Cu^{2+} + AA \rightarrow Cu^{2+} + DHAA + 2\,H_2O \quad (5.8)$$

where AA is ascorbic acid and DHAA is dehydroascorbic acid. Ascorbic acid and ascorbate salts are being used in the design of scavengers in both sachet and film technologies.

Another scavenging technology is based on catechol oxidation. As catechol is an organic compound, it passes metal detectors and is used for dry products such as spices, freeze-dried foods, and tea. These sachets do not require moisture for their oxygen scavenging reaction.

5.1.1.1.3 Enzymatic Oxidation (Glucose Oxidase and Alcohol Oxidase)

A different way of controlling the oxygen level in a food package is by using enzyme technology. A combination of two enzymes, glucose oxidase and catalase, has been applied for oxygen removal. In the presence of water, glucose oxidase transfers two hydrogens from the –CHOH group of glucose, which can be originally present or added to the product, to O_2 with the formation of glucono-delta-lactone and H_2O_2. The lactone then spontaneously reacts with water to form gluconic acid. The reaction is

$$2\ \text{Glucose} + 2O_2 + 2\,H_2O \rightarrow 2\ \text{Gluconic acid} + 2\,H_2O_2$$

where glucose is the substrate.

Since H_2O_2 is an unpleasant end product, catalase is introduced to breakdown the peroxide:

$$2\,H_2O_2 + \text{Catalase} \rightarrow 2\,H_2O + O_2$$

Enzymatic systems are usually very susceptible to changes in pH, water activity, temperature, and availability of solvents. Most systems require water for their action, and therefore they cannot be efficiently used with low-water-content foods. Besides glucose oxidase, other enzymes are able to scavenge oxygen. One such enzyme is alcohol oxidase, which oxidizes ethanol to acetaldehyde. It could be used for food products in a wide AW range since it does not require water to operate. If a lot of oxygen has to be absorbed from the package, a great amount of ethanol would be required, which could cause an off-odor in the package. In addition, considerable aldehyde would be produced, which could give the food a yogurt-like odor.

5.1.1.1.4 Unsaturated Hydrocarbon Oxidation

The oxidation of polyunsaturated fatty acids (PUFAs) is an alternative technique to scavenge oxygen. PUFAs are an exceptional oxygen scavenger for dry foods. Most known oxygen scavengers have a serious drawback: When water is absent, their oxygen scavenging reaction does not progress. In the presence of an oxygen scavenging system, the quality of the dry food products may fail rapidly because of the migration of water from the oxygen scavenger into the food. Mitsubishi Gas Chemical Co. holds a patent that uses PUFAs as a reactive agent. The PUFAs, preferably oleic, linoleic, or linolenic, are contained in carrier oil such as soybean, sesame, or cottonseed oil (Kuorwel et al., 2011). The oil and/or PUFA are compounded with a transition metal catalyst and a carrier substance (e.g., calcium carbonate) to harden the oxygen scavenger composition. In this way the scavenger can be made into granules or powder and can be packaged in sachets.

The main problem of this technology is that during the reaction between these polyunsaturated molecules and oxygen, byproducts such as organic acids, aldehydes, or ketones can be produced that affect the sensory quality of the food or raise food regulatory issues. Certainly, some of these compounds are used to govern the quality and shelf life of fatty foodstuffs because they are inherently related to rancidity. This problem can be reduced by the use of functional hurdles that impede migration of undesirable oxidation products. This functional layer must provide a high barrier to organic compounds but allow oxygen to migrate, and it has to be introduced between the food product and the scavenger layer (Brandon et al., 2009).

Although pouches are extensively used in AP technology, especially for oxygen scavengers, the pouches may be confused for food products and may be ingested accidentally by the consumers if they leak out or contaminate the product. They are not suitable for liquid foods. Because of these problems related to sachets, oxygen scavenger film is a better way to limit oxygen levels in packaging.

For an oxygen scavenger sachet to be effective, some conditions have to be satisfied. First of all, packaging containers or films with a high oxygen barrier must be used, else the scavenger will be saturated quickly and lose its capability to trap O_2. Films with an oxygen permeability not exceeding 20 ml/m^2.d.atm are recommended for packages in which an oxygen scavenger will be used. Second, for flexible packaging, heat sealing should be complete so that no air enters the package through the sealed part. Finally, an oxygen scavenger of a suitable type and size must be selected. The suitable size of the scavenger can be calculated using the following formulas. The volume of oxygen present at the time of packaging (*A*) can be calculated using the formula

$$A = \frac{(V - P)*[O_2]}{100}$$

where *V* is the volume of the finished pack determined by submission of water and expressed in milliliters, *P* is the weight of the finished pack in grams, and $[O_2]$ is the initial O_2 concentration in package (21% if air). In addition, it is necessary to calculate the volume of oxygen likely to permeate through the packaging during the shelf life of the product (*B*). This quantity in milliliters may be calculated as follows:

$$B = S \times P \times D$$

where S is the surface area of the pack in m^2, P is the permeability of the packaging in ml/m^2.d.atm, and D is the shelf life of the product in days.

The volume of oxygen to be absorbed is obtained by adding A and B. Based on these calculations, the size of the scavenger and the number of sachets can be determined.

5.1.1.2 Oxygen Scavenging Films

In order to overcome the drawbacks of sachets, oxygen removing agents can be integrated into the packaging material such as polymer films, labels, crown corks, and liners in closures. These oxygen scavenging materials have the added benefit that they can be used for all products, including liquid products. The oxygen consuming substrate can be either the polymer itself or some easily oxidizable compound dispersed or dissolved in the packaging material (Pereira de Abreu et al., 2012).

5.1.1.2.1 Photosensitive Dye Oxidation

An additional method of oxygen absorption is a photosensitive dye infused onto a polymeric film. When the film is irradiated by ultraviolet (UV) light, the dye triggers the O_2 to its singlet state, making the oxygen-removing reaction much more available.

The method involves sealing a small coil of ethyl cellulose film, containing a dissolved photosensitizing dye and a singlet oxygen acceptor, in the headspace of a transparent package. When the film is irradiated with light of the appropriate wavelength, excited dye molecules sensitize oxygen molecules, which have dispersed into the polymer, to the singlet state. These singlet oxygen molecules react with acceptor molecules and are thereby consumed. The photochemical reaction can be presented as follows:

$$\text{Photon} + \text{Dye} \rightarrow \text{Dye}*$$

$$\text{Dye}* + O_2 \rightarrow \text{Dye} + O_2*$$

$$O_2* + \text{Acceptor} \rightarrow \text{Acceptor Oxide}$$

This scavenging technique does not require water as an activator, so it is effective for wet and dry products. Its scavenging action is introduced on the processor's packaging line by an illumination-triggering process (Figure 5.1).

5.1.2 Ethylene Scavengers

Ethylene is a chemically simple, pervasive chemical that has varied and intense effects on the physiology of plants, and its effects are so dose-dependent that it has been recognized as a plant hormone. Ethylene functions in the sprouting of plant seedlings, the growth of plants, and the growth of fruits. Ethylene has been referred to as a ripening hormone because it can hasten softening and ripening of many kinds of fruit, followed by aging and ultimately death. Exposure of mature fruit to ethylene leads to increased respiration, increased production of endogenous ethylene, and

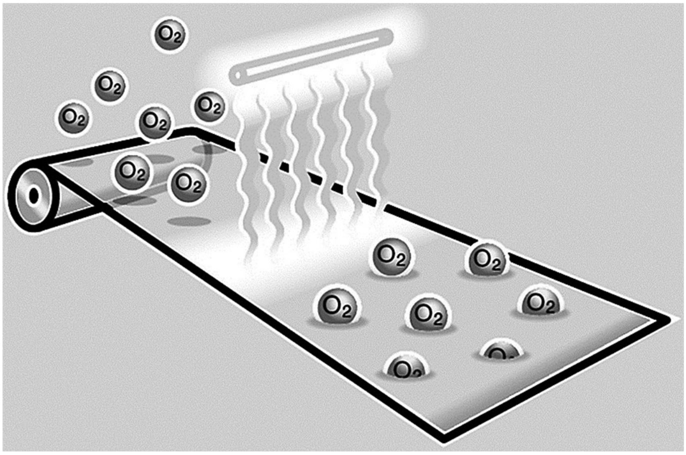

FIGURE 5.1 Light-activated oxygen scavenging films.

softening of fruit tissues. This is achieved through the direct or indirect stimulation of synthesis and activity of many ripening enzymes by ethylene.

Perishability of produce generally is well connected with respiration rate. Commodities such as asparagus, broccoli, and mushrooms that have very high respiration rates are very perishable, having post-harvest lives measured in days (Maschietti, 2010). Those commodities such as nuts, dates, dried fruits, potatoes, and onions that have very low respiration rates have post-harvest lives measured in months. Reduction of respiration rate increases post-harvest life, and an increase in respiration rate generally decreases it. Ethylene hastens the respiration of fruits, vegetables, and ornamental plants. In the case of climacteric fruit, ethylene can induce a rapid and irreversible elevation of respiration leading directly to maturity and senescence. In nonclimacteric plant organs, ethylene induces a reversible increase in respiration. Though the effects of ethylene are necessary (e.g., induction of flowering in pineapples and color development in citrus fruits, bananas, and tomatoes), in most horticultural situations it is desirable to remove ethylene or to suppress its effects. Consequently, much research has been undertaken to incorporate ethylene scavengers into fresh produce packaging and storage areas (Taoukis, 2011).

Many C_2H_4-absorbing substances have been described in the patent literature, but those that have been commercialized are based on potassium permanganate ($KMnO_4$), which oxidizes C_2H_4 in a series of reactions to acetaldehyde and then acetic acid, which, in turn, can be further oxidized to CO_2 and H_2O with the overall reaction as follows:

$$3\,C_2H_4 + 12\,KMnO_4 \rightarrow 12\,MnO_2 + 12\,KOH + 6\,CO_2$$

Because $KMnO_4$ is toxic, it cannot be integrated into food contact packaging. Instead, about 4–6% of $KMnO_4$ is added to an inert substrate with a large surface area such as perlite, alumina, silica gel, vermiculite, activated carbon, or celite and placed inside a sachet, which can be safely added to packages.

5.1.3 Carbon Dioxide Emitters

The use of carbon dioxide scavengers is predominantly applicable for fresh roasted or ground coffee, which produces substantial volumes of carbon dioxide. Fresh roasted or ground coffee cannot be left unpackaged since it will absorb moisture and oxygen and lose desirable volatile aromas and flavors. However, if coffee is hermetically sealed in packs directly after roasting, the carbon dioxide released will build up within the packs and eventually cause them to burst. The solution is to use a carbon dioxide scavenger or a dual-action oxygen and carbon dioxide scavenger system. A mixture of calcium oxide and activated charcoal has been used in polyethylene-lined coffee pouches to scavenge carbon dioxide. But dual-action oxygen and carbon dioxide scavenger sachets and labels are more common and are commercially used for canned and foil pouched coffees. The dual-action sachets and labels usually contain iron powder for scavenging oxygen and calcium hydroxide, which scavenges carbon dioxide when it is converted to calcium carbonate under adequately high humidity conditions (Charles et al., 2006).

A sodium bicarbonate/ascorbate system is extensively used in modified atmospheric packages of meat, in which a sodium bicarbonate/ascorbate sachet is placed under the MAP tray. When juice exudate from modified atmosphere packed meat or fish drips onto the sachet, carbon dioxide is emitted, and this antimicrobial gas can replace the carbon dioxide already absorbed by the fresh food so as to avoid pack collapse.

Pack collapse or the development of a partial vacuum can also be a problem for foods packed with an oxygen scavenger. To overcome this problem, dual-action oxygen scavenger/carbon dioxide emitter sachets and labels have been developed that absorb oxygen and generate an equal volume of carbon dioxide (Neethirajan et al., 2009). These sachets and labels usually contain ferrous carbonate and a metal halide catalyst, although nonferrous variants, such as ascorbate and sodium hydrogen carbonate, are available.

Carbon dioxide scavengers and emitters represent a relatively small but growing area of the AP market. The growth and development of this market is likely to revolve around the development of films that incorporate carbon dioxide scavenger/emitter functionality, although research into this is still in its early stages.

5.1.4 Moisture Absorbers

A foremost reason of food spoilage is excess moisture. Liquid water can mount up in packages as a result of temperature instabilities in high-moisture packages, “drip” or tissue fluid from flesh foods, and transpiration of horticultural produce. If this water is permitted to build up inside the package, it can lead to the growth of molds and bacteria, as well as fogging of films. Soaking up moisture by using various absorbers or desiccants is very effective at sustaining food quality and prolonging shelf life by preventing microbial growth and moisture-related degradation of texture and flavor.

Moisture absorbers comprise materials that absorb water from the immediate atmosphere and mostly consist of silica gel, calcium chloride, acrylate polymer, and so on. They can be in the form of bags, pads, polymer films, tablets, or granules. Tablet absorbers collect the moisture from the air and transform it to water in a tank or container. Absorbent pads are extensively used in contact with fish and meat. They are also known as drip pads. Their construction is usually a laminate of plastic gauze, adhesive, and either a cellulose fiber pad or a water absorbent acrylate polymer. Bags containing silica gels have also been stated to act as desiccants for use with moisture-sensitive foodstuffs. The benefit of silica gel absorber bags and calcium chloride tablets is that they can be dried and used again. The amount of the absorber depends on the size, temperature, and humidity of the environment where we want to use it (Jeong et al., 2024).

5.1.5 Flavor/Odor Absorbers and Releasers

The marketable use of flavor/odor absorbers and releasers is debated due to apprehensions arising from their ability to cover natural spoilage reactions and hence deceive consumers about the condition of packaged food. For this reason, flavor/odor absorbers and releasers have been effectively banned in Europe and the United States.

The impact of packaging on food flavors and aromas has long been recognized, particularly through the unwanted flavor scalping of desirable food components. For example, the scalping of a considerable proportion of desirable limonene has been proven after only 2 weeks' storage in aseptic packs of orange juice. Commercially, very few AP techniques have been used selectively to remove undesirable flavors and taints, but many possible chances exist. An example of such a chance is the debittering of pasteurized orange juices. Some varieties of orange, such as Navel, are particularly prone to bitter flavors caused by limonin that is liberated into the juice after the oranges have been subjected to pressing and subsequent pasteurization. Processes have been established for debittering such juices by passing them through columns of cellulose triacetate or nylon beads. A probable AP solution would be to include limonin absorbers (e.g., cellulose triacetate or acetylated paper) into the packaging material of orange juice.

Two types of taints agreeable for removal by AP are amines, which are formed from the breakdown of fish muscle proteins, and aldehydes, which are formed from the autoxidation of fats and oils (Kerry et al., 2006). Disagreeable smelling volatile amines, such as trimethylamine, associated with fish protein breakdown are alkaline and can be neutralized by various acidic compounds. The packaging bags made from film containing a ferrous salt and an organic acid such as citrate or ascorbate can also be used. These bags are claimed to oxidize amines as they are absorbed by the polymer film.

Removal of aldehydes like hexanal and heptanal from the package headspace of snack foods, cereals, dairy products, fish, and poultry has also been reported.

5.1.6 Antimicrobial Packaging

Antimicrobial packaging can kill or inhibit target microorganisms, thereby helping to extend the shelf life of the packaged food. The antimicrobial agent may be incorporated in any one of the three components of the packaged food, that is, in the packaging material or in the headspace that is provided in most of the packages or incorporated into the food itself as one of the ingredients. Hotchkiss and Banco

(1992), pioneers in the field of antimicrobial packaging, enumerated alternative antimicrobial packaging and systematically brought out the issues relating to antimicrobials in package structures and materials. Antimicrobial package materials may be classified into two types: those containing antimicrobial agents that migrate into the surface of the package material and thus can contact the food, and those that are effective against food surface microbiological growth without migration of the active agent(s) into the food (Appendini & Hotchkiss, 2002).

Package materials incorporating antimicrobial agents have been a packaging development objective for many years, with relatively few commercial successes. The safety of the food should be the foremost concern while incorporating antimicrobial agents as there are a number of such components being studied. Research groups from various parts of the globe are working on developing a functional and durable antimicrobial packaging wherein agents ranging from organic acids to antimicrobial enzymes, metal ions, sanitizing agents, and even IR radiation emitting films are being assessed. The most commonly studied metal ions are the silver ion, as it has the strongest antimicrobial activity, followed by cupric ions. However, copper is considered as toxic by most of the food regulatory bodies as it has the property of being an oxidation catalyst. This is c the reasons why research has recently turned toward in-depth study on the interaction of these antimicrobial agents with the food. Studies are also being carried out in the possible use of probiotics (*Lactobacillus reuteri*) to control *E. coli* O157:H7. Various microorganisms, for example lactic acid bacteria, produce bacteriocins and nonpeptide growth-inhibiting chemicals such as reuterin. These naturally produced antimicrobials can inhibit the growth of other bacteria, hence providing a dual benefit – probiotics and antimicrobial effect.

5.1.7 Antioxidative Packaging

Oxidation is often a prime quality factor limiting the shelf life of a wide range of foods. Compared to microbial spoilage, chemical oxidation is a slower process and is dominant in dry and/or fatty foods. The oxidation reaction starts conjoining with unsaturated fatty acids in the presence of a catalyst, such as iron, copper, enzymes, heat, or light. It is a chain reaction consisting of initial auto-oxidative propagation and final termination stages. Once it is in progress, self-acceleration of the process dominates. Over the stages of oxidation, conjugated dienes, hydroperoxides, alkanes, alkenes, aldehydes, and ketones are formed and contribute the rancid odors and flavors, and as a final point reacting with other functional groups to damage the physical properties of foods. Principally, cross-linking of aldehydes with amino groups in proteins may be a source of structural damage and textural change. Inhibition of lipid oxidation with antioxidant agents or AP is of pronounced significance in protecting foodstuffs with high amounts of unsaturated fatty acids from possible quality drops and in providing the required shelf life (Coma, 2008). To inhibit the oxidation over-formation of the food itself, antioxidants have been supplemented to food products. An additional revolutionary approach for averting oxidation in packaged foods is incorporation of an antioxidant in packaging material and its discharge to the contained food in a controlled manner. Many different antioxidants, synthetic or natural, have been tested for insertion into food packaging materials.

Any antioxidant packaging is established on the release of antioxidants from the packaging material to the contained food even though some antioxidant on the package surface may act to scavenge the free radicals in the package headspace. Antioxidants that are not volatile or are of low volatility, such as tocopherol and ascorbic acid, are suited for food structures such as liquids and semi-solids that come into direct contact with the package surface and absorb antioxidants released from the migrating agent. Volatile antioxidants, such as natural essential oils, butylated hydroxytoluene (BHT), and sesamol, exert their action through inhibition of gas-phase oxidation reactions with headspace free radicals and subsequent autoxidation in the food matrix with indirect migration.

For a long time, the packaging industry has been using synthetic antioxidants such as butylated hydroxyanisole (BHA) and BHT. Since synthetic antioxidants that drift into foods may induce off-flavors in the packaged food, particularly drinking water, natural antioxidants such as α-tocopherol, ascorbic acid, curcumin, tyrosine, essential oils, and plant extracts have been sought as replacements for the synthetic ones. Natural antioxidants were found to produce less off-flavor and thus improve the sensory quality of the food, and they currently are considered to be an important ingredient for antioxidant packaging.

With increased attention directed toward the protection of packaged food products by migrating antioxidants, a variety of methods to incorporate anti-oxidants, such as encapsulation, absorption, and blending, have been developed to enhance the effectiveness of antioxidant packaging systems (Lopez-de-Dicastillo et al., 2011).

5.2 INTELLIGENT PACKAGING

IP is a developing technology that uses the communication function of the package to enable the decision making to accomplish the benefits of improved food quality and safety, which can be defined as a packaging system that is capable of carrying out intelligent functions (such as detecting, sensing, recording, tracing, communicating, and applying scientific logic) to enable decision making to extend shelf life, enhance safety, improve quality, provide information, and warn about possible problems (Vermeiren et al., 1999).

The uniqueness of IP is in its capacity to communicate: Because the package and the food persistently travel together throughout the supply chain cycle, the package is the food's best confidante and is in the best position to communicate the conditions of the food. Thus when comparing IP and AP, IP is a provider of enhanced communication and AP is a provider of enhanced protection by taking some action (e.g., release of antimicrobial agents) to protect the food product. The beginning of IP has indicated another archetype shift in the concept of food packaging – shifting the package from an average communicator to an intelligent communicator.

IP can play an important role in enabling the flow of materials from one location to another by performing the basic functions of containment and protection of the product and also supplying information in the food supply chain cycle, that is, it can carry actual information in the direction of material flow (e.g., via truck, train, or ship), and it can convey information visually (e.g., via an indicator) or electronically (e.g., via a barcode) through every phase of the supply chain cycle.

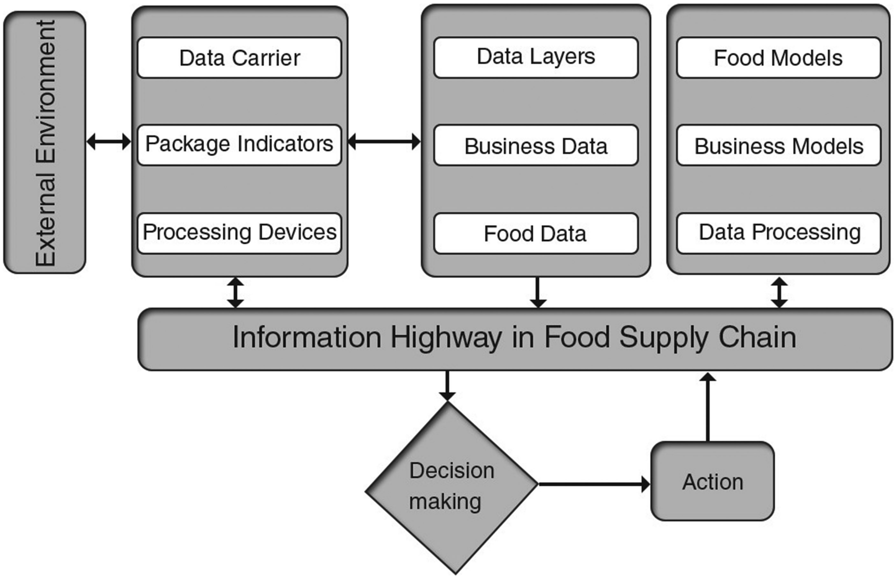

FIGURE 5.2 Conceptual framework of IP.

A conceptual framework describing the flow of information in an IP system is illustrated in Figure 5.2.

The system consists of four components: smart package devices, data layers, data processing, and information highway (wired or wireless communication networks) in the food supply chain. The smart package devices are largely accountable for giving birth to the concept of IP because they impart the package with a new facility to acquire, store, and transmit data. The data layers, data processing, and information highway are collectively referred to as the decision-support system (Day, 2008).

As depicted in Figure 5.3, the smart package devices and decision-support system are designed to work together to monitor changes in the internal and external environments of the food package and to communicate the conditions of the food product, so that sensible resolutions can be made and suitable actions can be taken. From the viewpoint of food quality and safety, the external environment can further be divided into physical, chemical, and microbiological factors, which are the factors significant for determining the shelf life. However, the commercial situation is also a vital factor; in point, the improvement of smart package devices (especially data carriers) and the information highway is largely driven by the aspiration to increase revenue and process efficiency.

5.2.1 Components of IP System

5.2.1.1 Indicators

Indicators are those devices that specify the occurrence or nonexistence of a target substance or the degree of reaction between two or more substances by means of a distinguishing change, usually in color. The dissimilarity between sensors and

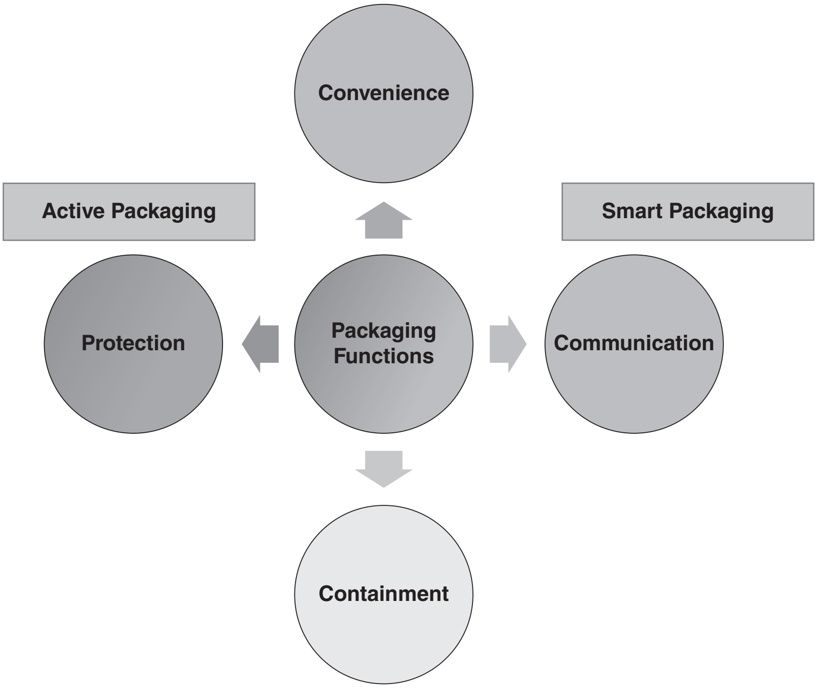

FIGURE 5.3 Model of packaging function.

indicators is that the latter do not have receptor and transducer components and instead communicate information through direct visual changes.

5.2.1.1.1 Time–Temperature Indicators

Temperature is one of the most significant environmental factors, and its variations cause apprehensions about the decline of food quality and safety for many products, such as chilled and frozen foods. Both time and temperature considerably contribute to the loss of hygienic, nutritional, and sensory qualities of perishable foods. Information relating to the durability of a product is currently being almost exclusively conveyed by the conventional use of an expiration date being printed on the packaging, which does not promise the safety of products or hold any information on their lifecycle after the printing of the date. Thus, in order to further ensure the safety of the supply chain from the producer to the consumer, many food business processors are now commending the development of scrupulous traceability tools for observing food temperature at every step in the supply chain, from "farm to fork." Such effective tools for constant observation of the time and temperature history of chilled products throughout the food chain are generally referred to as TTIs.

An ideal TTI or integrator is a simple, economical device that can show an easily measurable, time–temperature-dependent change that reveals the full or partial temperature history of a product to which it is attached. The major working methods of most TTIs include mechanical, chemical, electrochemical, enzymatic, or microbiological reactions, which result in an unalterable color change that is usually expressed as a visible response in the label.

TTIs have been categorized as either partial-history or full-history indicators based on their reaction mechanism: partial-history indicators usually react by changing color and retaining that color. Many such systems, designed for specific temperature-dependent products, do not change color unless the threshold temperature is exceeded. Full-history TTIs provide the continuous time–temperature history of a product throughout the distribution chain, with unceasingly emerging response and sensitivities to specific temperatures as opposed to a threshold temperature.

Ideally, TTIs should include the basic characteristics of being small, low cost, reliable, and easily integrated into packaging, and they should not themselves reduce the shelf life of a product by exposing it to environmental factors (light, air pollutants, humidity) or mechanical stresses (pressure, friction). They should also provide simple, continuous, and understandable indications for all target groups (e.g., producers, wholesalers, retailers, consumers) in a clear manner that can be measured both visually and electronically, and they should have no lethal effects on health and or the environment (Polyakov & Miltz, 2010).

Byrne classified TTIs based on the main functional difference, that is, whether the indicator responds above a preselected temperature or responds continuously, thus giving information on the cumulative time–temperature exposure. He proposed three types:

1. Critical temperature indicators (CTIs)
2. Critical temperature–time integrators (CTTIs)
3. Time–temperature integrators or indicators (TTIs)

5.2.1.1.2 Critical Temperature Indicators

CTIs show exposure above (or below) a reference temperature. They involve a time element (usually short; a few minutes up to a few hours) but are not envisioned to show the history of exposure above the critical temperature. They just indicate that the product was exposed to detrimental temperature for a time adequate to cause a change critical to the safety or quality of the product. They can serve as suitable cautions in cases where physicochemical or biological reactions show an intermittent change in rate. Good examples of such cases are the irreversible textural deterioration that happens when phase changes occur (e.g., upon defrosting frozen products or freezing fresh or chilled products).

5.2.1.1.3 Critical Temperature–Time Integrators

CTTIs show a response that reveals the cumulative time–temperature exposure above a reference critical temperature. Their response can be interpreted into corresponding exposure time at the critical temperature. They are beneficial in representing breakdowns in the distribution chain and for products in which reactions, vital to quality or safety, originate or occur at quantifiable rates above a critical temperature. Examples of such reactions are microbial growth or enzymatic activity that is inhibited below the critical temperature.

5.2.1.1.4 Time–Temperature Integrators or Indicators

TTI give a continuous, temperature-dependent response throughout the product's history. They integrate, in a single measurement, the full time–temperature history and can be used to specify an average temperature during distribution and possibly be connected to continuous, temperature-dependent quality loss reactions in foods. A different method of classification sometimes used is based on the principle of the indicators' operation. Thus, they can be categorized as mechanical, chemical, enzymatic, microbiological, polymer, electrochemical, diffusion based, and so on (Taoukis, 2010).

5.2.1.1.5 Requirements for TTIS

An ideal TTI would have all the following properties:

- It exhibits a continuous time- and temperature-dependent change.
- The change causes a response that is easily measurable and irreversible.
- The change mimics or can be correlated to the food's extent of quality deterioration and residual shelf life.
- It is reliable, giving consistent responses when exposed to the same temperature conditions.
- It has low cost.
- It is flexible, so that different configurations can be adopted for various temperature ranges (e.g., frozen, refrigerated, room temperature) with useful response periods of a few days as well as up to more than a year.
- It is small, easily integrated as part of the food package, and compatible with a high-speed packaging process.
- It has a long shelf life before activation and can be easily activated.
- It is unaffected by ambient conditions other than temperature, such as light, humidity, and air pollutants.
- It is resistant to normal mechanical abuse, and its response cannot be altered.
- It is nontoxic, posing no safety threat in the unlikely situation of product contact.
- It is able to convey in a simple and clear way the intended message to its target, be it distribution handlers or inspectors, retail store personnel, or consumers.
- Its response is both visually understandable and adaptable to measurement by electronic equipment for easier and faster information, storage, and subsequent use.

5.2.1.1.6 Integrity and Gas Indicators

Maintenance of the quality and safety of foods inside a packaging material is complicated, as the gas composition in a package headspace can easily be altered due to respiration of fresh foods, leakage, the invasion of gas through the packaging film from the surrounding air, or gas produced by microbial spoilage. Gas indicators in the form of labels or printed on the packaging films can monitor the changes in gas composition inside the package and thus can help to monitor the safety and quality of the products. These indicators change their color by either a chemical or enzymatic reaction, usually providing information about the presence or absence of oxygen or carbon dioxide. These indicators must be in direct contact with the food, as they monitor the gaseous environment within a package. These indicators are engaged for controlled or modified atmosphere food packaging.

Oxygen and carbon dioxide are the major gases in MAP products, although carbon monoxide, sulfur dioxide, nitrous oxide, ozone, and chlorine are also used in specific industries. The most common oxygen indicators are based on color change as a result of (1) an oxygen-binding reaction, (2) a redox reaction, or (3) a light-activated redox reaction. These indicators are available as a label, a printed layer, or a tablet or may be laminated in a polymer film.

A carbon dioxide indicator system consists of a chemical dye (bromocresol purple or methyl red), which is integrated into polymeric films (polypropylene resin or calcium hydroxide as a CO_2 absorbent) to estimate the degree of fermentation in kimchi (a traditional fermented vegetable food in Korea) products during storage and distribution without abolishing the packaging (Jeong et al., 2024). These indicators not only give information about the concentration of carbon dioxide in packages during shipment and storage but also detect the initial spoilage. The system is based on a pH-dependent color change irrespective of temperature.

During kimchi fermentation, hetero-fermentative lactic acid bacteria grows and produces lactic acid, acetic acid, CO_2, and ethanol as byproducts. As the concentration of CO_2 changes, it alters the pH, which subsequently changes the color of the indicator.

5.2.1.1.7 Freshness and Spoilage Indicators

Customers commonly evaluate the overall quality of a product by observing color, odor, and texture, which are indicative of a product's environment. However, sometimes the consumer cannot find the quality of a food product from these predictable freshness indicators because the food is confined within packaging material. A freshness indicator is a packaging system that has been developed to provide direct product quality information, instead of simply indicating temperature abuse or package leaks, using microbial growth metabolites, which determine the changes taking place within the food. Microbial metabolites such as glucose, organic acids such as acetic or lactic acid, ethanol, volatile nitrogen compounds (e.g., trimethylamine in packed fish products), biogenic amines, carbon dioxide, ATP degradation products, and sulfuric compounds are usually estimated to evaluate a product's freshness.

5.2.1.2 Smart Packaging Devices

Smart package devices are defined here as small, economical labels or tags that are attached onto primary packaging (e.g., pouches, trays, and bottles), or more often onto secondary packaging (e.g., shipping containers) to enable communication during the supply chain so that suitable actions may be taken to achieve anticipated benefits in food quality and safety enhancement.

There are two basic types of smart package devices: data carriers (such as barcode labels and RFID tags) that are used to store and transmit data, and package indicators (such as TTIs, gas indicators, and biosensors) that are used to monitor the external environment and, whenever suitable, issue warnings. These devices deliver a communication channel between the external environment and other components in the system. These devices differ from each other not only in hardware but also in the amount and type of data that can be carried and how the data are captured and distributed (Mills et al., 2012).

5.2.1.2.1 Bar Codes

A barcode is defined as a series of parallel bars and spaces arranged according to the encoding rules of a particular specification in order to signify data. Its purpose is to signify information in a form that is machine readable, typically by scanning devices that are programmed to analyze the structure of the bars and spaces and transmit the encoded data in electronic format to a computer. Although there are more than 200 barcode symbologies, only are few are in common use, with the most popular being European Article Number (EAN)/UPC, which is a continuous symbology encoding fixed-length numeric digits, and several variants exist. These barcodes always carry a number that is a unique identifier of the item on which the barcode is attached and is widely used on consumer products including food and has the benefit of omnidirectional scanning capability. In EAN/UPC symbology-based barcodes, a unique Global Trade Item Number (GTIN) is used to exclusively identify trade items at any point in the supply chain. Each trade item that is different from another is allocated its own separate GTIN. Consumer units (the smallest unit intended to be sold to the ultimate end user) are assigned a 12-digit number, of which the first two digits indicate the country in which the barcode was created, and the following four digits identify the manufacturer. The last six digits are the product code, which are assigned by the manufacturer. Through this system, every product has its own discrete code, but every code can be read by simple optical scanner systems. Trade items above the consumer unit such as intermediate packs, cartons, packs containing multiple consumer units, or standard mixtures of consumer units are assigned a 14-digit number. The GTIN-14 Serial Shipping Container Code (SSCC) uniquely identifies shipping containers and provides a method of linking the physical carton or shipping container to information about its contents.

The other type of barcodes is known as data matrix codes and consists of black and white "cells" or modules organized in either a square or rectangular pattern. They use a small area of square modules with a unique perimeter design, which helps the barcode scanner govern cell locations and decode the symbol. Characters, numbers, text, and actual bytes of data may be encoded, including Unicode characters and photos. Though the barcodes have been widely used in many fields, they have been found to have certain restrictions like providing only very inadequate information about the product. To overcome this problem, advanced barcoding systems are being introduced, such as reduced space symbology (RSS), PDF 417 and composite symbology, in order to provide newer and more inventive applications Duncan (2011) (Figures 5.4 and 5.5).

5.2.1.2.2 RFID Devices

RFID is categorized as neither a sensor nor an indicator, but rather it represents a separate electronic information-based form of IP that uses radio-frequency

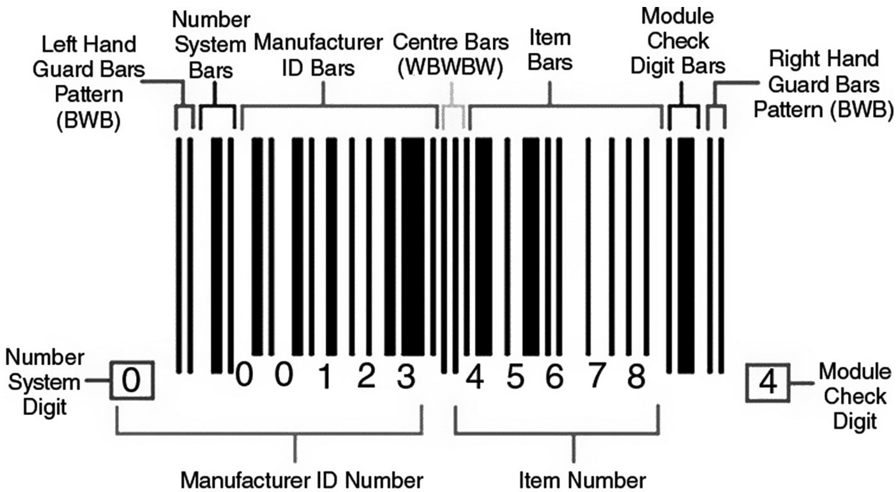

FIGURE 5.4 Anatomy of barcode GTIN 12.

FIGURE 5.5 Data matrix barcode.

electromagnetic fields to transfer data from a tag attached to an object for the purpose of automatic product identification and traceability.

Their advantages are that they can be read wirelessly and without line of sight, contain more information than barcodes (up to 4 kB in passive tags and 1 MB in active tags), can work under extreme temperatures and different pressures, and are more robust. To date, RFIDs have been used to increase convenience and efficiency in supply chain management and traceability, being normally applied to secondary or tertiary packaging. However, they still have some drawbacks including cost of implementation, reliability, performance, and potential for privacy misuse issues.

5.2.1.2.3 RFID System Operation

The RFID system consists of a tag (also known as a transponder), a reader or interrogator, and a central node or computer. A tag is a small electronic device attached to or embedded in the product to be identified. Each tag has a unique identification, which may only be a serial number or may be product-related information such as a stock number, lot or batch number, production date, or other specific information to be stored electronically via the microchip.

In order to operate functions such as sending radio signals to a reader, storing and retrieving data and other computations, tags require energy, which may be obtained from a battery or from electromagnetic waves emitted by readers that induce an electric current in the tags. RFID interrogators or readers are devices that send signals to the tags wirelessly in order to identify the item connected to each tag. Both the tag and the reader are two-way radios containing an antenna, and they can modulate and demodulate radio signals. The system begins its operation when the reader transmits a radiofrequency signal to interrogate the tag. The tag receives the message and responds by sending its information to the reader. These signals are then transmitted to a computer system running RFID software (Figure 5.6).

There are three types of RFID tags: active, passive, and semi-passive. Active tags have an internal power source and are extremely flexible in terms of the functionality they can offer due to their on-board battery, which extends their reading range. Passive tags are not self-powered but are activated by the electromagnetic field emitted by the reader. They are deployed primarily for their low cost and ease of implementation, due to established standards, and they find application in the retail supply chain, especially manufacturing, warehousing, and distribution. Semi-passive/semi-active tags contain a power source, but it is only used to power the circuitry. The radio signal is transmitted using power from the incoming radio signal. These tags are being developed primarily for reusable containers and pallets (Kumar et al., 2009).

In spite of the several advantages of RFID technology over barcodes, a number of practical limitations have been found. The major reason for its inactive market is the high cost; in addition, another limitation is the reading of ultra-high-frequency tags near a human body because of interference from the high water content of humans. It is also difficult to read information from tags on products containing large amount of moisture or that have been packed in metal containers because water molecules can absorb microwave signals, resulting in signal loss, and metals can reflect them.

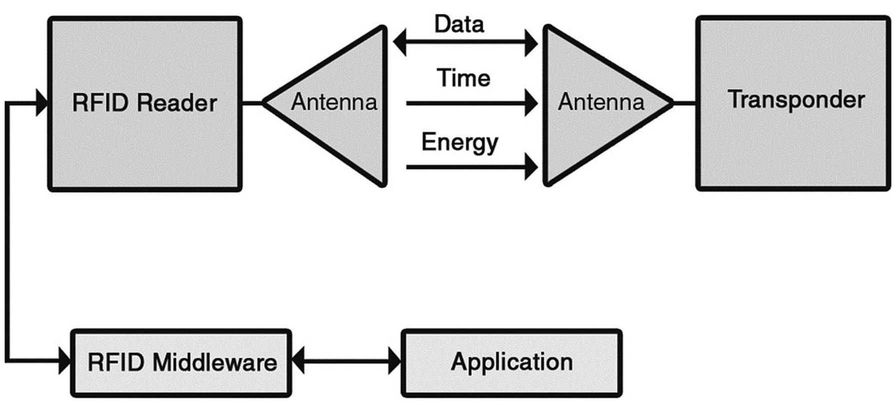

FIGURE 5.6 RFID system components.

5.2.1.2.4 Biosensors

Biosensors are used to detect, record, and transmit information pertaining to biological reactions. They contain bioreceptors and transducers; a bioreceptor recognizes the target analyte and the transducer converts bio-chemical signals into quantifiable electronic response. The bio receptors may be either organic or biological materials like enzyme, hormone, nucleic acid, antigen, microbes, and so on. The transducers may be optical, acoustic, or electrochemical. An ideal biosensor would have the necessary sensitivity and high specificity, precision, and accuracy, in addition to being economical, small, portable, and capable of being used by semi-skilled operators. It would be easily calibrated and have high linearity and dynamic range with no background signal. It would be stable under normal storage conditions and independent of physical parameters such as stirring, temperature or pH. Finally, such a sensor would offer good dynamic response (low measurement time) and would be biocompatible without any toxic or antigenic effects.

5.3 CONCLUSIONS

AP and IP concepts are at present in commercial use in many countries, predominantly the United States and Japan. Worldwide, there have been several attempts and many highly inventive developments in AP and IP that have shown great early promise but have failed to be successfully commercialized. Additionally, efforts are regularly made to commercialize new types of AP and IP before rigorous scientific assessments have been undertaken. The major disadvantage with novel packaging systems is the absence of technical information. Despite this lack of peer-reviewed literature, there is no doubt that the use of AP and IP systems for food will become gradually more popular, and new inventive applications that deliver enhanced shelf life and greater assurance of safety will become usual.

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6 Biopolymer for Food Packaging

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6.1 OVERVIEW OF BIOPOLYMERS: DEMAND, RESOURCES, AND VARIOUS APPLICATIONS

In recent times the market price of petroleum products and oils has increased. These facts have helped to raise interest in biopolymers and in particular biodegradable biopolymers. Biodegradable plastics and polymers were first introduced in the 1980s. There are many sources of biodegradable polymers, from synthetic to natural polymers. Natural polymers are available in large quantities from renewable sources, while synthetic polymers are produced from nonrenewable petroleum resources (Vroman & Tighzert, 2009).

These biopolymers are large macromolecules composed of single, repeating monomer units. They are of high molecular weight, and their material characteristics vary according to the nature of their monomer chemistry.

Agriculture offers a broad range of commodities including forest, plant/crop, and farm and marine animals, which have many uses. Plant-based materials have been used traditionally for food and feed and are increasingly being used in pharmaceuticals and nutraceuticals.

Figure 6.1 shows the production of biopolymers in three categories: polysaccharides from direct extract of plant biomass, polylactides (PLA) and poly(ϵ-caprolactone) (PCL) from the lactic acid fermentation of micro-organisms, and poly(β-hydroxyalkanoates) (PHA) and polyhydroxybutyrsyte (PHB) from the reduction of suitable substrates by genetically modified microorganisms.

Biopolymers are applied in food packaging, biomedical, and bioplastic industries as an alternative to petrochemical and synthetic polymers. Agricultural resources of starch and cellulose serve as the best biopolymers for solid packaging materials. These are very weak when they come in contact with water and they get diluted. This problem is resolved by adding composites such as starch-blended products to the packaging material. Adding cellulose and chitosan to the starch films gives partial resistance to water and increases the mechanical properties; these starch-blended films are completely biodegradable within 3 months.

Acetylation of the starch or cellulose gives more resistance to water and increases oxygen barrier and mechanical properties. However, in the acetylation procedure usage of chemicals such as pyridine and acetic acid may increase the biodegradability time.

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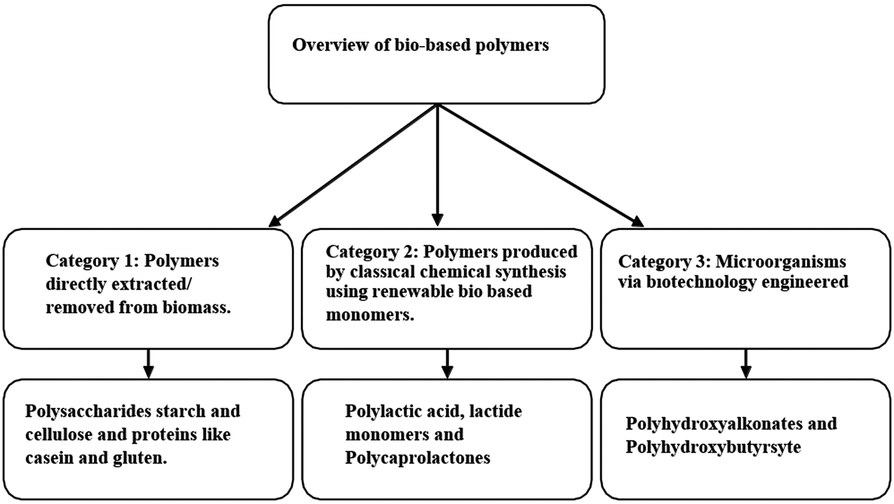

FIGURE 6.1 The overview of biopolymers and its resources.

The antibacterial activity of blend films (starch/chitosan) is enhanced by increasing the content of chitosan in blend systems (Zhai et al., 2004).

6.2 WHY THERE IS A NEED FOR BIOPOLYMER IN FOOD PACKAGING SYSTEMS

The food industry has witnessed a spate in the manufacturing of new food packaging materials. Most of them are colorful and aesthetic and cause increasing environmental concerns due to their nonbiodegradable nature. Thrown-out plastic causes pollution to land as well as the ocean. According to a new report by the Ellen MacArthur Foundation (Goncalves, 2020), there will be more waste plastic in the sea than fish by 2050 unless the industry cleans up its act. The new plastics will consume 20% of all oil production within 35 years, up from an estimated 5% today.

Plastic production has increased 20-fold since 1964, reaching 311 million tons in 2014, the report says. It is expected to double again in the next 20 years and almost quadruple by 2050.

Despite the growing demand, just 5% of plastics are recycled effectively, while 40% end up in landfill and one-third in fragile ecosystems such as oceans, as shown in Figure 6.2.

Much of the remainder is burned, generating energy but causing more fossil fuels to be consumed in order to make new plastic bags, cups, tubs, and consumer devices demanded by the economy. Nevertheless, food packaging is a noteworthy contributor to municipal solid waste (MSW) because food is the only product class typically consumed three times per day by virtually every person. Accordingly, food packaging

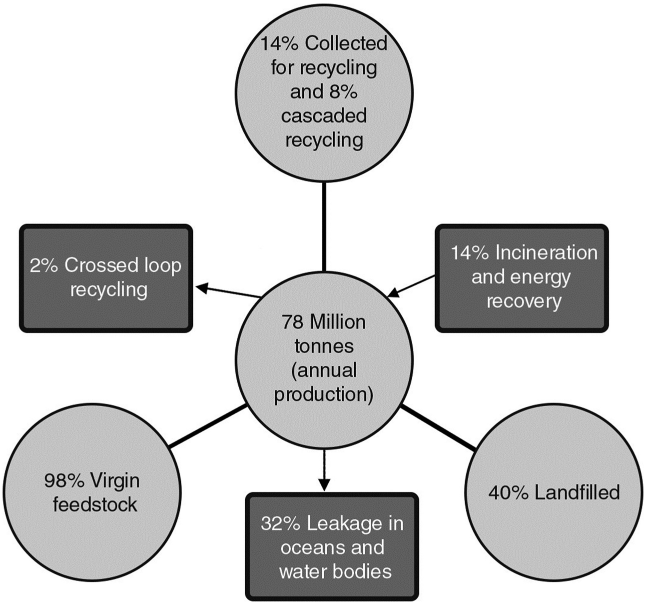

FIGURE 6.2 Global plastic packaging material flow.

accounts for almost two-thirds of total packaging waste by volume (Hunt et al., 1990). Moreover, food packaging is approximately 50% (by weight) of total packaging sales.

The principal roles of food packaging are to protect food products from outside influences and distribution damage, to contain the food, and to provide consumers with ingredient and nutrition information. Traceability, convenience, and tamper indications are secondary functions of increasing importance. The goal of food packaging is to contain food in a cost-effective way that satisfies industry requirements and consumer desires, maintains food safety, and minimizes environmental impact. Package design and construction play significant roles in determining the shelf life of a food product. The right selection of packaging materials and technologies maintains product quality and freshness during distribution and storage. Materials that have traditionally been used in food packaging include glass, metals (aluminum, foils and laminates, tinplate, and tin-free steel), paper and paperboards, and plastics. Today's food packages often combine several materials to exploit each material's functional or aesthetic properties (Marsh & Bugusu, 2007).

6.3 WASTE MANAGEMENT APPROACH TO BIOPLASTICS/ BIOPOLYMERS IN FOOD PACKAGING

Proper waste management is important to protect human health and the environment and to preserve natural resources. Integrated management approach involves source reduction, recycling, composting, combustion, and landfilling.

Source reduction involves the toxicity reduction of the waste, and it encompasses using less packaging, designing products to last longer, and reusing products and materials, according to the Environmental Protection Agency (EPA). Specific ways to achieve source reduction include using thinner gauges of packaging materials (i.e., light weighting), purchasing durable goods, purchasing larger sizes (which use less packaging per unit volume) or refillable containers, and selecting nontoxic products (Leverenz, 2002).

Recycling diverts materials from the waste stream to material recovery. Unlike reuse, which involves using a returned product in its original form, recycling involves reprocessing material into new products, such that food packaging materials can also be recyclable.

Composting, considered by the EPA as a form of recycling, is the controlled aerobic or biological degradation of organic materials. Composting of any biodegradable matter first involves arranging organic materials into piles and providing sufficient moisture for aerobic decomposition by microorganisms. Composting is a valuable alternative to waste disposal.

Combustion, the controlled burning of waste in a designated facility, is an increasingly attractive alternative for waste that cannot be recycled or composted. Reducing MSW volume by 70–90%, combustion incinerators can be equipped to produce steam that can either provide heat or generate electricity (Marsh & Bugusu, 2007).

The essential prerequisites of a good packaging film (Kader, 1989) are the following:

- Allow for a slow and controlled respiration with reduced oxygen absorption of the commodity
- Allow for a selective barrier to gas and water vapor
- Create a modified atmosphere with respect to internal gas composition, thus regulating the ripening process and leading to shelf life extension
- Maintain structural integrity and improve mechanical handling
- Serve as a vehicle to incorporate food additives and prevent microbial spoilage during extended storage

6.4 PLANT-BASED BIOPOLYMERS

The three major plant-based biopolymers are proteins, oils, and carbohydrates. Starch and cellulose, also called polysaccharides, are the main naturally occurring polymers in the large carbohydrate family. Natural fibers such as flax, hemp, paddy straw, kenaf, and jute mainly consist of cellulose, hemicelluloses, and lignin, but they are usually listed as a raw material used as a fiber in composites.

Corn, soybean, wheat, and sorghum are the four major crops grown in the United States with total annual production of about 400 million metric tons. About 10–15% of these grains are used for food, 40–50% for feeds, and the rest for various industrial uses. According to US Department of Agriculture statistics, the total land used for crops is about 455 million acres, which is about 20% of total usable land (Ebnesajjad, 2013).

In general, seeds make about 45–52% of the dry mass of a plant. This implies that there is a potential to produce about 400 million metric dry tons of cellulosic sugar-based biomass in the United States alone.

6.4.1 Starch and Cellulosic Biopolymers for Packaging Applications

Starch is a hydrocolloid biopolymer. It is a low-cost polysaccharide, one of the cheapest and most abundantly available biodegradable polymers. Starch is produced by agricultural plants in the form of granules, which are hydrophilic. Starch is mainly extracted from potatoes, corn, wheat, and rice. It is composed of amylose (poly-α-1,4-D-glucopyranoside), a linear and crystalline polymer and amylopectine (poly-α-1,4-D-glucopyranoside and α-1,6-D-glucopyranoside), a branched and amorphous polymer. The relative amounts and molar masses of amylose and amylopectin vary with the starch source, yielding materials of different mechanical properties and biodegradability (Fredriksson et al., 1998; Ratnayake et al., 2001). As the amylose content of starch increases, the elongation and strength also increase.

The stability of starch under stress is not high. The glucoside links start to break at 150°C, and above 250°C the granules collapse. Retrogradation, that is, reorganization of hydrogen bonds, is observed at low temperatures during cooling. In its applications starch can be mixed, kept intact, and used in various resins as a filler or melt for blending compounds. In the former form, fillers are starch whiskers used with polymer resins. Starch nanocrystals can be obtained by partial acid hydrolysis of the amorphous regions of granules. They are then incorporated into natural polymers as PHA natural rubber or starch itself (Dubief et al., 1999; Angellier et al., 2005, 2006). In the latter form, the molecular order inside the granules must be destroyed to improve starch processability. Granules are gelatinized in water at 130°C. Starch is usually used as a thermoplastic. It is plasticized through destructuration in the presence of specific amounts of water or plasticizers and heat, and then it is extruded (Martin et al., 2001). The most common plasticizers are polyols such as glycerol (Weber, 2000). When used, polyols may induce a recrystallization reaction called retrogradation.

The properties of the extruded starch depend on the water content and the relative humidity (Imam et al., 1995). Thermoplastic starch (TPS) has a high sensitivity to humidity. Thermal properties of TPS have been shown to be more influenced by the water content than the molecular weight (Van Soest et al., 1996). TPS thus obtained is almost amorphous. A new crystalline form induced by the process can remain in the thermoplasticized product. The plasticizer content is another important parameter. The interactions between the plasticizer and starch are weak if the plasticizer content is below 10 wt%. The material is then fragile and is difficult to work with it. When the plasticizer content is higher than 20 wt%, flexibility and elongation properties improve (Myllarinen et al., 2002).

Starch is renewable and biodegradable polysaccharides (Lenz, 1993). Usually native starch from plant contains about 30% amylose, 70% amylopectin-tin, and less than 1% lipids and proteins. Biodegradable starch-based plastics, such as starch/cellulose, starch/PVA (poly-vinyl alcohol), and so on, have recently been investigated due to great potential markets in agricultural foils, garbage or composting bags, food packaging, the fast food industry, as well as biomedical fields (Funke et al., 1998).

Starch is totally biodegradable; it can be hydrolyzed into glucose by microorganism or enzymes and then metabolized into carbon dioxide and water. It is worth noting that carbon dioxide will recycle into starch again via plants and sunlight. Starch itself is poor in processability, and its end products are also poor in thir dimensional stability and mechanical properties. Therefore, native starch is not used directly (Choi et al., 1999; Primarini & Ohta, 2000).

6.4.2 Starch Blend with Synthetic Degradable Polymers

In the beginning, starch was used as a filler of polyolefin by Griffin, and its concentration is as low as 6–15%. Adding starch to vinyl polymers will enhance biodegradability.

To prepare completely biodegradable starch-based composites by this strategy, biodegradable polymers are assumed. Usually, the components to blend with starch are aliphatic polyesters, PVA, and biopolymers. The commonly used polyesters are PHA, obtained by microbial synthesis, and PLA or PCL, derived from chemical polymerization. The goal of blending low-cost starch with completely degradable polyester is to improve its cost competitiveness while maintaining other properties at an acceptable level (Lu et al., 2009).

To improve the compatibility between PLA and starch, a suitable compatibilizer should be added. Besides, gelatinization of starch is also a good method to enhance the interfacial affinity. Starch is gelatinized to disintegrate granules and overcome the strong interaction of starch molecules in the presence of water and other plasticizers, which leads to good dispersion (Martin et al., 2001; Park et al., 2000). The glass transition temperature and mechanical properties of the TPS/PLA blend depend on the composition and the content of plasticizer, indicating the compatibility between PLA and TPS is low but some degree of interaction is formed. PCL is another important member of the synthetic biodegradable polymer family. It is linear, hydrophobic, partially crystalline polyester and can be slowly degraded by microbes (Scott & Gilead, 1995). Blends between starch and PCL have been well documented in the literature (Vikman et al., 1999). The weakness of pure starch materials including low resilience, high moisture sensitivity, and high shrinkage has been overcome by adding PCL to the starch matrix even at low PCL concentration.

6.4.3 Starch Blend with Microbial Biopolymers

Natural polymers such as chitosan and cellulose and their derivatives are inherently biodegradable and exhibit unique properties. A number of investigations have been devoted to studying its blend with starch. Starch and chitosan are abundant naturally occurring polysaccharides. Both of them are cheap, renewable, nontoxic, and biodegradable. The starch/chitosan blend exhibits good film-forming properties, which is attributed to the inter- and intramolecular hydrogen bonding formed between amino groups and hydroxyl groups on the backbone of the two components. The mechanical properties, water barrier properties, and miscibility of biodegradable blend films are affected by the ratio of starch to chitosan.

Extrusion of the mixture of corn starch and microcrystalline cellulose in the presence or absence of plasticizers is used to produce edible films. By increasing the content of the cellulose component, the rupture strength is increased, whereas the elongation at break and the permeability of films for water vapor are decreased. Starch can form thermodynamically compatible blend films with water-soluble carboxymethylcellulose when the starch content is below 25 mass%. Such films are biodegradable in the presence of microorganisms. Starch-based nanocomposite film is obtained by casting the mixture of plasticized starch and flax cellulose nanocrystals (CNC). The mechanical and water barrier properties are greatly improved. The tensile strengths of nanocomposite and unreinforced films are 498.2 and 11.9 MPa, respectively (Cao et al., 2008).

6.4.4 Cellulose Extraction and Processing Methodology for Biopolymer Packaging

The properties of cellulose like good tensile strength, low density, biodegradability, and so on have led to rising research interest. Cellulose has a highly organized hierarchical structure resulting in high crystallinity (~90%) and high Young's modulus (114 GPa) (Hsieh et al., 2008). Cellulose is the structural material of the fibrous cells with a high level of strength and stiffness per unit weight and has a straight carbohydrate polymer chain consisting of β-1-4 glucopyranose units and a degree of polymerization of about 10,000 (Lu et al., 2009). The molecules aggregate and are present in the form of microfibrils. The hydroxyl (–OH) groups in the cellulose structure play a major role in governing the reactivity and physical property of the cellulose.

6.4.5 Methodology in Processing and Extracting Cellulose from Raw Agricultural Resources

The preprocessing requires more physical methods than chemical extraction methods. Physical treatment includes pressing and drying of the agricultural source such as paddy straw, husk, and sugarcane bagasse (Figure 6.3).

6.4.5.1 Mechanical Properties of Tamarind Starch Films

Film formation was found be improper when cast with only 12% tamarind seed starch (w/v) mixed with 2.5% glycerol(v/v) as a plasticizer and 1.5% acetic acid (v/v) as anion-exchange polymerizer. Good interfacial adhesion between starch and cellulose was expected because both contained hydroxyl groups that can form hydrogen bonds between interfaces. Thus, the mixture of 12% tamarind seed starch (w/v) mixed with 2.5% glycerol (v/v) and 1.5% acetic acid (v/v) was reinforced and homogenized with 4% cellulose (w/v) for preparation of films and also to improve the mechanical properties of the film. These cellulose-reinforced tamarind (CRT) starch films were analyzed for their mechanical properties (tensile strength and

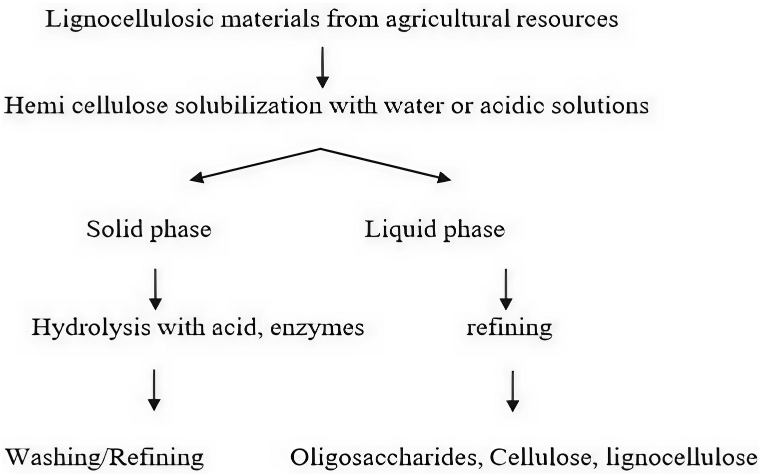

FIGURE 6.3 Preprocessing of lignocellulosic materials.

elongation at break). The tensile strength and elongation at break of CRT starch films were found to be 4.05 MPa and 354.47%, respectively (Sudharsan et al., 2016). Thus, the composite material cellulose gives better mechanical properties as well as showing high thermostability.

Cellulose-reinforced starch shows improvement in tensile strength; this may be due to increased concentration of cellulose powder. Oxygen transfer rate (OTR) of optimized CRT film was found to be 1034.45 $\pm$ 2.57, 682.76 $\pm$ 3.41, and 395.23 $\pm$ 3.75 cc m^{-1} day^{-1} for film thicknesses of 0.25, 0.38, and 0.47 mm, respectively. Water vapor permeability (WVP) of optimized CRT film was found to be 0.91, 0.73, and 0.65 g s^{-1} m^{-1} Pa^{-1} for film thicknesses of 0.25, 0.38, and 0.47 mm, respectively. Increase in thickness of CRT film was found to reduce its OTR and WVP properties. The low WVP of optimized CRT film may be due to the rich amylose content of tamarind seed starch. Increase in amylose content of starch tends to reduce the WVP of starch-based films. The reason for such behavior may be that during recrystallization, amylose forms a B-type crystalline structure, whereas amylopectin has an amorphous structure. Diffusion of moisture is easier in amorphous systems than in crystalline ones.

The empty fruit bunch (EPF) of palm also serves as a good source for cellulose production. EPF is composed of 40.37% cellulose, 20.06% hemicellulose, and 23.89% lignin. Having high cellulose content, EFB has high potential as a source for cellulosic derived products such as cellulose fiber, nanocellulose, glucose, xylose, and ethanol. Cellulose also has other potential uses as a source for bioplastic production. Cellulose has no plasticity feature.

Uses of cellulose in bioplastic production need some modification. Derivates of cellulose that have been used in bioplastic synthesis include CNC, nanofiber cellulose (NFC), cellulose acetate butyrate, cellulose acetate, and bio-PE. Cellulose derivate was mixed with other biopolymers, such as starch and PLA, in a matrix in order to increase physical properties or as a filler. The demand for bioplastic increases along with the rising concern about environmental problems caused by petroleum-based plastic. Global production capacity of bioplastic increased by 38% per year during 2003–2007 and is predicted to reach 3.45 million tons in 2020. Cellulose and cellulose derivate are about 11% of the global capacity.

Cellulose from EFB could be used as a bioplastic composite source. Potential cellulose from EFB is 11.5 million tons in Indonesia, making EFB a good source for bioplastic. Cellulose is produced using sodium hydroxide and sodium hypochlorite. Cellulose obtained from EFB is modified in order to increase physical properties of the bioplastic.

Bioplastics are made from corn starch, potato starch, or banana starch, which is used by humans and animals for their living. Instead of using starches that are extracted from edible things, we should use waste newspaper, which is mainly made up of cellulose, and these newspapers are dumped into oceans for disposal.

Cellulose is converted to glucose in a two-stage process in which cellobiose is produced from a cellulosic feedstock under the influence of *Trichoderma reesei* in the first stage, and cellobiose from the first stage is converted to glucose in the second stage by the action of purified cellobiose derived from *Aspergillus terreus*. Cellobiose from *A. terreus* is purified by contacting a crude aqueous extract of the cellobiose with an ion exchange resin and an anion exchange resin. The purified cellobiose may be immobilized on a suitable substrate. The present invention relates to a process for the production of glucose from cellulose. In one of its more specific aspects, this invention relates to a process for the conversion of cellulose to glucose wherein cellulose is converted to cellobiose under the influence of *T. reesei*, and cellobiose is converted to glucose by a purified cellobiose derived from *A. terreus*. In another of its more specific aspects, this invention relates to a process for the production of a purified enzyme having a very high activity for the production of glucose from cellobiose.

6.4.6 Chitosan-Blended Starch Composite Bioplastic

Chitin is a white, hard, inelastic, nitrogenous polysaccharide and is the major source of surface pollution in coastal areas. Chitin consists of 2-acetamido 2-deoxy-b-D-glucose through a β (1–4) linkage. Chitin is usually isolated from the exoskeletons of crustaceans and more particularly from shrimps and crabs (Austin et al., 1989; Minke & Blackwell, 1978). Squid is another important source of chitin in which it exists in the β form, which was found to be more amenable for deacetylation. It also shows higher solubility, higher reactivity, and higher affinity toward solvents and swelling than α-chitin due to much weaker intermolecular hydrogen bonding ascribable to the parallel arrangement of the main chains.

The production of chitosan from crustacean shells obtained as a food waste is economically feasible, especially if it includes the recovery of carotenoids. The shells contain a considerable amount of astaxanthin, a carotenoid that has so far not been synthesized and that is marked as a fish food additive in aquaculture. The major procedure for obtaining chitosan is based on the alkaline deacetylation of chitin with strong alkaline solution. Isolation of chitin itself from different sources is affected by the source. Generally, the raw material is crushed, washed with water or detergent, and cut into small pieces. The mineral content of the exoskeleton of the different crustaceans is not the same, and consequently different treatments may be used. The potential of chitosan is to act as a natural food preservative. The incorporation of natural antimicrobial substances in the packaging film is an alternative way to reduce the chemical substances used in food preservation (Cissé et al., 2013).

The mechanical properties of the films showed slight enhancement due to the incorporation of the enzyme system; however, the WVP, which is a key parameter to ensure the organoleptic qualities of food and the film's capability to fight against dehydration or rehydration, was not improved with this modification. The chitosan films obtained containing different amounts of the peroxidase system were used for mango packaging and coating to protect them against pathogens. Their use can help prevent the loss of mango due to fungi and bacteria during storage and transport. A comprehensive review dealing with the application of chitosan in food protection applications has been published by No et al. (2007). The application of chitosan in the food industry is mainly due to its film-forming ability and its antimicrobial activity against a wide range of food-borne filamentous fungi, yeasts, and bacteria. Three mechanisms were proposed to explain the antimicrobial mechanism of chitosan, albeit not being very exclusive. The first hypothesis attributes the antimicrobial property of chitosan to a change in cell permeability due to interactions between the positively charged chitosan molecules and the negatively charged microbial cell membranes. This interaction leads to the leakage of proteinaceous and other intracellular constituents. Other mechanisms are the interaction of diffused hydrolysis products with microbial DNA, which leads to the inhibition of the mRNA and protein synthesis. Finally, a chelation of metals and spore elements with chitosan results in depriving the cells of their essential nutrients, leading to their starvation and death. This research (No et al., 2007) discussed the effect of chitosan on several food items.

De Moura et al. (2008) proposed nanocomposites using chitosan as nanofiller in hydroxypropyl methylcellulose (HPMC) to improve mechanical and film barrier properties. Different concentrations of CS nanoparticles (NPs) were incorporated in HPMC to evaluate changes in mechanical properties, WVP, and oxygen permeability. Incorporation of chitosan NPs in the films improved tensile strength (30.7–66.9 MPa) and film barrier properties.

6.5 MICROBIAL SEMI-SYNTHETIC POLYMER PRODUCTION AND ITS APPLICATION AS BIOPLASTICS

The fermentation of sugars produces different monomers, which are converted to polymers. A new range of PLA was first manufactured by Cargill Dow Polymers (Marshall, 1998). PLA is produced from the ring open polymerization of the produced lactic acid via fermentation of sugar. The lactic acid prepared by this biotechnological method is almost exclusively l-lactic acid. PLA is completely degraded under compost conditions. PLA is not soluble in water; nevertheless, microorganisms in marine environments can degrade it. PLA is a hard material. Its hardness is similar to acrylic plastic (Vroman & Tighzert, 2009).

Any starch and even cellulosic compounds converted into sugar can be used to produce lactic acid by fermenting with biotechnically engineered bacterial strains, so the produced lactic acid is further converted chemically and purified and stored as PLA bioplastic material.

6.5.1 PLA: Another Biodegradable Polymer

PLA has been explored extensively. Lactic acid, which is the main precursor in PLA synthesis, is produced in large amounts by the bacterial fermentation of the hexoses (carbon source) using lactic acid bacteria. PLA is used in biomedical applications such as implants, sutures, drug delivery, tissue engineering, and stent development due to its biocompatibility properties. PLA can be processed using various techniques and is commercially available in the market in different grades. It is reasonably priced and target only the biomedical market.

Lactic acid is produced by the bacterial fermentation of carbohydrates. The large-scale production of lactic acid has been carried out using a range of feedstocks including corn, sugar beet, molasses, whey, spent grain, sugarcane, and wastepaper as a cellulosic feedstock. Lactic acid contains an asymmetric carbon atom and hence two different configurations, the l and D isomers. Both the isomers can be produced using bacterial systems. Fermentation processes involved in the lactic acid production differ based on the kind of bacteria used. Two different methods used in lactic acid production include (1) the homo-fermentative and (2) the hetero-fermentative method. The homo-fermentative method involves the conversion of each molecule of glucose into two molecules of lactic acid. This method is prevalent in most industrial processes due to high yields of lactic acid. The hetero-fermentative method is a type of fermentation in which the lactic acid yield is surpassed by the production of significant amounts of byproducts such as ethanol, acetic acid, and carbon dioxide. Hence, its use is not widespread due to the low yields of lactic acid. Maximum yields have been achieved by using glucose feedstock as the main carbon source. *Lactobacilli* species are the most commonly used microorganisms for the production of lactic acid. The most commonly used lactic acid bacteria include *Lactobacillus rhamnosus*, *L. delbrueckii*, *L. amylophilus*, *L. bavaricus*, and *L. casei*. Lactic acid can be produced by various other bacteria and fungi, as well as yeast. The production media contains 5% sugar and a nitrogen-containing nutrient. Both batch and continuous processes can be used for lactic acid production. Various parameters such as pH, temperature, and impeller speed are considered important during lactic acid fermentation. About 90–99% of lactic acid conversion occurs within two days of fermentation.

Continuous fermentation produces higher yield compared to batch fermentation. Lactic acid fermentations have also been carried out by repeated batch production of the immobilized lactic acid bacteria. After the fermentation is complete, lactic acid has to be separated from the fermentation broth and purified to be used for the polymerization process. A traditional method to obtain highly pure lactic acid involves neutralization with a base accompanied by filtration, concentration, and acidification.

A liquid/liquid extraction process is one method used for the recovery of lactic acid. Another process for lactic acid recovery is based on the esterification with alcohols accompanied by distillation and hydrolysis. Various separation techniques such as ultrafiltration, nanofiltration, electrodialysis, and ion exchange can be used in combination with the aforementioned recovery processes for the purification of lactic acid (Basnett & Roy, 2010). Reduction in the cost of production resulting in a competitive price of the biodegradable polymers will broaden their range of application. The key properties of these biopolymers such as biodegradability and biocompatibility have made it feasible to envisage the extensive use of these biopolymers in the biomedical field. Their role in cardiac stent development is significant. It is impossible to predict the future with certainty, but the data revealed from the studies so far have been very promising. Hence, biopolymers have emerged as one of the most promising candidates for use in coronary stent development.

6.5.2 Polyhydroxyalkanoate

Bio-based materials such as polynucleotides, polyamides, polysaccharides, polyoxoesters, polythioesters, polyanhydrides, polyisoprenoids, and polyphenols are potential candidates for the substitution of synthetic plastics. Among these, PHA, which belongs to the group of polyoxoesters, has received intensive attention because it possesses biodegradable thermoplastic properties. PHA is synthesized by bacteria under unbalanced growth conditions. Some bacteria have been reported capable to produce PHA at as much as 90% (w/w) of dry cells during depletion of essential nutrients such as nitrogen, phosphorus, or magnesium. PHA serves as a storage compound of carbon, an energy source, and also as a sink for reducing equivalents for some microorganisms. PHA acts as an ideal storage compound due to its insolubility inside bacterial cytoplasm, which exerts negligible increase in osmotic pressure. It was shown that the bacteria containing PHA storage materials would be able to survive during a starvation period compared to those without PHA as this energy-reserve material slows down the cell autolysis and subsequently mortality.

6.5.2.1 Biosynthesis of PHA

PHA is produced using natural isolates and recombinant bacteria from renewable carbon sources. Among the more than 250 different natural PHA producers, only a few bacteria have been employed for the biosynthesis of PHA. These include *Alcaligenes latus*, *Bacillus megaterium*, *Cupriavidus necator*, and *Pseudomonas oleovorans*, which are capable of utilizing various carbon sources including plant oils or wastes to produce PHA. *C. necator* has been the most extensively studied and commonly used bacterium for PHA production. In the 1980s, a glucose-utilizing mutant of *C. necator* was employed by Imperial Chemical Industries (UK) for the industrial production of poly (3-hydroxybutyrate-co-3-hydroxyvalerate) [P(3HB-co-3HV)], which was sold under the trade name of Biopol. However, there are some limitations associated with the use of natural PHA producers. Natural PHA-producing bacteria usually harbor native machinery for polymer degradation and are often hard to lyse, making the recovery of PHA difficult. For industrial production of PHA, it is desirable to develop strains that can reach high final cell density in a relatively short period of time and produce high PHA content from simple, inexpensive substrates. Thus, genetic engineering serves as a powerful tool in the development of strains that can efficiently produce PHA from inexpensive renewable resources. Genetically engineered bacteria such as recombinant strains of *Escherichia coli*, which produce PHA containing 3HB, 3HHx, and 3HO monomers from soybean oil, and a recombinant strain of *C. necator* harboring the *Aeromonas caviae* PHA synthase gene, which produces P (3HB-co-3HHx) from palm oil, have been developed.

Microorganisms that produce PHA can be classified into two types. The first group of bacteria requires limitation of essential nutrients such as nitrogen and oxygen, and the presence of an excess carbon source for the efficient synthesis of PHA. The representative bacteria belonging to this group include *C. necator*, *Protomonas extorquens*, and *Protomonas oleovorans*. On the other hand, the second group of bacteria does not require nutrient limitation for PHA synthesis and can accumulate PHA during its exponential growth phase. Some of the bacteria included in this group are *A. latus*, a mutant strain of *Azotobacter vinelandii*, and recombinant *E. coli* harboring the PHA biosynthetic operon of *C. necator*. Therefore, the simplest approach is to choose renewable, inexpensive, and readily available carbon substrates that could support both the microbial growth and PHA production efficiently (Chee et al., 2010).

6.5.3 Poly (Hydroxybutyrate)

Polyester was produced biotechnologically in 1925; PHB was attentively studied as a biodegradable polyester. PHB is highly crystalline with crystallinity above 50%. Its melting temperature is 180°C. The pure homopolymer is a brittle material. Its glass transition temperature is approximately 55°C. It has some mechanical properties comparable to synthetic degradable polyesters such as PLA. During storage time at room temperature, a secondary crystallization of the amorphous phase occurs. As a result, stress and elongation modulus increase ($E = 1.7$ GPa), while the polymer becomes more brittle and harder. Elongation at break is then much lower (10%). Compared to conventional plastics, it suffers from a narrow processability window (Vroman & Tighzert, 2009).

PHB is susceptible to thermal degradation at temperatures in the region of the melting point. To make the process easier, PHB can be plasticized with citrate ester. PHB is degraded by numerous microorganisms (bacteria, fungi, and algae) in various environments. The hydrolytic degradation yields 3-hydroxy butyric acid, a normal constituent of blood, nevertheless with a relatively low rate. Different monomers have been grafted onto PHB to prepare biodegradable polymers to be used for wastewater treatments. The grafted monomers were either hydrophilic, such as acrylic acid or sodium-p-styrene sulphonate, or hydrophobic, such as styrene or methyl acrylate. The degree of grafting was different according to the monomers, increasing in the following order: styrene, sodium-p-styrene sulfonate, methyl acrylate, and acrylic acid. Multicomponent polymeric systems containing PHB have been obtained in two ways. The first is by radical polymerization of an acrylic polymer in the presence of PHB. The second is by melt mixing PCL with PHB. Peroxide is used in both processes to form intergrafted species responsible for compatibilization. These methods have been considered as reactive blending. It should be noted that apart from the bacterial synthetic method, other chemical ways have been developed for the production of PHB. The ring opening polymerization of β-butyrolactone yields PHB.

PHB serves as an energy storage molecule and accumulates intracellularly as storage granules in microbes. Bacterial samples known for bioplastic producers are *Ralstonia*, *Bacillus*, and *Pseudomonas*. These species were identified by 16S rRNA sequencing. Conditions were extensively optimized by varying the temperature, carbon, nitrogen, and substrate sources for maximal PHB production. Accumulation of PHB in these strains was confirmed by microscopic staining. The phenotypic profiles of these species were subsequently studied using phenotype microarray panels, which allowed the testing of the effect of more than 90 different carbon, nitrogen, sulfur, and phosphorus sources as well as pH on the growth characteristics of these strains (Singh & Parmar, 2011).

6.5.4 Polycaprolactone

Poly-ϵ-caprolactone is a relatively cheap cyclic monomer. A semi-crystalline linear polymer is obtained from ring opening polymerization of ϵ-caprolactone in the presence of tin octoate catalyst (Mochizuki & Hirami, 1997). PCL is soluble in a wide range of solvents. Its glass transition temperature is low, around –60°C, and its melting point is 60–65°C. PCL is a semi-rigid material at room temperature, has a modulus in the range of low-density polyethylene and high-density polyethylene, a low tensile strength of 23 MPa, and a high elongation to break (more than 700%). Thanks to its low Tg, PCL is often used as a compatibilizer or as a soft block in polyurethane formulations. To improve the degradation rate, several copolymers with lactide or glycoside have been prepared (Nair & Laurencin, 2007). PCL is commercially available under the trade names CAPA® (Solvay, Belgium), Tone® (Union Carbide, USA), or Celgreen® (Daicel, Japan) and many others. Possible applications in packaging have been investigated.

6.6 NANOCOMPOSITES FOR ACTIVE FOOD PACKAGING MATERIAL

Silver NPs have been synthesized using starch as a reducing agent (Ayala Valencia et al., 2013). The design and development of nanostructured materials with metallic NPs, such as silver NPs (Ag-NPs), is highly useful to minimize the growth of contaminants by microorganisms. Therefore, there is a rising interest in developing bio-based polymers with antimicrobial activity. SAg-NPs are known to have inhibitory and antimicrobial properties and low toxicity, receiving special attention from the industry. Ag-NPs can also be employed as absorbent pads in food packaging to absorb moisture and fluids exuded from meat and fish, keeping the products looking fresh and creating an aesthetically attractive packaging.

6.7 BIODEGRADATION OF BIOPLASTICS

A large variety of wheat gluten-based bioplastics, which were plasticized with glycerol, were subjected to biodegradation. The biodegradability tests were performed in a liquid medium (modified Sturm test) and in farmland soil. All gluten materials were fully degraded after 36 days in aerobic fermentation and within 50 days in farmland soil. No significant differences were observed between the samples. The mineralization half-life time of 3.8 days in the modified Sturm test situated gluten materials among the fast-degrading polymers. The tests of microbial inhibition experiments revealed no toxic effects of the modified gluten or of its metabolites. Thus, the protein bulk of wheat gluten materials is nontoxic and fully biodegradable, whatever the technological process applied (Domenek et al., 2004).

Biodegradability tests are of two types: One is screening tests with enzymatic and aquatic versions of aerobic and anaerobic tests on the selected samples. The second one is the real-life test of soil burial, in which composting field testing applies. Bioplastics are degraded by many kinds of microorganisms in nature, and the bioplastics are converted into water and carbon dioxide by microbial metabolism. Nonbiodegradable petrochemical plastics such as PA66, polypropylene, and polyethylene remain in the environment for a long time because the plastics are resistant to the invasion of microorganisms. To analyze the biodegradability of each plastic in nature, three kinds of commercial bioplastics (PBS, PBS-starch, and PLA) and a nonbiodegradable petrochemical plastic (PA66) were buried in an agricultural soil (initial bacterial biomass: 1 × 109 cells/g soil), and the weight reductions of plastics were analyzed after 28 days, and samples were tested for their biodegradability. The powdered bioplastics were added in soil, and the rate of decrease in soil TC was measured after 28 days. The degradation ratios of PBS-starch, PBS, and PLA after 28 days were 24.4%, 16.8%, and 13.8%, respectively. These bioplastics were degraded faster than the commercial bioplastics. The enhancement of biodegradability of powdered bioplastics in the soil seemed to be caused by the increase in the surface area. The relative biodegradability of each powdered bioplastic was similar to those of the commercial bioplastics.

Therefore, for PLA degradation, microbial attack at a high temperature (such as by thermophilic bacteria under a composting process) might be needed. For the treatment of waste bioplastics in the soil, the biodegradability of each bioplastic should be considered. The degradation rates of bioplastics were proportionate to the bacterial biomass in the soil. Many kinds of bioplastic-degrading bacteria might exist in the soil environments, and a higher number of bioplastic-degrading bacteria seem to exist in soil rich in total bacterial biomass. Since fertile soil is rich in bacterial biomass, bioplastics seemed to be efficiently degraded in fertile soil environments. When bioplastics were buried in soils for 28 days and 2 years, bacterial biomass and diversity were not influenced by the degradation of bioplastics. In the case of using powdered bioplastics, the bacterial biomass did not change either. However, the bacterial biomass decreased when PA66 was buried in soil for two years. The presence of PA66 in the soil might lead to the inhibition of aeration for the well-functioning of microorganisms. Utilization of bioplastics in agricultural fields was expected to increase in the future; thus the influence of bioplastic degradation on material circulation in the agricultural soil should be understood (Adhikari et al., 2016). Nitrogen is an essential nutrient for plant growth; therefore, nitrogen circulation is one of the most important activities for both conventional and organic agriculture. In this study, nitrogen circulation activity in the bioplastic-buried soil was measured, and a negative effect of PLA degradation on the activity was observed. In addition, the fungal biomass was not increased by the degradation of bioplastics in this experiment; however, studies on the effects of large amounts of buried bioplastics in agricultural fields on the growth of phytopathogens would be necessary for the safe usage of bioplastics. Although the degradation of bioplastics in this study did not affect the bacterial diversity in the soil environment, the degradation rate in the soil was low. New bioplastics having high degradation rates in soil, which are safer and greener for the environmental microorganisms, should be developed in the near future (De Wolf & Isard, 2007).

6.7.1 Biodegradation of Plant-Based Plastics

Starch is composed of two distinct macromolecules: (1) amylose, a linear α-D-glucopyranosyl unit linked with α-1,4 bonds, and (2) amylopectin, a highly branched fraction of α-1,4-linked glucan chains connected by α-1,6 linkages, and it is considered as a major energy reserve for a large variety of green plants (Miao et al., 2015). Starch-based bioplastic is one of the most economic, abundant, and renewable biomaterials widely used for biomedical and disposal purposes. Chemically or physically modified starch-based materials are frequently studied to understand degradation kinetics and drug delivery. In vitro enzymatic degradation by fungal amylase is used to hydrolyze starch films with different molecular, crystalline, and granular types in order to understand the effect of different structures on enzymatic degradation (Li et al., 2015). Degradation of cassava starch-based composite films is investigated using the indoor soil burial method. Increased water sorption promotes the entry of soil microorganisms, and the starch films are utilized as a source of energy for their growth. The loss of matrix components of the films is monitored by the reduction in weight, and the morphology is studied through scanning electron microscopy.

6.8 BIODEGRADATION OF GELATIN

Gelatin is derived from the fibrous insoluble protein called collagen by chemical denaturation and is comprised of three polypeptide chains having a repeating Gly–X–Y sequence (glycine–proline–hydroxyproline) arranged in a triple helix, stabilized through hydrogen and hydrophobic bonds. Changes in pH and temperature or the presence of denaturing chemicals can cause a disruption of the gelatin structure arising from the loss of the triple helix conformation. The processing of gelatin needs to be well controlled to achieve high gelling strength, avoiding the extensive degradation of the peptide structure. The degradiation of gelatin and its composite with MMT by lysozyme and proteinase K has a much faster rate in CPX–gel (ciprofloxacin loaded) as compared to CPX–MMT–gel, or MMT–gel, mainly due to their 3D structures. The CPX–gel degrades rapidly because of the large number of hydrophilic amino and carboxyl groups and the physical structure of the CPX–gel scaffold has a higher porosity and leaner pore walls. Thus, the gelation and biodegradation are the two key factors that affect the cellular behavior and tissue regeneration and ultimately control the in vivo drug delivery.

6.8.1 Biodegradation of Alginate

Alginate, a water-soluble linear polymer obtained from brown algae, is composed of (1-4)-β-D-mannuronic acid (M) and (1-4)-α-L-guluronic acid (G) units in the form of homopolymeric (MM- or GG-blocks) and heteropolymeric sequences (MG- or GM-blocks). The degradation kinetics of alginate are controlled by varying the molecular weight, chemical structure, and crosslinking. The modulation of the degradation rate of alginate gels is done with an oxidation reaction using uronic acid residues by inducing hydrolytically labile acetal-like groups within the alginates. The oxidation of alginate leads to the cleavage of the carbon–carbon bond of the *cis*-diol groups. However, the oxidation makes the gel more malleable, leading to an inverse relation between degradation rate and gel stiffness.

6.9 BIODEGRADATION OF CHITOSON

Chitosan is one of the most important biodegradable and biocompatible polymers, made up of β-(1,4) linked 2-deoxy-2-amino-D-glucopyranose and partially of β-(1,4) linked 2-deoxy-2-acetamido-D-glucopyranose, and is obtained by the alkaline deacetylation of chitin, which is the major component of the exoskeleton in crustaceans. Chitosan is hydrolyzed (chitosanolysis) by specific enzymes (chitinase/chitosanase) and nonspecific enzymes (cellulases, pectinases, papains, lipases). Research isolated the chitinase-producing actinomycete *Streptomyces rimosus* for the biodegradation of chitinous substances. The lysozyme-loaded chitosan films exhibited a ~21% mass loss after 4 weeks of implantation in rats compared to the control that suffered only a 7% mass loss. The degradation products of monomers and oligomers of glucosamine and *N*-acetyl-glucosamine have been detected using capillary electrophoresis–mass spectroscopy.

Guar gum is a polygalactomannan obtained from the seeds of *Cyamopsis tetragonalobus*, found in the northwestern region of India. Guar gum (GG) is a nonionic, water soluble, and biodegradable heteropolysaccharide made up of a β-(1 → 4) D-mannose backbone randomly linked with α-(1 → 6) D-galactose units. The enzymatic hydrolysis of guar gum significantly affects its physico-chemical and rheological characteristics, which become useful for its incorporation in food products as dietary fiber.

Agar is a mixture of heterogeneous galactans, mainly composed of 3,6-anhydro-L-galactoses (or L-galactose-6-sulfates), D-galactoses, and L-galac toses alternately linked by β-(1,4) and α-(1,3) linkages. Many microorganisms that can hydrolyze and metabolize agar as a carbon and energy source have been identified in seawater and marine sediments. Agarolytic microorganisms such as *Saccharophagus degradans* and *Streptomyces coelicolor* commonly produce α-agarase, β-agarase, and β-porphyranase enzymes, which catalyze the hydrolysis of agar. During the photodegradation process, temperature and humidity variations promote a decrease in agar's mechanical properties caused by a reduction in molecular size and a decrease in the number of sulfate groups. These variations alter agar's crystallinity and lead to the formation of microfractures and embrittlement and promote microbial attack (Kumar & Maiti, 2016).

6.10 FOOD PACKAGING COMPOSITES DEGRADATION

Currently, nonbiodegradable plastics are commercially used for the packaging of beverages, biscuits, food, and medicines and in agricultural sectors and are being disposed of without recycling. Therefore, substantial research efforts have been focused on the use of biodegradable plastics to reduce the environmental pollution. PLA has been approved for its intended use in food packaging by the Food and Drug Administration (FDA). PLA-based packaging products for items like water, juice, and yogurt are widely used in the supermarkets of Europe and North America and meet the food standards, maintain aroma and freshness after processing, and are also resistant to microbial stains. Therefore, PLA is gradually moving toward becoming a "green" food packaging material for goods under different trade names such as Biota, Noble, Dannon, and so on (Ahmed & Varshney, 2011). Kale et al. (2006) showed the biodegradation of a PLA bottle in compost media after 30 days of treatment. Danone is the first company in Europe to replace packaging made from polystyrene with PLA for yogurt products. Food-borne diseases have become an increasingly relevant health and safety concern in the food industry. In order to inhibit the growth of unwanted microbes on foods, antimicrobial packaging offers a means to potentially extend the shelf life of perishable foods to maintain quality. Incorporating antimicrobial substances like cinnamaldehyde in poly(lactic acid)/poly (tri-methylene carbonate) (PLA/PTMC) films is to find out better ways to extend the shelf life of foods. Biocompatible and biodegradable ϵ-poly-L-lysine (EPL)/ PCL copolymers are made to self-assemble into monodispersed NPs, which show a broad spectrum of antibacterial activity against *E. coli*, *Staphylococcus aureus*, and *Bacillus subtilis*.

The self-assembled NPs induce changes in the bacterial osmotic pressure, thereby resulting in cell invagination to form holes and create a leakage of cytoplasm. The organically modified MMT (Cloisite 30B) exhibited antimicrobial activity against gram-positive bacteria (*Listeria monocytogenes* and *S. aureus*), presumably due to the quaternary ammonium group present in the modified organoclay, while the natural MMT did not show any such antimicrobial activity. Antimicrobial PCL-based bionanocomposites using quaternary ammonium modified montmorillonites (OMMTs) have been prepared for packaging.

The performance of the composite films against *S. aureus* (gram positive) and *E. coli* (gram negative) has been evaluated from the number density of bacteria in the sample. When 7.5 log cells of *E. coli* O157:H7 were inoculated in orange juice, a significant reduction of 3.5 log units in the *E. coli* cell population was observed after 72 hours when PLA/nisin was used, whereas the control had decreased to about 6 log units. This suggests that nisin incorporation into PLA films was an effective inhibitor of *E. coli* O157:H7 in orange juice at a ratio of 2.08 mL of liquid per square centimeter of exposed polymer surface. An agar diffusion test was investigated to monitor the antimicrobial activity of PLA/nisin films for solid food packaging. The antimicrobial activity of the film was expressed in terms of the inhibition zone. The formation of an inhibition zone around the PLA/nisin film showed its potential for antimicrobial packaging in food applications (Kumar & Maiti, 2016).

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7 Packaging Design and Machineries

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Packaging design for food products plays a vital role in the protection of food products and also gives sensory appeal to consumers. Packaging design for food items is a crucial component that combines technical functionality and consumer-oriented aesthetics. The design process entails making decisions that not only ensure the product's safety, shelf life, and integrity but also meet the consumer's emotional and functional expectations.

- *Functional aspects of packaging design*: These include considerations for keeping the product fresh and uncontaminated until it reaches the consumer. Important design characteristics in this category include:
  - *Barrier properties*: These include resistance to oxygen, moisture, and light, depending on the food type.
  - *Structural strength*: Food must be protected during transportation and storage.
  - *Tamper evidence*: Security seals demonstrate product integrity.
  - *Ease of use*: Features include resealability, portioning, and quick dispensing.
- *Visual and aesthetic design*: Packaging must also attract buyers and communicate brand values. This includes:
  - *Color schemes and typography*: Aligning with the product theme and brand identity
  - *Imagery and graphics*: Creating visual appeal and effectively conveying product information
  - *Shape and ergonomics*: Ensuring ease of handling and storage while standing out on shelves
- *Designing for sustainability*: To lessen the environmental effect, modern packaging design uses more ecofriendly materials and minimalist designs. Many packaging techniques now incorporate biodegradable films, recyclable polymers, and reduced material utilization.
- *Smart and active packaging trends*: Smart packaging (e.g., QR codes, freshness indicators) and active packaging (e.g., oxygen scavengers, antimicrobial layers) are recent inventions that aim to improve food quality and consumer engagement.

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There are two main concepts that have to be taken into consideration in designing a package for food products:

1. Packaging design that can cover all the technical facets to prevent the spoilage of food
2. Packaging design with aesthetics for customer satisfaction and convenience

The trade-off in packaging between preserving the food and presenting it attractively is about interim compatibility problems, possible packaging materials, the package's form, and also the food's aesthetic needs. The approach by which the intended objectives are achieved fall under three categories: hype, work of genius, and a source of strength, each of which requires its own strategy. So, the widespread image management approach will be involved with

- Advertising
- Promotion
- Public relations
- Sales
- Packaging

Hence, packaging requires study for the development of different types of packages. Both structure and graphics are important tools of the marketing mix. They assist in positioning the product in the supermarket, its success, and eventually, on many occasions, in evaluating the product after purchase.

Packaging of chilled material is the most significant element in merchandising today. Fifty years ago, sales of mass price products depended more on questions about their well-known product status than they do today, and the differences in how things stack up between disparate brands of the same comparable products were greater. Consumers could taste and evaluate the products economically, and they would give more for the product with more quality.

Today, with all the external developments in areas of food technology that continue to grow, the nature of the food industry is different. Therefore, the emergence of technology has decreases the differences between mass price products, which no longer go straight to the consumer. The melee for customer preference currently hinges not just practically on quality and price but also on other features of the marketing, comprising advertisement, promotion, and packaging. When price and quality are balanced, the products appear comparable, and the key factors influencing their acceptance turn out to be other, often contradictory, features.

Products on supermarket shelves must sell themselves with the emergence of self-service merchandising. The embodiment of the advertisement to consumers largely influences their choices of purchase; it is generally recognized that at the moment of decision when the consumer reaches for a particular product in the supermarket, it is the packaging that regularly tips the scale.

The nature of food packaging, as rightly pointed out, is greater than providing security to the food or making it easier to use. It is a lot more than an attention-getting device; it is the art of technology developed using engineering machinery.

A package with profound communication can describe and incorporate the information and ideas (through images) that the manufacturer wishes to instill in the consumer's mind to position it as a unique product and outstrip the competing products.

The novel concepts of packaging are based on the idea that what certainly interests the customer is not the brand, the ingredients, or even the output product itself. Essentially, regular shoppers are caught in the benefits they thinks they will gain from the product. Thus, a package of neonatal food might be of greater interest to the potential consumer – a mom who only thinks of her child's healthier life – if the package is laid out with an image of a healthy baby. This will drive the consumer to buy the product rather than the ingredients the food is made of or the bowl of food it supplies. Finding the right facets of consumer needs and being alert to current trends for benefiting consumers with satisfying products in a convenient form, when and where they need them, are core features of marketing mass-consumption products. A study on package design is adopted as a professional vehicle for implementing this strategy.

Old packaging methods, as a communication expert describes, have developed from contemplation on brand, product, and clarity of the regular shoppers regarding products, which are three bodily fundamental features and likewise components of executive packaging design, or at least the metaphysics that goes into producing the packaging design. In the simplest sense, the three phrases disclose who sells what to whom. Much of the twist in designing a package is in the sophistication with which these components are elaborated and utilized. If we catch a glimpse of several new packages, physically present in the convenience store, we may well encounter that one package focuses on acceptance of branded products, another on benefiting consumers, and another on the ingredients of the product. The relative weight of these features in the completion of a particular package is, or should be, the result of a careful experiment of the market position and an undeniable definition of image management goals. Even so, the source of any valuable marketing strategy should be about consumer relations; the specially designed package from the study may not depict consumer benefits and can be a mask over those benefits. The idea of benefit can be managed by imparting it to the consumers through various other methods, such as well-known television advertising, so the marketing team may require that the package should emulate the brand. Any package should be created and analyzed in the framework of group marketing. If it is not, a package that looks useful may not be of any use as an appealing product salesperson.

7.1 MEETING CUSTOMER SATISFACTION

First, we have to understand that the customer and the consumer are not the same every time. A manufacturer uses the package to hold the product that it wants to sell to a shopper, who uses the product.

Packaging is a practice that is omnipresent throughout the world and used by manufacturers and industries to prepare the product for sale to final consumers. Hence, it is worthwhile to classify the users of the final packaged products. There are ultimately four kinds of users of packaging:

1. Makers and packers of products
2. Distributors, carriers, and warehousers
3. Retailers of all kinds of products
4. Consumers

The important customer requirements depend on the product, yet there are evident points that should be expected for every product and end user. Every end user expects a quality product to be delivered in a proper package for retention of quality for a stipulated time, at a price that is economical in relation to convenient alternatives. In every instance, it is the only product that the customer wants; the packaging, with the vital exceptions of products such as cosmetics and gifts, is an ancillary kind of transaction. Moreover, savvy customers will understand that the packaging intends to be efficient; if it appears too elaborate, it reflects and gives a bad intuition that the price of the product has been unnecessarily hiked by the packaging, and this will have a negative effect on sales. All packages must be attractive and legal, easy to open and use, and involve only a few problems in their disposal.

However, the manifold factors influencing regular shopper requirements will vary according to their ability, lifestyle, income, and socioeconomic level. The location of their residence will also affect their ideas about the appropriateness of a package for any product. They will have diverse color preferences and associations; they may prefer different sizes and quantities, and customers may need proof considerations, such as tamper evidence, child resistance, or built-in antipilfering devices.

Another pertinent way of understanding customer needs is by studying trends in distinct fields. A trend is understood in this sense as a convincing movement in a distinct direction with long-term potential; if there is a brief potential only, it is not a trend but mere novelty and will not last.

Packaging graphics design provides the file (for gift and display) and also information about directions for handling (warnings, shelf career, batch zip code, tape, and computerized information conditions in the store, transit, and handling). Printing is the core means of fulfilling these functions; materials may be preprinted, printed, or over-printed across the product packaging operation. So, only necessary information has to be used in the packaging prints.

7.2 PACKAGING EQUIPMENT

Packaging takes on many forms and functions depending on the type and features of the food ingredients. The packaging type used is determined by various aspects, including the product's nature (solid, liquid, granular, or viscous), shelf-life requirements, market value, and target consumer category. A variety of specialized food packaging machines are used to handle and package food components efficiently. These machines are designed to meet the specific needs of various food products, such as vacuum packing for perishables, bottling for liquids, and blister packaging for ready-to-eat goods.

In today's advanced food business, automatic packaging systems are commonplace. These systems are intended to fill, seal, and label items aseptically and effectively, requiring little human intervention. They use computerized controls and sensors to regulate the packing process in a continuous flow, ensuring consistency, hygiene, and speed throughout the manufacturing line. Such automation not only increases productivity but also contributes to food safety requirements by lowering the risk of contamination.

Furthermore, many current packaging machines have smart technologies such as real-time monitoring, fault detection, and digital traceability capabilities. These enhancements help to ensure compliance with food safety regulations while also increasing operational transparency.

7.2.1 Food Vacuum Packaging Machine

Vacuum packaging is a widely used technology that includes removing air – particularly oxygen –from the product before sealing. This is performed by employing specialized vacuum packing equipment that uses controlled suction to extract air and enclose the food product in an airtight container. By removing oxygen, vacuum packaging dramatically reduces the growth of aerobic microorganisms like bacteria and mold, which are primarily responsible for food degradation. This procedure aids in the preservation of food products' freshness, flavor, and nutritional content over lengthy periods of time. The lack of air also inhibits oxidation, which can result in coloring, rancidity in lipids, and degradation of sensitive nutrients. As a result, vacuum packaging is ideal for perishable commodities such as meats, cheeses, processed foods, and ready-made meals.

Vacuum-packaged foods are perfect for frozen storage and cold display units in retail locations, allowing firms to present their products in an eye-catching and sanitary manner. This strategy promotes longer shelf life, less food waste, and more effective inventory management, making it a key technology in modern food packaging systems.

7.2.2 Biscuit Packing Machines

Biscuit packing machines are a type of food packaging equipment built specifically for fragile, dry, and crispy items such as biscuits and cookies. These devices ensure that the biscuits are packed effectively and without breaking while preserving their texture, freshness, and hygiene.

Modern biscuit packaging systems often include electronic digital humidity and temperature controllers, which are critical for ensuring the optimal packing environment. These controllers help regulate the inside conditions of the packaging zone, ensuring that moisture levels are kept low to prevent sogginess, and temperature control helps maintain product crispness and hardness.

One of these machines' primary characteristics is the ability to monitor packing operations in real time. With the use of sensors and digital interfaces, the packaging process is automatically tracked and recorded, offering insights into production performance. This enables food processing firms to:

- Monitor daily output correctly
- Detect errors or irregularities in the packaging line
- Increase process efficiency and reduce waste
- Ensure consistency in product quality

Furthermore, many biscuit packaging machines allow high-speed, multilane packing and work with a variety of wrapping materials, including pillow packs, flow wraps, and heat-sealed packs. Their automation and precision make them essential components in large-scale biscuit manufacturing plants.

7.2.3 Bundling Food Packaging Machinery

Bundling food packaging machinery, also known as a banding machine, is widely used by food suppliers to combine many packed items into a single, manageable package. This type of equipment is very beneficial for secondary packing, when the purpose is to combine goods rather than package them individually.

Bundling machines are great for products that have already been individually packaged, such as candies, snack bars, sausages, or hot dogs, but that must be combined into multipacks for commercial distribution. The machine wraps a plastic film, heat-shrink wrap, or banding material around the grouped pieces, securing them as one unit.

Bundling packaging machinery has the following key advantages:

- Enhanced convenience for handling and shelf-stocking
- Increased marketing opportunity, such as discounts like "buy one, get one free"
- Improved product organization for consumers and retailers
- Reduced packaging waste, especially when contrasted with individual outer wrapping for each item

These devices are capable of operating at high speeds, allowing for simple integration into automated food manufacturing lines. Bundling also helps to save costs by streamlining logistics and lowering packing materials while preserving the product's visual appeal and brand presentation.

7.2.4 Bagging Machines

Bagging machines are widely employed in the food processing industry all over the world, particularly in nations with large-scale production, like China. These machines are intended to efficiently pack food products into bags, sacks, or pouches, making them appropriate for both retail and bulk packaging. Bagging equipment is ideal for granular, powdered, and dry food goods like sugar, flour, salt, rice, cereals, legumes, and spices. Depending on the product and production volume, bagging machines can handle a wide range of materials, from little consumer sachets to massive industrial sacks for wholesale distribution. Key features include the following:

- Automated weighing systems for accurate portioning
- Sealing mechanisms that include heat sealing, stitching, and zipper locking
- Dust control methods to ensure hygiene during the packing process
- Adjustable fill volumes to fit various bag sizes

These devices improve efficiency, lower labor costs, and reduce material waste, making them indispensable in high-volume food manufacturing environments.

Advanced models may additionally feature programmable logic controller (PLC) technologies to improve control and real-time monitoring of activities.

Bagging machines are frequently integrated into larger packing lines, operating in tandem with conveyors, labeling machines, and palletizers to guarantee a smooth and automated process from manufacturing to delivery.

7.2.5 Accumulation Machinery

Accumulation machinery is an essential component in automated food and beverage packaging lines. It is typically used in conjunction with filling and capping machines to ensure a smooth and continuous flow of containers, such as bottles or jars, throughout the production process.

The primary function of accumulation equipment is to temporarily hold and align containers before or after key operations like filling, capping, or labeling. This helps prevent congestion or stoppages on the production line and allows other machines to continue running even if there is a brief delay or pause in the downstream process.

Accumulation systems are especially common in carbonated beverage plants, bottled water facilities, and other liquid food production units, where maintaining speed and hygiene is crucial. These machines are available in different configurations, such as:

- Rotary accumulation tables for circular collection and discharge
- Inline accumulation conveyors for space-saving and high-speed operations
- Buffer zones designed to handle surges in production volume

Benefits of accumulation machinery include:

- Improved line efficiency and synchronization
- Reduced downtime due to bottlenecks
- Gentle handling of fragile containers
- Increased productivity in high-speed lines

Accumulation equipment plays a supporting yet vital role in modern food packaging systems, ensuring that the entire process remains streamlined and uninterrupted.

7.3 PACKAGING LINE REQUIREMENTS

This stipulation could have a subheading of "machinability and the furnishing properties influencing it." Until the requirements as to the package to be utilized are understood, work on the packaging horizon engineering cannot start. However, once this has been decided, the choice lies among the various appliance types accessible for producing the package structure. It should be established that the apparatus, the product, and the package are part of a single integrated system. If the equipment is abundantly made, it is the most decisive part of the system; meanwhile, both the product and the packaging are probably more variable. Hence, the machinery is intended to be adapted to the variations (in dimensions and in actual properties) that will inevitably materialize in both product and package (Robertson, 2010).

The manufacturers of the machines at hand are not always in a situation to comprehend very closely the variability of the distinctive products to be packed, and while they will be interested in the variability of general package types, they commit not to having the details of the distinct packaging specified. Information on both of these subjects should be loaded by the product maker and the packaging supplier (preferably in written specifications). The equipment function is broken down into an array of subsystems. Under this situation, although the subsystems encroach upon each other, it becomes easier to analyze the possibilities. The subsystems are:

1. The product handling system – filling, weighing, loading, and so on
2. The packaging handling system – unreeling, erecting, end of the line, and so on
3. The integral machine framework
4. The capacity transmission
5. The approach system
6. The timing system
7. The lubrication system

Once identified, each subsystem is analyzed for both action and effectiveness. The timing program is well known to be of primary importance, and in many machines, there is an oblige shaft that makes one revolution for each package produced.

A significant factor in the trouble-free every-day running of machines is that the materials have the correct property profile. This is the criterion utilized to interpret the limits of each salient property of the materials with which the equipment operates successfully. The various operations performed on packaging materials take into consideration the diverse properties involved. As a concrete illustration, the unreeling of a plastic sheet led to static electricity generated at the bottom of the blocking during the turns on the reel; it was not affected much by the stiffness or the frictional properties of the material. Both of these properties are, anyway, engrossed in the bending and sliding movements as the material passes through a machine to be wrapped around a product or be formed directed towards a pouch (Piringer & Baner, 2008).

7.3.1 Bottling

The term "bottling," like its accomplice "packaging," means little unless related to a product, for it is clear that the problems specific to bottling hair cream, for example, are different from those associated with bottling milk or instant coffee. At a well-known presage, bottling lines handled forlorn glass bottles, whereas today the container is not one of glass, but one of a diversity of plastics of all of shapes and durabilities, as diversified as marketing demand requires. Different-shaped containers require handling in diverse ways, and their content is filled according to their characteristics. A bottling line is a group of independent machines connected by a conveyor belt or a collection of intensely sophisticated, fully independent units overall integrated by a synchronized control arrangement. Semiautomatic lines rely to some extent on the quickness of machine operators for their maximum output, and in a job, speeds on these range from 30 to 60 units a minute. Above this speed, a fully automated bottling line is necessary, but while changing from semiautomatic to fully automatic equipment, there are points to consider, the most important of which is the container (Robertson, 2010).

Although it is convenient on most modern bottling lines, due to the synchronous movement and positive action, to use containers that will seldom stand up on their sides, it is best to have a container study that will address sales appeal but at the same time hold stability in both the vertical and horizontal planes. A steady container has a relatively ample base angle, a low center of gravity, and temporary join points on each tag end, so there is no possibility for it to dislodge if a short-lived hold-up brings it into contact with others. Similarly, the cross section of the bottle should be designed so as to avoid the possibility of jams and breakages which might occur when containers of cylindrical or evocative section twist and cause stoppage in conveyor spin rails. When using bottles of this shape, it is advisable to avoid orienting them along their side (major axis) and instead maintain the largest possible contact area between bottles by rounding off the sharp radii at each end. Having established that the expected bottle shapes and bounce sizes can be handled on a free line, the individual bottling processes can be considered. These are:

1. Bottle feeding
2. Bottle cleaning
3. Filling
4. Closing
5. Labeling
6. Collating and packing for transport

7.3.2 Bottle Feeding

Apart from specialized operators such as dairies, breweries, and a decreasing number of carbonated soft drinks manufacturers who handle de-crating machines for removing incoming bottles from metallic, plastic, or wooden crates, many bottlers arrange with their glass manufacturer and fiberboard suppliers for their unique glassware to arrive from the annealing conveyor directly into the cases where the loaded bottles will eventually be shipped. This saves much room, labor, and the necessity of tying up the budget on returnables, and it is a method in which relatively simple devices can be used to assist bottle feeding. A rotary unscrambling plate is likely the simplest; nonetheless, where shapes are other than round, case feeders are perhaps advisable. Once the stuffed cases have been turned over and the bottles pushed onto a moving belt, they are conveyed, consequently, a horizon at a time, to the slat feeder conveyor (Piringer & Baner, 2000).

7.3.3 Bottle Cleaning

The traditional way of washing glassware is to wash it on a well-known chain of bottle washers, and such washers are generally handed down in dairies, breweries, and other compatible industries via returnable bottles. Washers are, as a matter of course, two types, namely "hydro" or "soaker-hydro," the former employing liquid jets and the latter complete immersion of the bottles, customarily with the insertion of rotary brushes. Operating speeds can be multiplied, and a diversity of washers can be fitted out for various conditions. However, where the one-use bottle is utilized, a much simpler method of washing is regularly employed, utilizing compressed air. Assuming that, as mentioned in the specification under "bottle feeding," the glassware has been loaded into clear, handy fiberboard cases and the flaps have been folded completely for transit, the glassware that was commercially hygienic when loaded may have been contaminated by paper dust, straw, or perhaps the fitful glass wreck which can be unsettled by the air-cleaning operation. It should be stressed here, nevertheless, that air cleaning is only a step toward obtaining clear glassware, and cooperation should be maintained with glass manufacturers to ensure that they are thoroughly aware of the user's intentions and are therefore able to commit to the uninterrupted deliveries so important for the success of this system. Particular attention needs to be paid to the conditions under which the bottles are stacked, as saturation or atmospheric condition variations may create condensation, causing dust to adhere to the container and therefore nullify the air-cleaning process; instrument air quality, free from oil and water vapor, is essential (Paine & Paine, 1992).

7.3.4 Filling

The traditional approach to washing glassware is to wash it on a chain of filling machines for putting liquids into bottles, which can be divided into four main types: vacuum filling, measured dosing, gravity filling, and pressure filling. Most liquid-filling machines are specially designed to use only one of these four methods. But there are one or two multipurpose machines that can handle a combination of gravity-, vacuum-, or pressure-filling methods. Filling by vacuum is the cleanest and most low-priced way to manage many products. Regardless of the care taken in making bottles and washing them, there are always a percentage of faulty bottles, for the most part ones with holes, chips, and cracks. These are not always detected in the prehandling of bottles before filling, but vacuum-filling machines automatically sidestep such bottles.

Moreover, with vacuum filling, there is no overflow or other mess. There is a small loss of product, and it is unnecessary to wash or scrub the bottles before labeling. Vacuum fillers are of three types: rotary, tray, and ad hoc feed. On rotary equipment, each bottle is handled individually. It is centered under a filling system, raised prior to loading, as it travels over the equipment, alone out all the various bottles. On tray-type equipment, bottles are placed regularly in trays and pass by conveyors under the filling front, which may consist of one to eight feeding stems. The ad hoc feed method involves a turning device that discharges the aggregation of filled bottles and moves the empty bottles into placement under these stems (Robertson, 2010).

Apart from counting (which can range from sorting equipment with electronic counters to devices consisting of a sequence of pockets, each claiming an item, mounted over a rotating drum), there are two integral methods of filling powders and granules into containers. These are volumetric filling and filling after weighing.

The method of production normally determines which means is used. Developments are currently taking place in the trade of counting devices via checking systems that involve photocells, check weighers, and sensing devices, each of which can detect and reject if underfilled containers arrive.

7.3.5 Volumetric Filling

The available methods are filling by auger, jug (or cup) fillers, and vacuum filling. In auger fillers, a punch is fitted facing a sleeve mounted below a hopper containing the output, which should be granular and not extra powdery. The thickness of the auger, *D*, and the pitch of its helix, *P*, are designed according to the output being filled. The quantity shipped is controlled by the number of turns the bit makes in one cycle. Cup or jug fillers manage powders as easily as granular materials. A jug of known and discretionary volume (the degree is constantly adjusted telescopically) accepts the output from a supply hopper, and when brim-full, the feed cuts aside and the jug discharges its contents down an appropriately designed chute. The vacuum-filling means is virtually the whether liquids, powders, or granules are filled. The containers are above the filling front, making a vacuum-tight seal. The filling nozzle projects into the sealing ring, the distance of penetration governing the turning point of fill. When the seal is restrained, the case is evacuated, and the product flows till the vacuum is cut off. With containers that could overflow under a vacuum, the filling front can be fitted with an airtight mask and the vacuum exhausted in both the case and the mask, thereby equalizing the pressure and preventing collapse.

7.3.6 Filling by Weight

Weight filling is absolutely the most satisfactory practice for meeting the requirements of whole weights and measures regulations. There are many different weighing techniques, which involve single- or double-action mount beams, heads that are operated by compressed air, and most recently self-moving and microprocessor-controlled systems. It is furthermore possible to receive products from a weight-balanced conveyor. In all, the integral principle is to vary the supply of output into a main ingest and feed ahead of the weighing front. At the beginning of the weighing cycle, both the body and the fine feed are engaged to feed the weighed amount; meantime, about 80% or 90% of the required material has been added. When this is reached, the advantage feed stops, and the dribble feed continues until a perfect balance is reached. At that instant, the fine feed ceases and the fill is cleared, usually by tipping into the container.

7.3.7 Capping of Bottles and Jars

For this practice, the loaded containers, with preformed pin caps loosely applied, are presented in turn manually or automatically to a rubber marked spinning elbow, which has a clutch set to engage when a constant resistance is reached. For speedy operations, full ad hoc capping equipment is prescribed, and this is normally supplied with a cap unscrambler for feeding caps to the equipment in an uninterrupted stream and in an appropriate manner. Transfer of the caps from the cap chute to the jar is achieved by one of two methods:

1. The bottles pick up their caps as they arrive under the wind up of the chute.
2. Rotating arms on a rotary turret collect the caps from the chute and place them into the capping chucks individually.

7.3.8 Automatic Capping Machines

These fall into two dominant categories: in-line and rotary. In-line cappers are simpler, incorporating the control cap pick-off mechanism; the bottles are held by traveling belts while another group of belts, operating customarily on the outstrip of the cap and on the skirt, turn the cap home. Rotary cappers are preferably sophisticated; they control the containers individually while rotating chucks screw on the caps. The chucks on most rotary cappers operate by three or four self-centering jaws, which are appropriate for tinplate or other durable caps. However, to place plastic caps or closures where a delicate reach is required, a pneumatic chuck is used. This grips the caps by means of an adjustable neoprene "doughnut," which is compressed by an air piston and so grips the cap gently yet firmly. In-line cappers are available for speedy operations on simple bottle shapes, but to place caps decisively, torque control is necessary, or where the container design is different, a rotary model is recommended.

- *Roll-on capping*: The roll-on cap has as wide handle for multiple bottling applications and, as the name suggests, the cap threads are formed by rotary heads while the cap is standing on the bottle. This description of the cap can also involve a pilfer-proof device (roll-on pilfer proof, or ROPP) in which the action of removing the rolled-on cap breaks a chain of perforations and leaves a tell-tale ring on the jar neck. Roll-on cappers are leased by the cap manufacturers to the users and are of the rotary design with clear cap pick-off.
- *Corking and plugging*: Corking and plugging machines are common in connection with rotary cappers, the corks or plugs being fed from an unscrambling hopper to a chuck by a transfer effort or disc. The chucks do not whirl but press the closure home with a descending thrust. Some corking machines apply one or more blows to the press on the corking front to certify that it rests firmly in position.
- *Crown corks*: The crown cork, chiefly used for beer bottles on filling lines, is applied by a rotary capper, usually a fundamental part of the filling machine. Pressure is exerted on the crown to cut the roll or liner; meanwhile, clinching heads crimp the corrugated circle into a groove on the bottleneck. The finished closure can withstand internal pressures of likely 100 psi (Paine & Paine, 1992).

7.3.9 Labeling

Semiautomatic labeling machines are generally adequate. This demands an operation to express a package to the equipment that, at the start, glues and applies the label. Apart from the means of handling the case, there are three useful methods of glue application used on all ad hoc labelers:

1. An adhesive is applied rapidly to the labels while they are held by a vacuum cram or by grippers.
2. The adhesive is applied to a plate or turret that, at the start, applies the adhesive to the label.
3. The bottles engage a pattern of adhesive somewhat smaller than the label itself, and the label is then applied to the bottle.

The means adopted would perhaps be dictated by the nature of the application, that is, the placement and situation of labels, whether they are subsequently washed, and so on. High-speed labeling of round containers can generally be achieved satisfactorily on one of a wide array of rotary labeling machines, although where shapes other than round are used, or where a round jar is labeled in register by an registration mark or “blip” on the bottle itself, an in-line labeler is required.

7.3.10 Case Packing and Sealing

After the bottles have been stuffed, capped, and labeled, they are continually loaded toward a fiberboard outer package for transit to the trade depot or retailer. (Quite frequently, this is preceded or followed by shrink-wrapping). The case packing practice is often performed manually, coupled with all of the necessary inspection of the finished bottles. Where dividers are required, as with multiple glass bottles, a drop-packer is required, which collates the bottles and then drops them, guided by a romp or plastic guides, into the waiting cases with dividers fitted. When this process is organized, the loaded cases are moved to the case gluer, which glues the flaps, folds them into place, and then places the cases in a compression passage of adequate length to support the adhesive to set while the case is released. A discretionary means of placement packing is the wrap-around method, which, as its name implies, is a program of wrapping a fiberboard case blank over a collation of bottles or other containers, thereby giving a tighter package and often Amex savings of a desirable 15%. Dividers can intervene if required, but these are not present on many containers due to the tightness of the wrap (Theobald & Winder, 2006).

7.3.11 Shrink- or Stretch-Wrapping

Jars of jams and so on, were the first containers to be shrink-wrapped instead of packed in fiberboard cases. The use of shrink- or stretch-wrappers has rapidly extended to all forms of food- stuffs, whether in bottles, cartons, or cans, as well as many distinctive types of client goods. The choice around case packing and shrink- or stretch-wrapping is not dealt with entirely here; nonetheless, where shrink-wrapping is operating, the collation of containers is constantly wrapped in a loosely conforming tube of shrink-film, normally polyethylene, which has been biaxially oriented, and the pack is subsequently passed through a heated tunnel that softens the film at the bottom to squeeze and tightly bind the contents. A cooling provision normally follows the heated tunnel in case the packs need be handled immediately. With stretch-wrapping, the film is tensioned over the collation, and no heat is needed.

7.3.12 Palletizing

Pallets are omnipresent, recognized as a easy assist to stacking and storing regular-shaped packages. They are coop platforms, regularly made of timber, with a space between the upper and lower faces for the admittance of the forks on forklift trucks. Pallet loads are approximately cubic in shape, being formed by layers of cases or goods that have been effectively placed to address a valuable stock or interlock between layers. While manual loading of pallets is common, valuable outputs demand automatic palletizing apparatus that receives loaded cases from one or more lines, collates them a load at a time, and loads them on to pallets for aggregation by forklift trucks. Shrink- or stretch-wrapping of pallet loads is still widely used. This practice obviates the provision of strapping, gives a firmer bond to the fill, and is an aid against pilferage and a method of protection from the elements (Robertson, 2010).

7.3.13 Canning

The canning of foods may be separated into eight divisions or integral operations:

1. Handling and storage of empty cans
2. Cleaning empty cans
3. Product preparation
4. Filling
5. Closing (seaming)
6. Processing
7. Cooling
8. Handling and storage of filled cans

7.3.13.1 Handling and Storage of Cans

Tinplate containers do not have total resistance to physical destruction, nor can they be considered to address indefinite demand, which could promote corrosion. Cans should appropriately be used in a method that will sidestep damage to the rims, extreme denting, or rift of soldered laps. When transport conditions are unavoidably problematic, hollow cans should be packaged in hand-out wrappers or fiberboard cases. They should, indubitably, be kept clean and hygienic over transport. Empty cans should be stacked in storage and invulnerable to temperature changes that will result in moisture condensation and eventual rusting. In naval areas, small amounts of sea salt encourage corrosion. Storage facilities should be arranged such that the first cans received are those that are used soonest (Paine & Paine, 1992).

7.3.13.2 Cleaning Hollow Cans

Although cans are shipped to the customers in a clean condition, it is nevertheless constantly necessary to clean, which will promise their safety before they are filled. To be efficient and effective, the sterilization should be done by spraying hot steam on the cans in an upright position. A jet of steam alone is not sufficient to ensure consistent cleaning.

7.3.13.3 Product Preparation

A pertinent step in the consolidation of canning operations is that of washing and preparing the food before filling it in cans. This can be carried out in a variety of ways, depending on the product. From an aesthetic or utilitarian perspective, the motive of such preparation steps as trimming and slicing is evident. It is also indisputable that thorough washing will greatly diminish the proportions to which the food is contaminated by spoilage bacteria, which could decrease the chance of processing that follows filling and closing.

7.3.13.4 Filling

Cans should be loaded uniformly and with the proper amount of contents. Proper filling serves to remove undesirable gases, particularly oxygen, and at the same time helps in creating an internal vacuum during processing and cooling. The production of a vacuum in the case is achieved by filling with a hot product or by baking the contents after filling but before closing. Under-filling the can gives a front space, generally in the range of 6–9 mm, which varies comparatively with the quality of the product and the length of the can (Paine & Paine, 1992).

7.3.13.5 Closing (Seaming)

The canning practice is based on baking the sealed containers till the contents are commercially sterile. Earlier, it was crucial that the sealing process, also called closure or double-seaming, be such that recontamination of the food by microorganisms was precluded over the inevitable cooling, handling, and storage of the cans. In recent canning, closing can be carried out at high speeds, 1,000 or more cans per minute, by highly sensitive closing machines. Alternatively, closing can be done on a relatively simple, nonetheless powerful, machine or even with the help of manually operated devices. Regardless of whether the complicated or simple closing machine is used, it is imperative that operators thoroughly understand the principles of seam formation (Robertson, 2010).

7.3.13.6 Processing

The thermal processing of canned foods, generally termed hot, retorting, or processing, is the use of heat at a suggested temperature for a specified time. This process has two integral purposes. The first is to express a commercially clean product. In this manner the product is subjected to torch treatment at a temperature and for a time ample to obstruct not only organisms that might adversely affect the consumer's health but also those organisms that can cause spoilage under appropriate storage conditions. The second purpose is to refine the contents to a state where minimum additional preparation is need by the consumer. The destruction of microorganisms by incineration and their ability to multiply themselves is highly dependent upon the acidity of the product. In general, products having a pH lower that 4.5 can be stacked without resort to temperatures above that of boiling water. Products that have a pH greater than 4.5 require a higher temperature in the case that the processing lead is not overly long. Of course, the texture of the product and the length of the case also affect the processing time. Heat penetration in viscous or semisolid products such as bread and butter is slow. Accordingly, for solid products and larger cans, a longer passage is required before the temperature at the center of the can rises to the correct level.

7.3.13.7 Cooling

The final important operation before cans are moved for labeling, storage, and marketing is to cool the sealed cans after processing. The purpose of cooling is to hinder the deleterious effects that over-cooking might have on the output, for example, extreme softening of the food or unacceptable changes in flavor or color. Small cans for simple products may be air-cooled; nonetheless, cooling is generally done in water in various ways. The hot cans may be cooled by admitting water into the retort in which they were stacked, or the cans may be moved from the retort and conveyed through a tank or mist of cool water. Large cans and irregularly shaped cans should be cool under pressure in order to avoid extreme strains on the container. This makes it necessary in the retort, via either air or fume, to counterbalance the pressure developed within the can around the processing operations.

7.3.13.8 Handling and Storage of Filled Cans

The handling and storage of canned foods are not a part of the canning operation per se. Nevertheless, they are significant to a profitable operation. Rough handling and contaminated runways can lead to spoilage due to the growth of microorganisms; storage of cans at excessively high temperatures or under conditions favorable to deterioration may wreck an otherwise sufficient pack. The storage of canned foods in gentle climates presents no real problem so long as preferred practices are followed and provided cans are secure from moisture. The storage of loaded cans in a moist warehouse or the filling of moist cans into cartons should be avoided.

7.4 WRAPPING

Wrapping mass-produced articles in a continuous stream, ad hoc wrapping machines do not require a manual operator. The speed of packaging is profoundly increased, and in the case of little objects one as toffees, which are easy to pack and wrap, speeds can be achieved by using a piece of film, forming it facing a tube over the object, and twisting the ends of the tube; this is known as twist-wrapping. Rectangular objects offer themselves to a mechanized narrative of the parcel wrap. There are various versions that can be selected depending on the amount and shape of the objects to be wrapped. In each, the principle is broadly similar: A breadth of wrapping material is drawn or fed from a stream and peeled off; the object to be loaded is pushed directly toward it, and the ends are folded over the object, forming a tube with an overlap. The bare ends of the tube are tucked in suitably, and the overlap and tucks are sealed in place by torch seals or adhesive. Neatly rectangular packets of cereals or cigarettes can have one end tucked in by grippers, after which the parcel is pushed on pairs of ploughs that fold the other flaps in order. When the objects to be loaded are not constant in substance or are muffled and compressible, in terms of achieving each fold as it is bent, the ends are folded perfectly in a style suitable for soft loaves of bread. This element of the bread-wrapping equipment produces a clear wrap via machinery from the reel. The product is fed by a flighted conveyor over a curtain of heat-sealable material onto an elevator. The wrapper is gripped during the output by a keep-plate on the elevator, and the first end-fold is made. As the elevator moves upward, the wrapper is pulled from the flap, formed over the loaf, and the instant end-fold is made. By using the product to pull-feed the film, the breadth of film used is determined by the output girth. This is particularly convenient for bread, which varies a little in length from loaf to loaf. The wrapper is separated by a jagged knife as the loaf is pushed forward by a reciprocating pusher. The third and final end-folds are formed, and the base of operation longitudinal seam is made. This and the end-folds are then heat-sealed, and the wrapped loaf is cleared by belt conveyors. Waxed paper and heat-sealable cellulose film boots are used by the standard equipment, and a variation is available to handle polyethylene and cast polypropylene. Sealing of the plastic films is achieved by heated depose belts (Piringer & Baner, 2008).

7.5 BAG FILLING AND CLOSING EQUIPMENT

There are four operations engaged in bagging:

1. Feeding the flat bag to the loading point
2. Opening the bag and keeping it open
3. Loading the product
4. Making the closure

The front opening is generally achieved by an air-blowing system, routinely assisted by the incorporation of lips on the bag. Mechanical fingers are further used either independently or to aid the air-opening device. Originally, the bag was kept unmasked, and the output guided facing it by an chute or other means down which the product slid. Now, the discretionary component of inserting scoops directed toward the bag and (holding it under slight tension) pulling the bag around the product is employed specifically for the bagging of sliced bread. The principle of facing the bag alternative rather than the product enables bagging to be performed on products despite little obstruction to fabrication and without crushing; a wide choice of closures is available. Ties, clips, staples, tapes, and torch seals are employed widely.

7.6 BAG-IN-BOX PACKAGES

Given a wrapping material inherently water-vapor-and-torch sealable (whether the press is a weld right through or only a surface seal), it is always possible to draw a bag more easily than an over-wrap for a box of a particular size. Moreover, many film materials are also odor resistant and consequently can preserve food products better when in automatic contact, and thus avoid locking up potential sources of odor within an over-wrapped and consistently printed carton. Cheaper grades of boxboard may be used for the carton if an alimentary bag is employed.

7.7 CARTONING

A cartoning program combines a distinctive carton with all of the apparatus to raise it from a coop condition, feed it a product, and settle it. The accessories vary from simple hand-fed machines to ad hoc stations coupled with all of the means for packing the cartons rapidly into cases for dispatch. Whatever the program engaged, three dominant operations are performed:

1. *Forming or erecting the container*: Material may be fed to the carton erection hold as a never-ending web, as a coop carton blank, or as a folded carton flat secured by a manufacturer's joint.
2. *Loading or filling the container*: In the never-ending web-fed and top-loading systems, the container has only one face unmasked at the instant of filling; mutually, an end-loading program is accessible by all of the various products to fill the carton and close both ends afterward.
3. *Closing or sealing*: After these major operations, cartoning systems may be designed to execute secondary operations such as handling paper liners, embossing codes, and inserting leaflets. All these can be performed along with the three major operations on manual, semi-automatic, or fully ad hoc lines. When forming, filling, and closing must be carried out on one machine in a single activity, fully ad hoc machinery is generally used. The grade between semi-automatic and fully ad hoc machines relates chiefly to how the filling or loading of the carton is carried out. If loading is done instantly into the cartons, buy eventually a technician inserts it into the feed conveyor by hand, the program is classed as automatic. If the whole of the operation is ad hoc, but the fill is inserted instantly into the carton by hand, the system is termed semi-automatic. Most systems requiring high speeds involve continuous-motion machines; lower-speed systems generally use intermittent-motion machines. The latter can further be of advantage where the quality of the product demands an unchanging carton at the breadth of filling (Theobald & Winder, 2006).

7.7.1 Cartons for Liquid Products

Requirements generally involve impermeability, and public health is particularly stringent when packing liquid food products. It is, therefore, constantly necessary to use other methods than those earlier indicated to gain satisfactory results. Sealing must fundamentally be tight, and there are problems expected in connection mostly with the filling and at which point to seal or dodge open-cut edges. The most important liquids at issue are milk and milk products and fruit juices. The machines described in the following section are normally used for all these products. There are two main groups of machines: those that function from a flap, which comprise the package and feed it in a never-ending operation, and those that work from a premanufactured blank.

7.7.2 Cartons for Hard Products

As mentioned earlier, cartoning systems can load the product in the end of the carton or feed the product vertically, and both of these may be performed as never-ending processes. Cartons may also be fitted for systems that will raise, feed, and close either a prelined carton or one that makes its liner on the machine. Both these types of lined carton can be used for vac/gas and vacuum packaging at speeds of a desirable 60 or 70 cartons a minute.

7.7.3 Cartoning Systems

From watching the package client, there is a favorable circumstance in using a cartoning framework. Right off the bat, the administration activity engaged is less difficult. One partner is obligated for the loan and overhauling of both contraption and containers. Since the particular provider of containers will regularly be creating them for the use of the machine utilized as a part of the program in a generally huge amount, they ought to be connected with the majority of the various prerequisites of the container spaces or pads and the requirements of the container dealing with the material concerned. The package client will not, all the same, be anywhere equivalent to just a single container provider as the greater part of the frameworks available are prohibitive for production in excess of one creation unit. In a few cases, they figure out how to have a few suppliers inside one gathering of organizations, and with a huge number of different frameworks, extremely common organizations who are generally licensees for a particular program can give optional sources of supply. The tied cartoning framework is chiefly acceptable where adaptability and adoptability instead of whole computerization are enabled, and this is routinely the necessity with numerous sustenance lines.

There are a few variables to be considered when choosing a cartoning framework.

7.8 MACHINERY CONSIDERATIONS

These include:

1. The required creation rate of the machine both immediately after establishment and at the normal pinnacle of generation
2. The quantity of package sizes that might be included
3. The occurrence of size changes
4. Whether the framework should provide support for changes of the item composition or number inside the size variety foreseen
5. The accessibility of work for the machine lines. For instance, if in the underlying stages a group of five or six administrators is required for one line and the normal creation peak would mean an aggregate generation of four

times the volume provided feed for on one line, will the framework require fourfold the number of administrators, or would it be able to work withy just seven or eight? On the off chance that four times the quantity of administrators is included, are they available in the specific territory concerned?
6. The space is accessible for putting in the hardware, remembering a possible increment underway later on.

7.9 PRODUCT FACTORS

These include:

1. The variety ordinarily present in the item itself – how simple it will be to control the extent of the item and inside what limits
2. The technique is accessible for taking care of the containers after they have been filled. For instance, are they required to go into a deep cooler, or are they to be over-wrapped with an obstruction material to give protection from dampness to a fair degree? Such factors will decide the question of any defensive boundaries that might be required on the board itself.
3. Coupled with the prerequisites of the last inquiry, the insurance the item itself requires from dampness, from oxygen, from outside scents, and so on. Is it oily, or wet, or generally ready to influence the board from which the container is made?
4. If comparable items have been pressed before, the involvement with the technique is utilized. For instance, has it been discovered that stacking is superior to side stacking as far as item handling capacity? In the event that there have been trends previously, are there new reasons that would invalidate such outcomes now?

7.9.1 Board and Carton Requirements

These include:

1. The specifications for the board in terms of decoration and presentation effects are required.
2. The support the container must give to its substance, and whether this will have repercussions on the simplicity of working with the container framework from the receiving, raising, and shutting points of view.

7.9.2 General Contemplations

These include:

1. Whether the proposed new gear must connect up with some other hardware currently present, for example, over-wrapping machines, case packers, or filling heads.
2. Whether assistance can be acquired from the container provider on such other auxiliary gear with which they may have had experience with their containers on different lines.

7.10 FORM, FILL, AND SEAL MACHINES

These machines handle a fold of pliable material (paper, film, or overlays of paper/film/thwart) and either shape it into a tube and after that press and expand it at constant interims, or crease it the long way and press it at appropriate edges to overlap and develop an arrangement of pockets (sachets), which are full and shut. Machines of the principal variety develop pockets with the greater part of a seal at each location and down the focal point of one face; meanwhile the second sort of action produces sachets with three or substantially all four edges. Notice that the difference between the main sort and the Tetra Pak procedure is that in the advanced system, exchange seals are constrained at appropriate points to each other, while in the pocket hardware, they are all in a similar plane.

Form-fill-seal (FFS) hardware is helpfully appropriated into three sorts, which we will discuss in more detail:

1. Vertical machines, in which the material is shaped into a roundabout segment tube over a framing neckline.
2. Horizontal machines, in which the material is framed into a rectangular segment tube through a shaping box.
3. Sachet-framing machines, which themselves are of two sorts. The principal sort utilizes a single web collapsed down the middle and after that cross-fixed, and the second uses two networks that are united and at first fixed on three sides. In each occurrence, in the wake of filling, the remaining side is fixed to frame the total pack.

The seals in sachets are always made between different areas of the same film. However, whether the sachet edges meet face to face or overlap after sealing determines the appearance of the final seal when the tube is formed.

7.10.1 Vertical Form-Fill-Seal Machines

Vertical machines can create three styles of package:

1. *Pillow packs*: These typically have blade or cover seals on the base of the pack and transverse seals at either end. The most widely recognized applications are "strong" preformed items or multipacks, for example, pieces of candy or chocolate-covered rolls, and accumulations of smaller strong preformed things, for example, a given weight of prewrapped desserts or a given volume of nonwrapped desserts.
2. *Sachet packs*: These have a four-sided balance seal (once in a while just three) around the edge of the pack. The most widely recognized applications are powdered and granular or comparable items (e.g., instant soups, instant potatoes, and instant sweets).
3. *Strip packs*: These comprise two layers of material fixed together to contain the item between them in singular pockets. The most well-known applications are in pharmaceuticals: pills, cases, and suppositories.

The mix of operations of a typical fundamental machine of vertical FFS make use of a forming launch to shift the coop web drawn from the flap into a tube. In most machines, the parallel sealing system contains a dedicated sealing carriage. The sealing jaws hit together to draw the cross press and then drive downward, pulling the required length of packaging material from the reel. At the end of this descent, the sealing jaws unmask and boomerang to begin the next pull off/sealing cycle. The straightforward press may be, as a choice, an overlap seal or a fin seal depending on the fill presentation required, whatever the packaging material used. There is a well-known significant alternative program used on reliable vertical pillow-pouch machines. This is the foundation of the fixed parallel seal carriage, working in conjunction with a friction-driven film feed. Here the sealing spread carriage does not return vertically; only the sealing jaws open and settle in a timed sequence.

Overlap seal: The overlap seal is more reasonable in wrapping material usage than the fin seal. It is adequate for most monofilms and for laminates that have a sealing augur on both sides. One-sided films and laminates demand a fin seal system.

Sealing techniques: The packaging material used will be affected by a number of factors, including the style of the output, its marketing parameters, and the distribution program used for that product. The material used will have a notable influence as well as the sealing system engaged on the packaging machine. This may be one of the two types.

Resistance sealing is used where the film consists of a carrier or body material with a torch seal coating. The carrier material is not normally caught by the torch and on its own would not adhere with heat and pressure (e.g., aluminum foil, paper, or cellulose film). Such materials should be coated with, or laminated to, a torch sealable layer. Continuously heated sealing jaws are routinely corrugated or grooved, and the corrugations on the jaws should be in mesh to gain a valuable seal. Such sealing systems involve a knife to cut the seal in two (one-bag top seal, one-bag base seal).

Impulse sealing is used for unsupported materials, where the material can be sealed to itself on either surface. The nichrome resistance girder is heated (often to red heat) by a properly timed low voltage electrical current impulse. The radiant heat wave melts the polymer films clamped in the sealing jaws. The quick duration of the impulse is followed by a cooling head to give valuable seal strength (Theobald & Winder, 2006).

7.10.2 Horizontal Form-Fill-Seal Machines

These have most features in common with their vertical counterparts. Like the vertical machine, the horizontal machine combines the three separate operations of pack forming or shaping, product inception directed toward the pack, and wedge closure. The process further uses a flap or reels of wrapping material; the principal difference is that material is pulled from the flap directed toward a horizontal plane where the operations take place. Pack styles can be conveniently grouped into two main types. Pillow packs are typically similar to the vertical packs. The most common horizontal applications are for solid, preformed single items or multipacks (e.g., candy bars, biscuits). Sachet packs generally have three- or (more usually) four-sided fin seals over the edges of the pack. The most common applications are actually the same as for the vertical sachet machine – powdered, granular, or similar products and liquids, for example, instant soup, instant potatoes, and instant desserts.

7.10.2.1 The Mix of Operations of a Typical Fundamental Machine

The products are fed into a continuously moving feed conveyor. The constitution of the conveyor is dependent on the product, yet a chain-lug in feed is the most routinely used. The wrapping material is formed into a tube inside a folding box. The edges of the tube are fin-sealed en masse as they get through a pair (or several pairs) of horizontally mounted propelling and sealing rollers. The products are pushed into the formed tube by the advancing in-feed. A couple of rotating sealing jaws seal the tube transversely between the products and separate the packs with an integrally mounted knife:

- *Automatic product feeding*: For pouch wedge machines, these may range from relatively simple units for the more common applications to custom-designed systems to suit a particular individual requirement.
- *Alternative sealing systems*: The nature of the folding box and the commercial art of the long seam propelling/sealing unit depend upon the packaging consideration and the materials used. Additionally, diverse types of transverse sealing units may be required.
- *High-integrity pack sealing*: For pack seals of valuable integrity on heavier gauges of materials, it may be suitable to have a reciprocating sealing front instead of the customary rotary crimp jaw assembly. Such a front is used for pharmaceutical packs or long shelf-life packs, as required by the bakery, biscuit, and other food industries. The unit increases both the sealing demand and the time over which the sealing jaws are in contact with the wrapping material. It comprises a reciprocating carriage with combined cross-sealing jaws and a cam-operated knife. At the beginning of the cycle, the high-pressure jaws arrive together to draw the transverse wedge seals. The meshed jaws then drag forward at the same linear speed as the wrapping material. At the stop of the horizontal stroke, the cut-off knife operates, and the jaws diverge vertically. The boomerang stroke then commences, ready to begin making the seals on the next pack.

7.10.3 Thermoformed Form-Fill-Seal Packs

Containers may also be produced from reels of material by thermoforming a sequence of trays in a net, filling them all with the product, and then feeding another web around the open tray to barely cover the flanges of the trays to enable a torch seal closing. The web of loaded and closed packages is then punched out to form individual packages, or may be slit at intervals to give several units united together. Such machines work at speeds of 6 to 20 cycles per minute, and the number of packages produced will count on the number formed per cycle, which in turn is commonly dependent on the orientation they maintain (Paine & Paine, 1992).

Thermoforming the film is specifically important. In these methods, the heated film is formed in a mold (negative forming). In vacuum forming, the force is provided separately, with a difference in pressure of 1 bar (1 kg/cm). In compressed air forming, forming pressures of 6–8 bars are common.

Vacuum forming results in irregular encumbrance thicknesses in a deep-drawn cavity; the nearly uniform encumbrance thickness distribution is produced using compressed air forming with a plug assist. Compressed air forming without a plug also results in more uniform wall thicknesses than with vacuum forming. However, the material required for this means is more complicated (and more expensive) than comparable machines for vacuum forming.

7.11 LABELING

Marking machines for packing have three parts: the case to be labeled, the paste, and the label. They might be group into two major classes in view of the general style of the paste framework: machines utilizing we' glue (provided separately from the labeled) and those utilizing preglued labels.

In choosing machines, we should be concerned with which program is best capable of the intended application – wet paste, burn actuated, or weight sensitive cement. Common components are:

1. Economic
   a. Basic label cost
   b. Adhesive cost
   c. Setting up, cleaning down, and routine stoppages
   d. Inventory cost
2. Marketing
   a. Label material and print necessities
   b. Package materials
   c. Package shape
   d. Package reuse
   e. Warranty contemplations
3. Handling
   a. Storage needs
   b. Transit perils
   c. Conditions while available for purchase
   d. Use conditions

The arrangement of the label stipulation and the cement quality will sigsignificantly affect the gear chosen. Wet-gum machines reliably work with cut labels; thermo-sensitive gums are provided as wipe-outs or reel feed; weight sensitive gums are always reel-fed to packaging films. Cut marks can always be renewed while the gear is locked in; meanwhile, reel-sustained stock requires a machine deflect to restock. As fold breadth is prohibitive, the recurrence of stop-pages will rely upon label length and thicknesses of labels and helping material. Four essential activities are performed by a labeling machine:

1. Feed the label from the warehouse or roll.
2. Pick up the label, routinely by suction cups, packed air, or auxiliary cement.
3. Apply glue with appropriate scope or in clear or even stripes (by and large from rollers), onto either label or holder.
4. Press the label to the case by weight cushions, compacted air, belt, or brushes, over which the case will be moved into position, held solidly while the label is applied, and after that evacuated. This might be accomplished by a revolving procedure, with the holders being held in a turning turret, or by a straight-line activity with a transport star wheel or clasp instrument. Straight line activity is more routinely used, particularly where holders of strange shapes are concerned. Most jug-marking machines hold the jugs vertically; however, a few machines, especially for jars, help the compartments on a level plane.

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8 Testing of Packaging Materials

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8.1 INTRODUCTION

Packaging is a closed system whose objective is to protect the contained product against external factors like water, water vapor, oxygen, microorganisms, insects, other intruders, dirt, pilferage, and so on. The words "package" and "packaging" have different meanings; the *package* is the physical entity that actually contains the product (Aarnio & Hamalainen, 2008). *Packaging* is the integration of the physical elements through technology to generate the package, and it is the combination of materials, machinery, products, consumers, and marketing that together provide protection and communication. Packaging is designed to facilitate the movement of a product from its point of production to its ultimate consumption and is always correlated with the function of the product contained. Packaging creates a barrier between the contained product and the environment that surrounds (Urbanek et al., 2011). For example, dry products must be protected to control their moisture content. Most dry products are highly susceptible to moisture or liquid water, whereas hygroscopic foods absorb water and deteriorate. Conversely, most wet products are susceptible to loss of their water content. Oxygen present in the atmosphere reacts with most food products. By establishing a barrier between the air and the product, packaging can retard the oxidation of fat in foods by removing the provided oxygen in the package. Packaging retards the oxidation of foods and the related product deterioration. Flavor ingredients present in foods may be adversely affected by the presence of oxygen. Carbon dioxide is flushed into products such as beer, champagne, sparkling wine, and carbonated beverages to ensure that the flavor quality is maintained throughout distribution. In present complex distribution systems, the product is manufactured and fabricated in one geographic region, and its consumption is in another geographic area that is far from its origin; hence packaging is required to ensure the product's integrity during transport and in storage to prolong the shelf life. The regulatory agencies emphasize the assurance of the materials being developed to meet the necessary safety standards to ensure that products will not be contaminated by the materials in which they are packaged (Kiyohide, 2004). On the environmental side, there are demands for the use of less material and to reuse or recycle feasible material. In the current era, not only are new materials being developed but also innovative ways of combining existing materials are being

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investigated. The type of packaging material used with a specific food product depends on the function the package must perform, the protection needed, the chemical composition of the food, and conditions of shipping and storage. One of the approaches is to create edible barriers to enhance the quality of certain products. When looking at barriers in packaging, there are standard tests for oxygen, water vapor, and other individual gases. A suitable example where this technology plays a role is baked products and pizza containing wet toppings over it. The sauce and fruits possess higher moisture content than the surrounding goods, and a barrier could help to prevent the fruit from drying out and the baked product from getting soggy. Extensive test development has occurred to prove the safety of both recycled and reused packaging materials. Testing can be carried out to determine the potential for migration from packaging materials into foods and the loss of flavors from the food through the packaging material (Aarnio & Hamalainen, 2008).

8.1.1 Functions of Packaging

- *Containment* – Protecting the environment
- *Protection* – Protecting the product from environmental effects
- *Convenience* – Product design
- *Communication* – Branding and labeling (Figure 8.1)

8.1.2 Criteria for the Selection of Packaging Materials

Package design and construction and their selection play a significant role in determining the shelf life of a food product, which follows certain conditions:

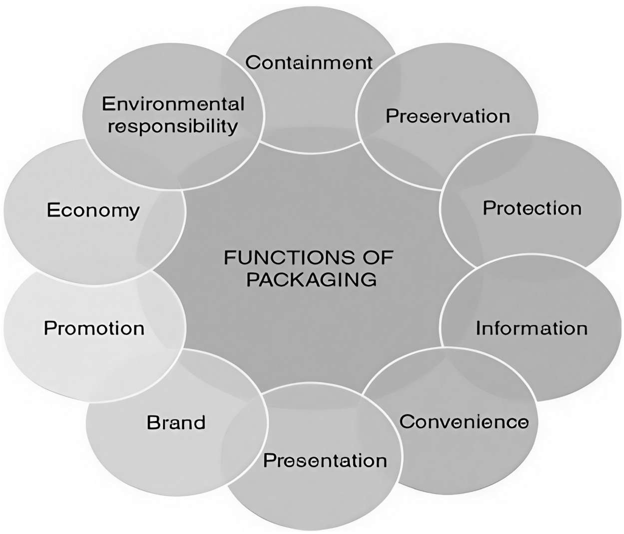

FIGURE 8.1 Multiple functions of packaging.

- Specific sensitivities of the contents
- Factors changing the contents like temperature, RH, pH, and so on
- Weight and shape of the container
- Effect on filling and sealing speeds
- Contamination by the constituents of packaging material
- Biodegradability and recycling potential
- Storage conditions

8.1.3 Types of Packaging Materials

8.1.3.1 Shipping Containers

Shipping containers are employed for bulk packaging purposes with no function of marketing. They include sacks, corrugated fiberboard (cardboard), cartons, shrink-wrapped or stretch-wrapped containers, crates, barrels, or drums (Johnson, 1995).

8.1.3.2 Retail Containers

These are meant for advertising the food for retail sale and home storage. Examples include metal cans, glass or plastic bottles and jars, plastic tubs, pots and trays, flexible plastic or paper bags, sachets, collapsible tubes, paperboard cartons, and overwraps.

8.2 MATERIALS USED IN FOOD PACKAGING

The food packaging materials (FPMs) should be solid, stable, convenient, and consumer friendly in various aspects. The right selection of packaging materials and technologies maintains product quality and freshness during distribution and storage. Materials that have traditionally been used in food packaging include glass, metals (aluminum, foils and laminates, tinplate, and tin-free steel), paper and paperboards, and plastics. The wide variety of plastics has been introduced in both rigid and flexible forms. At present, food packages often combine several materials to exploit each material's functional or aesthetic properties (Marcondes et al., 2003) (Table 8.1).

TABLE 8.1
Packaging Materials for Major Food Products

Food Products	Packaging Material/Packages
Bakery products	Tinplate containers, wax papers, paperboard cartons, polyethylene (PE) bags, cellophane pouches, or aluminum laminates
Beverages	Glass bottles, PET bottles
Breakfast cereals	Plastic bags, cellophane, wraps, tinplate containers, glass bottles
Cashew kernels	Tinplate cans, PE pouches
Food grains	Gunny bags and PE bags
Confectionery	Plastic bags, cellophane wraps, tinplate containers, glass containers
Coffee	Glass bottles, tin cans, and lined cartons

8.2.1 Glass

Glass has an extremely long history in food packaging. The production of glass containers involves heating a mixture of silica (the glass former), sodium carbonate (the melting agent), and limestone/calcium carbonate and alumina (stabilizers) to high temperatures until the materials melt into a thick liquid mass that is then poured into molds. Recycled broken glass (cullet) is also used in glass manufacture and may account for as much as 60% of all raw materials. Glass containers used in food packaging are often surface coated to provide lubrication. Glass coatings also increase and preserve the strength of the bottle to reduce breakage. Improved break resistance allows manufacturers to use thinner glass, which reduces weight and is better for disposal and transportation.

Glass is odorless and chemically inert with virtually all food products; glass has several advantages for food-packaging applications. It is impermeable to gases and vapors, so it maintains product freshness for a long period of time without impairing taste or flavor. The ability to withstand high processing temperatures makes glass useful for heat sterilization of both low-acid and high-acid foods. Glass is rigid, provides good insulation, and can be produced in numerous different shapes. The transparency of glass allows consumers to see the product, yet variations in glass color can protect light-sensitive contents. Finally, glass packaging benefits the environment because it is reusable and recyclable (Bix et al., 2010). Apart from advantages, glass has some disadvantages like any other material. Despite efforts to use thinner glass, its heavy weight adds to transportation costs. Another concern is its brittleness and susceptibility to breakage from internal pressure, impact, or thermal shock.

8.2.2 Metal

Metal is the most versatile of all packaging forms. It offers a combination of excellent physical protection and barrier properties, formability and decorative potential, recyclability, and consumer acceptance. The metals most predominantly used in packaging are aluminum and steel (Singh et al., 2007).

8.2.2.1 Aluminum

Generally used to make cans, foil, and laminated paper or plastic packaging, aluminum is a lightweight, silvery white metal derived from bauxite ore, where it exists in combination with oxygen as alumina. Magnesium and manganese are often added to aluminum to improve its strength properties. Unlike many metals, aluminum is highly resistant to most forms of corrosion; its natural coating of aluminum oxide provides a highly effective barrier to the effects of air, temperature, moisture, and chemical attack (Vogel et al., 2002).

Besides providing an excellent barrier to moisture, air, odors, light, and microorganisms, aluminum has good flexibility and surface resilience, and excellent malleability and formability. It is also an ideal material for recycling because it is easy to reclaim and process into new products. Pure aluminum is used for light packaging of primarily soft-drink cans, pet food, seafood, and prethreaded closures.

The main disadvantages of aluminum are its high cost compared to other metals (e.g., steel) and its inability to be welded, which renders it useful only for making seamless containers (Maloney, 2003).

8.2.2.2 Aluminum Foil

Aluminum foil is made by rolling pure aluminum metal into very thin sheets, followed by annealing to achieve dead-folding properties (a crease or fold made in the film will stay in place), which allows it to be folded tightly. Moreover, aluminum foil is available in a wide range of thicknesses, with thinner foils used to wrap food and thicker foils used for trays. Like all aluminum packaging, foil provides an excellent barrier to moisture, air, odors, light, and microorganisms. It is inert to acidic foods and does not require lacquer or other protection. Although aluminum is easily recyclable, foils cannot be made from recycled aluminum without pinhole formation in the thin sheets (Bix et al., 2010).

8.2.2.3 Laminates and Metallized Films

Lamination of packaging involves the binding of aluminum foil to paper or plastic film to improve barrier properties. Although lamination to plastic enables heat sealability, the seal does not completely bar moisture and air. Because laminated aluminum is relatively expensive, it is typically used to pack high-value foods such as dried soups, herbs, and spices. A less expensive alternative to laminated packaging is metallized film. Metallized films are plastics containing a thin layer of aluminum metal (Fellows & Axtell, 2002). These films have improved barrier properties to moisture, oils, air, and odors, and the highly reflective surface of the aluminum is attractive to consumers. More flexible than laminated films, metallized films are mainly used to package snacks. The individual components of laminates and metallized films are technically recyclable (Johnson, 1995).

8.2.2.4 Tinplate

Produced from low-carbon steel (blackplate), tinplate is the result of coating both sides of blackplate with thin layers of tin. The coating is achieved by dipping sheets of steel in molten tin (hot-dipped tinplate) or by the electro-deposition of tin on the steel sheet (electrolytic tinplate). Tin provides steel with some corrosion resistance; tinplate containers are often lacquered to provide an inert barrier between the metal and the food product. Commonly used lacquers are materials of epoxy phenolic and oleoresinous groups and vinyl resins.

In addition to its excellent barrier properties to gases, water vapor, light, and odors, tinplate can be heat treated and sealed hermetically, making it suitable for sterile products. Since it has good ductility and formability, tinplate can be used for containers of many different shapes. Thus, tinplate is widely used to form cans for drinks, processed foods, and aerosols; containers for powdered foods and sugar- or flour-based confections; and as package closures. Tinplate is an excellent substrate for modern metal coating and printing technology, enabling outstanding graphical decoration. Its relatively low weight and high mechanical strength make it easy to ship and store (Cooke, 1998). Finally, tinplate is easily recycled many times without loss of quality and is significantly lower in cost than aluminum.

8.2.2.5 Tin-Free Steel

This is also known as electrolytic chromium or chrome-oxide-coated steel; tin-free steel requires a coating of organic material to provide complete corrosion resistance. Even though the chrome/chrome oxide makes tin-free steel unsuitable for welding, this property makes it excellent for adhesion of coatings such as paints, lacquers, and inks. Like tinplate, tin-free steel has good formability and strength, but it is marginally less expensive than tinplate. Food cans, can ends, trays, bottle caps and closures can all be made from tin-free steel. In addition, it can also be used to make large containers (such as drums) for bulk sale and bulk storage of ingredients or finished goods (Dvorak, 2008).

8.2.3 Plastics

Plastic polymers of various compositions can satisfy many of these functions in a more or less acceptable way. In India, 12 different types of thermoplastics are used as raw materials for the production of packaging materials. The Bureau of Indian Standards (BIS) has formulated guidelines on the suitability of plastics for food packaging (IS 10171). A major limitation of plastic FPMs is they require additives that guarantee certain properties required for suitable function. These are combined to provide sufficient plasticity: antioxidants to protect the product from degradation by atmospheric oxygen, light filters to decrease UV-light-dependent degradation, colors to generate the intended attractive appearance of the package, printing inks to apply written and graphic information, and so on. However, the nature of the polymerization process makes it negligible that the plastic FPMs contain residues of mono- and oligomers of the starting materials as well as additives required for the polymerization and maturation process of the polymer such as catalysts, cross-linkers, polymerization modifiers, stopping components, and so on. Hence there are possible risks for biodegradability, migration of compounds toward the contained product, and greater compatibility. Plastics are made by condensation polymerization (polycondensation) or addition polymerization (polyaddition) of monomer units. In polycondensation, the polymer chain grows by condensation reactions between molecules and is accompanied by the formation of low-molecular- weight byproducts such as water and methanol. Polycondensation involves monomers with at least two functional groups such as alcohol, amine, or carboxylic groups (Urbanek et al., 2011). In polyaddition, polymer chains grow by addition reactions, in which two or more molecules combine to form a larger molecule without liberation of byproducts. Polyaddition involves unsaturated monomers; double or triple bonds are broken to link monomer chains. There are several advantages to using plastics for food packaging. Fluid and moldable, plastics can be made into sheets, shapes, and structures, offering considerable design flexibility. Because they are chemically resistant, plastics are inexpensive and lightweight with a wide range of physical and optical properties. In fact, many plastics are heat sealable, easy to print, and can be integrated into production processes where the package is formed, filled, and sealed. The major disadvantage of plastics is their permeability to light, gases, vapors and low-molecular-weight molecules (Singh et al., 2007). There are two major categories of plastics: thermosets and thermoplastics. Thermosets are polymers that solidify or set irreversibly when heated and cannot be remolded. Because they are strong and durable, they tend to be used primarily in automobiles and construction applications such as adhesives and coatings, not in food packaging applications. On the other hand, thermoplastics are polymers that soften upon exposure to heat and return to their original condition at room temperature. Because thermoplastics can easily be shaped and molded into various products such as bottles, jugs, and plastic films, they are ideal for food packaging. Moreover, all thermoplastics are recyclable (melted and reused as raw materials for production of new products), although separation poses some practical limitations for certain products. The recycling process requires separation by resin type as identified by the American Plastics Council (Marcondes et al., 2003).

There have been some health concerns regarding residual monomers and components in plastics, including stabilizers, plasticizers, and condensation components such as bisphenol A. To ensure public safety, the Food and Drug Administration (FDA) carefully reviews and regulates substances used to make plastics and other packaging materials. Any substance that can reasonably expect to migrate into food is classified as an indirect food additive subject to FDA regulations. A threshold of regulation (TOR) – defined as a specific level of dietary exposure that typically induces toxic effects and therefore poses negligible safety concerns – may be used to exempt substances used in food contact materials from regulation as food additives. Furthermore, FDA advises consumers to use plastics for intended purposes in accordance with the manufacturer's directions to avoid unintentional safety concerns (Ahmed et al., 2005).

Despite these safety concerns, the use of plastics in food packaging has continued to increase due to the low cost of materials and functional advantages (such as thermosealability, microwavability, optical properties, and unlimited sizes and shapes) over traditional materials such as glass and tinplate (Rubio et al., 2004). Multiple types of plastics are being used as materials for packaging food, including polyolefin, polyester, polyvinyl chloride, polyvinylidene chloride (PVdC), polystyrene (PS), polyamide (PA), and ethylene vinyl alcohol (EVOH). Although more than 30 types of plastics have been used as packaging materials (Lau & Wong, 2000), polyolefins and polyesters are the most common (Urbanek et al., 2011).

8.2.3.1 Polyolefins

Polyolefin is a collective term for polyethylene (PE) and polypropylene (PP), the two most widely used plastics in food packaging, and other less popular olefin polymers. PE and PP both possess a successful combination of properties, including flexibility, strength, lightness, stability, moisture and chemical resistance, and easy processability, and they are suitable for recycling and reuse.

The simplest and most inexpensive plastic made by addition polymerization of ethylene is PE. There are two basic categories of PE: high density and low density. High-density PE (HDPE) is stiff, strong, tough, resistant to chemicals and moisture, permeable to gas, easy to process, and easy to form. It is used to make bottles for milk, juice, and water; cereal box liners; margarine tubs; and grocery, trash, and retail bags. Low-density PE (LDPE) is flexible, strong, tough, easy to seal, and resistant to moisture. Because LDPE is relatively transparent, it is predominately used in film applications and in applications where heat sealing is necessary. Bread and frozen food bags, flexible lids, and squeezable food bottles are examples of LDPE. PE bags are sometimes reused. Among the two categories of PE, HDPE containers, especially milk bottles, are the most recycled among plastic packages (Marcondes et al., 2003).

Harder, denser, and more transparent than PE, PP has good resistance to chemicals and is effective at barring water vapor. Its high melting point (160°C) makes it suitable for applications where thermal resistance is required, such as hot-filled and microwavable packaging. Popular uses include yogurt containers and margarine tubs. When used in combination with an oxygen barrier such as EVOH or PVdC, PP provides the strength and moisture barrier.

8.2.3.2 Polyesters

Polyethylene terephthalate (PET or PETE), polycarbonate, and polyethylene naphthalate (PEN) are polyesters, which are condensation polymers formed from ester monomers that result from the reaction between carboxylic acid and alcohol. The most commonly used polyester in food packaging is PETE (Ampuero & Vila, 2006).

8.2.3.3 Polyethylene Terephthalate

This is formed when terephthalic acid reacts with ethylene glycol; PETE provides a good barrier to gases (oxygen and carbon dioxide) and moisture. It also has good resistance to heat, mineral oils, solvents, and acids, but not to bases. Consequently, PETE is becoming the packaging material of choice for many food products, particularly beverages and mineral waters. The use of PETE to make plastic bottles for carbonated drinks is increasing rapidly. The main reasons for its application are its glass-like transparency, adequate gas barrier for retention of carbonation, light weight, and shatter resistance. The three major packaging applications of PETE are containers (bottles, jars, and tubs), semi-rigid sheets for thermoforming (trays and blisters), and thin-oriented films (bags and snack food wrappers). PETE exists both as an amorphous (transparent) and a semi-crystalline (opaque and white) thermoplastic material. Amorphous PETE has better ductility but less stiffness and hardness than semicrystalline PETE, which has good strength, ductility, stiffness, and hardness. Recycled PETE from soda bottles is used as fibres and for insulation and other non-food-packaging applications (Vogel et al., 2002).

8.2.3.4 Polycarbonate

Polycarbonate is formed by polymerization of a sodium salt of bisphenol acid with carbonyl dichloride (phosgene). It is clear, heat resistant, and durable and is mainly used as a replacement for glass in items such as large refillable water bottles and sterilizable baby bottles. Care must be taken when cleaning with polycarbonate because harsh detergents such as sodium hypochlorite catalyze the release of bisphenol A, a potential health hazard (Singh et al., 2007).

8.2.3.5 Polyethylene Naphthalate

This is a condensation polymer of dimethyl naphthalene dicarboxylate and ethylene glycol. It is a relatively new member of the polyester family with excellent performance because of its high glass transition temperature. PEN's barrier properties for carbon dioxide, oxygen, and water vapor are superior to those of PETE, and PEN provides better performance at high temperatures, allowing hot refills, rewashing, and reuse. However, PEN costs three to four times more than PETE. Because PEN provides protection against transfer of flavors and odors, it is well suited for manufacturing bottles for beverages such as beer (Bix et al., 2010).

8.2.3.6 Polyvinyl Chloride (PVC)

This is an addition polymer of vinyl chloride. It is heavy, stiff, and ductile and is a medium strength, amorphous, transparent material. It has excellent resistance to chemicals, grease, and oil; good flow characteristics; and stable electrical properties. Although PVC is primarily used in medical and other nonfood applications, its food uses include bottles and packaging films. Because it is easily thermoformed, PVC sheets are widely used for blister packs such as those for meat products and unit dose pharmaceutical packaging.

PVC can be transformed into materials with a wide range of flexibility with the addition of plasticizers such as phthalates, adipates, citrates, and phosphates. Phthalates are mainly used in non-food-packaging applications such as cosmetics, toys, and medical devices. Safety concerns have emerged over the use of phthalates in certain products, such as toys. Because of these safety concerns, phthalates are not used in FPMs in the United States; instead, alternative non-phthalate plasticizers such as adipates are used. For example, di-(2-ethylhexyl) adipate (DEHA) is used in the manufacture of plastic cling wraps. These alternative plasticizers also have the potential to leach into food but at lower levels than phthalates. Low levels of DEHA have shown no toxicity in animals. Finally, PVC is difficult to recycle; in addition incineration of PVC presents environmental problems because of its chlorine content (Urbanek et al., 2011).

8.2.3.7 Polyvinylidene Chloride

This is an addition polymer of vinylidene chloride. It is heat sealable and serves as an excellent barrier to water vapor, gases, and fatty and oily products. It is used in flexible packaging as a monolayer film, a coating, or part of a co-extruded product. Major applications include packaging of poultry, cured meats, cheese, snack foods, tea, coffee, and confectionaries. It is also used in hot filling, retorting, low-temperature storage, and modified atmosphere packaging (MAP). PVdC contains twice the amount of chlorine as PVC and therefore also presents problems with incineration (Cooke, 1998).

8.2.3.8 Polystyrene

PS, an addition polymer of styrene, is clear, hard, and brittle with a relatively low melting point. It can be mono-extruded, co-extruded with other plastics, injection molded, or foamed to produce a range of products. Foaming produces an opaque, rigid, lightweight material with impact protection and thermal insulation properties. Typical applications include protective packaging such as egg cartons, containers, disposable plastic silverware, lids, cups, plates, bottles, and food trays. In expanded form, PS is used for non-food packaging and cushioning, and it can be recycled or incinerated (Urbanek et al., 2011).

8.2.3.9 Polyamide

Commonly known as nylon, PAs were originally used in textiles. Formed by a condensation reaction between diamine and diacid, PAs are polymers in which the repeating units are held together by amide links. Different types of PAs are characterized by a number that relates to the number of carbons in the originating monomer. For example, nylon-6 has six carbons and is typically used in packaging. It has mechanical and thermal properties similar to PET, so it has similar usefulness, such as boil-in-bag packaging. Nylon also offers good chemical resistance, toughness, and low gas permeability (Brown, 1958).

8.2.3.10 Ethylene Vinyl Alcohol

EVOH is a copolymer of ethylene and vinyl alcohol. It is an excellent barrier to oil, fat, and oxygen. However, EVOH is moisture sensitive and is thus mostly used in multilayered co-extruded films in situations where it is not in direct contact with liquids.

8.2.3.11 Laminates and Co-extrusions

Plastic materials can be manufactured either as a single film or as a combination of more than one plastic. There are two ways of combining plastics: lamination and co-extrusion. Lamination involves bonding together two or more plastics or bonding plastic to another material such as paper or aluminum. Bonding is commonly achieved by use of water, solvent, or solid-based adhesives. After the application of adhesives to one film, the two films are passed between rollers to pressure bond them together. Lamination using lasers rather than adhesives has also been used for thermoplastics (Kirwan & Strawbridge, 2003). Lamination enables reverse printing, in which the printing lies between layers and is thus not subject to abrasion, and can add or enhance heat sealability (Capsule, 2008).

In co-extrusion, two or more layers of molten plastics are combined during the film manufacture. This process is more rapid but requires materials that have thermal characteristics that allow co-extrusion. Because co-extrusion and lamination combine multiple materials, recycling is complicated. However, combining materials results in the additive advantage of properties from each individual material and often reduces the total amount of packaging material required. Therefore, co-extrusion and lamination can be sources of packaging reduction.

Some of the combinations of plastics used for packaging are as follows:

- BOPP (biaxially oriented PP)/LDPE
- BOPP/polyester/LDPE
- Metallized polyester/LDPE
- BOPP/metallized polyester/LDPE
- Polyester/LDPE
- Polyester/Aluminum foil/LDPE

8.2.4 Paper and Paperboard

Further alternatives for FPMs are paper and cardboard. These materials mainly originate from wood, which is treated in various ways. Paper and cardboard are widely considered as recycling products to represent “natural” FPMs; however, the manufacturing process of these materials may require the use of a broad spectrum of chemicals. These include preservatives protecting the FPM from degradation by microorganisms, plastic polymer coatings to improve the normally weak barrier function of paper, printing inks and colors, UV protectants, and chemicals used in the pulp and paper production. Since noncoated paper and cardboard are relatively porous materials, aqueous or oily liquids (from the food) may have access to the body of the material, eventually extracting those chemicals from the FPM. The use of recycled paper and cardboard for the production of FPMs is another problematic issue because of chemicals already present in the recycled materials (Cardello, 1994).

The use of paper and paperboards for food packaging dates back to the 17th century with accelerated usage in the later part of the 19th century (Kirwan & Strawbridge, 2003). Paper and paperboard are sheet materials made from an interlaced network of cellulose fibers derived from wood using sulfate and sulfite. The fibers are then pulped and/or bleached and treated with chemicals such as slimicides and strengthening agents to produce the paper product. The FDA regulates the additives used in paper and paperboard food packaging. Paper and paperboards are commonly used in corrugated boxes, milk cartons, folding cartons, bags and sacks, and wrapping paper. Tissue paper, paper plates, and cups are other examples of paper and paperboard products (Urbanek et al., 2011).

8.2.4.1 Paper

Plain paper is not used to protect foods for long periods of time because it has poor barrier properties and is not heat sealable. When used as primary packaging (i.e., in contact with food), paper is almost always treated, coated, laminated, or impregnated with materials such as waxes, resins, or lacquers to improve functional and protective properties. The many different types of paper used in food packaging are as follows:

- *Kraft paper*: Produced by a sulfate treatment process, kraft paper is available in several forms: natural brown, unbleached, heavy duty, and bleached white. The natural kraft is the strongest of all paper and is commonly used for bags and wrapping. It is also used to package flour, sugar, and dried fruits and vegetables.
- *Sulfite paper*: Lighter and weaker than kraft paper, sulfite paper is glazed to improve its appearance and to increase its wet strength and oil resistance. It can be coated for higher print quality and is also used in laminates with plastic or foil. It is used to make small bags or wrappers for packaging biscuits and confectionary.
- *Greaseproof paper*: Greaseproof paper is made through a process known as beating, in which the cellulose fibers undergo a longer than normal hydration period that causes the fibers to break up and become gelatinous. These fine fibers then pack densely to provide a surface that is resistant to oils but not wet agents. Greaseproof paper is used to wrap snack foods, cookies, candy bars and other oily foods, a use that is being replaced by plastic films.

- *Glassine*: Glassine is greaseproof paper taken to an extreme to produce a very dense sheet with a highly smooth and glossy finish. It is used as a liner for biscuits, cooking fats, fast foods, and baked goods.
- *Parchment paper*: Parchment paper is made from acid-treated pulp (passed through a sulfuric acid bath). The acid modifies the cellulose to make it smoother and impervious to water and oil, which adds some wet strength. It does not provide a good barrier to air and moisture, is not heat sealable, and is used to package fats such as butter and lard (Cooke, 1998).

8.2.4.2 Paperboard

Paperboard is thicker than paper with a higher weight per unit area and is often made in multiple layers. It is commonly used to make containers for shipping such as boxes, cartons, and trays and seldom used for direct food contact. The various types of paperboard are as follows:

- *White board*: Made from several thin layers of bleached chemical pulp, white board is typically used as the inner layer of a carton. White board may be coated with wax or laminated with PE for heat sealability, and it is the only form of paperboard recommended for direct food contact.
- *Solid board*: Possessing strength and durability, solid board has multiple layers of bleached sulfate board. When laminated with PE, it is used to create liquid cartons (known as milk board). Solid board is also used to package fruit juices and soft drinks.
- *Chipboard*: Chipboard is made from recycled paper and often contains blemishes and impurities from the original paper, which makes it unsuitable for direct contact with food, printing, and folding. It is often lined with white board to improve both appearance and strength. The least expensive form of paperboard, chipboard, is used to make the outer layers of cartons for foods such as tea and cereals.
- *Fiberboard*: The fiberboard can be solid or corrugated. The solid type has an inner white board layer and outer kraft layer and provides good protection against impact and compression. When laminated with plastics or aluminum, solid fiberboard can improve barrier properties and is used to pack dry products such as coffee and milk powder. The corrugated type, also known as corrugated board, is made with two layers of kraft paper with a central corrugating (or fluting) material. Fiberboard's resistance to impact abrasion and crushing damage makes it widely used for shipping bulk food and packing of retail food products (Urbanek et al., 2011).

8.2.4.3 Paper Laminates

Paper laminates are coated or uncoated papers based on kraft and sulfite pulp. They can be laminated with plastic or aluminum to improve various properties. For example, paper can be laminated with PE to make it heat sealable and to improve gas and moisture barrier properties. However, lamination substantially increases the cost of paper. Laminated paper is used to package dried products such as soups, herbs, and spices.

8.3 TESTING FOR FPMS

In food production, packaging makes food more convenient. It gives the food greater safety assurance from microorganisms and biological and chemical changes such that the packaged foods can enjoy a longer shelf life. As a result, packaging has become an indispensable element in the food manufacturing process. Several testing methods for the materials used for food packaging have been carried out before approving them. The basis of packaging design and performance is the component materials. The physical properties, and sometimes chemical properties, of the materials need to be communicated to packaging engineers to aid in the design process. Packaging materials testing is often needed to identify the critical material characteristics and engineering tolerances. These are used to prepare and enforce specifications.

For example, shrink film data might include tensile strength (MD and CD), elongation, elastic modulus, surface energy, thickness, moisture vapor transmission rate, oxygen transmission rate (OTR), heat seal strength, heat sealing conditions, heat shrinking conditions, and so on. Average and process capability is often provided. The chemical properties related touse as food contact materials may be necessary.

Many suppliers or vendors offer limited material and package testing as a free service to customers. It is common for packagers to partner with reputable suppliers: Many suppliers have certified quality management systems such as ISO 9000 or allow customers to conduct technical and quality audits. Data from testing is commonly shared. There is sometimes a risk that supplier testing may tend to be self-serving and not completely impartial.

Large companies often have their own packaging staff and a package testing and development laboratory. Corporate engineers know their products, manufacturing capabilities, logistics system, and their customers best. Cost reduction of existing products and cost avoidance for new products have been documented (Bix et al., 2010).

Another option is to use a paid consultant, independent contractor, and third-party independent testing laboratory. They are commonly chosen for specialized expertise, for access to certain test equipment, for surge projects, or where independent testing is otherwise required. Many have certifications and accreditations: ISO 9000, ISO/IEC 17025, and various governing agencies.

8.3.1 Migration of Compounds from FPM

The term "migration" usually describes a diffusion process, which may be strongly influenced by an interaction of components of the food with the packaging material. This interaction may substantially affect the properties of the packaging material. However, food components, particularly fat, that migrate into plastics will considerably increase the mobility of plastic components, thus enhancing the migration into the contained food.

8.3.1.1 Migration from Paper and Paperboards

Paper and paperboards are widely used as FPMs. As far as public interest is concerned, the conservation of natural resources has increased in the past several years, and the use of recycled paper and board has increased. Recycled fiber materials can be used within certain limits as food contact materials. The safety of recycled fiber-based materials for food contact applications is largely affected by the ability of postconsumer contaminants to be absorbed into recycled materials and later released by the packaging material and trapped on the food. In an accelerated study at 70°C and 100°C, it was found that benzophenone, which is widely used as a photo-initiator for inks that are cured with ultraviolet (UV) light, is a carcinogen at higher levels of exposure and is a highly fat-soluble compound; whole milk powders in direct contact with paper samples pick up benzophenone at higher levels compared to food products with less fat content. Migration is generally rapid and extensive, and to keep migration in acceptable limits a low storage temperature should be applied in combination with a suitable barrier layer for indirect contact when recycled paper is used. Certain heavy metals are also found to be transferred from recycled paper to food (Marcondes et al., 2003).

8.3.1.2 Migration from Metals

Metal food packaging itself covers a wide range of packaging types including food and beverage cans and ends, closures, tubes, trays, drums, and pails. Although metal is the defining component of these packages providing strength and integrity, the additional materials required to make a functional package are more often the primary food contact materials in the package. The metals used to manufacture cans, ends, and closures are either steel (tinplated) or aluminum. In most cases, they are coated on the food contact surface with a resinous or polymeric protective coating to avoid interaction between the food and the metal. These coatings use bisphenol A diglycidyl ether (BADGE) as plasticizer. Bisphenol A (BPA) may act as an endocrine disruptor, which can cause developmental and neurological impacts. Some studies have investigated BPA release from can linings. The amount of BPA migrated from the can coating into the food during processing (90 min at 121°C) was found to be very high (80–100% of the total BPA present in the can coating), indicating that high processing temperatures promote migration (Maloney, 2003).

The nature of the gasket materials used for vacuum closures (PVC plastisols) can lead to significant levels of plasticizer migration when used in contact with fatty foods under sterilization or pasteurization conditions. It is not possible to obtain tin with zero lead contamination as the elements coexist in the ore. As a consequence, the tin content of tinplate will always contain traces of lead, but the regulations have been made to limit the lead content in the tin coating of tinplate for food packaging to 100 mg/kg as defined in European Standard EN 10333 (Ahmed et al., 2005).

8.3.1.3 Migration from Glass

Glass is the most inert packaging material for foods. Several studies in various countries have investigated that glass as a packaging material itself is harmless considering migration of heavy metals – lead, cadmium, total chromium, and mercury. All results were negative, that is, below the threshold. Using clean lab methods and protocols developed for measuring lead in polar snow and ice, it is found that the greatest lead concentration found in water from a glass bottle (417 ng/L) is well below the maximum allowable concentration for lead in drinking water set by the EU, Health Canada, and the WHO (10 μg/L).

8.3.1.4 Migration from Polymeric Materials

Plastic packaging includes trays and lids, films, pouches, bottles, and so on. Plastic reinforces metals for lining closures, glass to reduce container breakage, and paper for moisture resistance. Multilayer polymeric packaging is made by combining two or more plastic films through co-extrusion, blending, lamination, and coating to achieve desired features such as gas and moisture barrier properties, UV and visible light transmission, flexibility, stretchability, heat sealability, low glass transition, and other mechanical properties indicative of strength or performance characteristics (Brown, 1958).

8.3.1.5 Hazardous Migrating Components in Plastic Packages

Additives enhance the performance of polymers during processing and fabrication. Plasticizers, antioxidants, light stabilizers, lubricants, antistatic agents, slip compounds, thermal stabilizers, and printing ink are the most commonly used additives in different types of polymeric packaging materials. Unreacted monomers and oligomers may also migrate from plastics to foods. The restriction has also been applied to the specific migration limits for some metals and primary aromatic amines migrating from plastic packages into food.

8.3.1.6 Methods for Detecting the Migration of Compounds

Appropriate analytical methods are needed to determine migration from packaging materials into food. Regulatory agencies have specified analytical methods for some, but not all, migrants. Official test methods are usually time-consuming, complicated, and impractical for routine or daily controls. The methods used are based mainly on the extraction followed by chromatographic or spectrophotometric analysis. Mathematical models have been developed and are used frequently to predict the migration of the low-molecular-weight components from plastic packaging and may be suitable for materials with migration data. However, these models do not adjust to different polymeric properties and behavior, especially in terms of migration from new polymeric materials without well-characterized properties. Therefore, experimental determination of migrating compounds must be conducted to verify the accuracy of the migration results predicted by the developed mathematical models. A number of gas-chromatographic techniques for different plasticizers have been developed. Determinations of styrene monomers in food and food simulants using gas chromatography (GC) techniques are common. PET oligomers in olive oil and iso-octane have been determined using gas chromatography-mass spectroscopy (GC-MS) with selective ion monitoring (SIM) and high performance liquid chromatography–ultraviolet (HPLC-UV) (Cardello, 1994).

8.3.2 Migration Tests

Types of testing food contact materials are migration tests, simple testing for identification of types of packaging polymers, and permeability testing. Generally there are two types of migration:

- *Global migration*: There is a monitored transmission level of all compounds or components of polymers into food or food simulants.
- *Specific migration*: There is a monitored transmission level of specific compounds or components (e.g., primary aromatic amines) of polymers into food or food simulants. There is a problem, because many types of food material have very complex matrices, which are not chemically uniform, and determination of migrant substance is very complicated.

For better determination of compound migration there are four basic food simulants:

1. Distilled water (substitution of neutral food)
2. Diluted acid solution (e.g., 3% (w/v) acetic acid solution, substitution of acidic food)
3. Ethanol/water mixtures (e.g., 10% (v/v) ethanol solution, substitution of alcoholic food)
4. Olive oil or iso-octane (substitution of fatty food)

Aromatic amines extracted from tested samples that are in contact with tested material at the specific time and the specific temperature react in the presence of hydrochloric acid (HCl), sodium nitrite ($NaNO_2$), and ammonium sulfamate with *N*-(1-naphthyl) ethylene diamine dihydrochloride to produce a violet product whose intensity is measured by a spectrophotometer at wavelength 550 nm.

For calculation of migration of aromatic amines from a food contact material into a food simulant, the following formula can be used:

$$Mi = \frac{Vci \times mi}{Pi \times Vi},$$

where Pi means area of the tested sample that was in contact with the food stimulant; mi means the amount of aniline (amines) in an aliquot volume of food stimulant that was deducted from the calibration curve; Vi means the aliquot volume that was added into test tube; Vci means the total volume of food simulant that was in contact with the tested sample; Mi means the amount of aromatic amines that was transferred from the food contact material into the food stimulant.

8.3.2.1 Tensile Profile

Tensile strength (and other tensile properties) of packaging material is obtained by an Instron device. This device measures the required force to break the strips that were cut out from the packaging material. Strips cut from the packaging material by the cutting device measure the thickness of strips. A tensile profile of the packaging material is determined by the Instron measuring device. The software program itself will assess the tensile profile and will calculate four basic parameters: maximal force at break moment (N), tensile strength (M Pa), elongation at break moment (mm), and mechanical work (J) required for irreversible deformation (Singh et al., 2007).

8.3.2.2 Water Vapor Permeability

Water vapor permeability is determined by gravimetric analysis. Dry silica gel in boxes with a cap from packaging material changes its own weight, because silica gel receives water vapor through packaging material in an environment with known relative humidity and temperature. A circle with specific proportions was cut from the tested packaging material. Dry silica gel was placed into boxes (approximately the same amount of silica gel in each box), and the open space over the silica gel was covered by the circle from the packaging material. The space between the packaging material and the box was sealed by a molten mixture of wax and paraffin. Boxes were weighed immediately after sealing; at the time interval of 1 hour the weight and the time of weighing were noted. For determination of water vapor permeability in g $H_2O/(m^2 \times \text{day})$, the following formula can be used:

$$q = \frac{240 \times \Delta m}{S \times \Delta t},$$

where Δt means the difference of time (hours) between two weighings; Δm means difference of box weight (mg) between two weighings; S means area (cm^2) of cap from packaging materials; q means water vapor permeability in g $H_2O/(m^2 \times \text{day})$ (Vogel et al., 2002).

8.3.3 Sensory Analysis (Taint Test)

The packaging materials have a great influence on the taste and flavor of the food through their contact with the food. The Robinson test is considered to be the most appropriate sensorial analytical method to evaluate the effect of packaging materials on the organoleptic properties of the packed food products. During the Robinson test, a panel assesses possible taste differences of milk chocolate caused by the packaging material. Given the fatty matrix and the high affinity to migration components, milk chocolate is an ideal test medium. For the organoleptic evaluation, three alternative testing procedures are described: the triangle test, the extended triangle test, and the multi-comparison test. Triangle tests are performed to check whether a difference exists between two products (Maloney, 2003).

The assessors simultaneously receive three standardized samples (e.g., same size, same temperature, same quantity, and same homogeneity). Two samples are identical; the third sample is different (two test samples and one blank or two blank samples and one test sample). The assessors have to indicate which sample is the different sample. Data are processed statistically. If an assessor indicates the correct different sample, then an extended triangle test also asks to evaluate the intensity of the taint by using a scale from 0 to 4. In a multi-comparison test, a known reference (blank sample) is applied. The intensity of the taint is evaluated in relation to this reference on a scale from 0 to 4.

Some types of package testing do not use scientific instruments but use people for the evaluation. The regulations for child-resistant packaging require a test protocol that involves children. Samples of the test packages are given to a prescribed population of children. With specified 50-child panels, a high percentage must be unable to open a test package within 5 min. Adults are also tested for their ability to open a child-resistant package. Consumer packages are often evaluated by focus groups. The consumer responses are treated qualitatively for feedback into the new packaging process (Dvorak, 2008).

Some food packagers use organoleptic evaluations. People use their senses (taste, smell, etc.) to determine if a package component has tainted the food in the package. A new package may be evaluated in a test market that uses people to try the packages at home. Packaging evaluations are an important part of marketing research. Legibility of text on packaging and labels is always subjective due to the inherent variations of people. Efforts have been made to help better quantify this by people in a laboratory.

8.3.4 Irradiation of FPMs

The US FDA allows the use of irradiation as a means for improving food safety and extending the shelf life of certain foods. Although not yet widely used, irradiation can kill the bacteria responsible for food-borne illness and food spoilage, as well as insects and parasites that may be present on food. Additionally, in certain fruits and vegetables, irradiation can inhibit sprouting and delay ripening. For example, irradiated strawberries stay unspoiled up to three weeks. Foods are typically packaged in final form prior to being irradiated, thus reducing the likelihood that new pathogens will be introduced after the irradiation step. This means that the packaging materials are being exposed to the same radiation source as the food itself. In an effort to ensure the safety of the food, the packaging material must not be altered in a way that causes a chemical change in the packaging to be added indirectly to the food. Over the years many FPMs have been approved for irradiation. Likewise, new food packaging products, such as oxygen barrier materials, have also been introduced. The safety assessment of such complex materials has presented new challenges to the FDA and the food industry (Maloney, 2003).

8.3.5 Regulatory Requirements

Provisions to ensure the safety of FPMs exposed to irradiation are found in a number of parts of the Federal Food, Drug, and Cosmetic Act. The primary regulation covering the use of irradiation in the production, processing, and handling of food is 21 Code of Federal Regulations (*CFR*) 179. This regulation explains the general provisions for food irradiation, lists approvals FDA has granted to food additive petitions pertaining to irradiation, and describes radiation and radiation sources, including ionizing, radio frequency, ultraviolet, and pulsed light radiation. Most significantly, 21 *CFR* 179 specifies that the irradiation of both food and packaging materials in contact with food is subject to premarket approval before introduction of the food into commercial markets. It further specifies that the current good manufacturing practice for irradiated foods includes three things. First, manufacturers must comply with the general requirements of the current good manufacturing practice for manufacturing, packaging, or holding human food found in 21 *CFR* 110. Second, manufacturers must ensure that the radiation dose used is the minimum dose required to achieve the intended technical effect and does not exceed the level specified in the regulations. Third, the packaging materials used during the irradiation treatment must comply with the requirements found in 21 *CFR* 179.45, the specifications for an effective food contact notification or a TOR exemption. Foods currently permitted to be irradiated are listed in 21 *CFR* 179.26(b) (Bix et al., 2010). Finally, the irradiated food must be properly labeled.

8.3.6 Effects of Irradiation

Irradiation can cause changes to a packaging material that might affect its integrity and functionality as a barrier to chemical or microbial contamination. Radiation does not generally affect all properties of a polymer or adjuvant to the same degree. Two concepts are important here. First, most FPMs are composed of polymers that may be susceptible to chemical changes induced by ionizing radiation that are the result of two competing reactions, cross-linking (polymerization) and chain scission (degradation). Radiation-induced cross-linking of polymers dominates under vacuum or an inert atmosphere. Chain scission dominates during irradiation of polymers in the presence of oxygen or air. Both reactions are random, generally proportional to dose, and depend on dose rate and the oxygen content of the atmosphere in which the polymer is irradiated. The idea of cross-linking predominating under vacuum or in an inert atmosphere is important because it served as the basis for granting recent exemption requests under 21 *CFR* 170.39 for packaging materials irradiated in contact with food either in a verifiably oxygen-free environment or while frozen and contained under vacuum.

Second, in the presence of atmosphere oxygen, radiation-induced degradation of both the base polymer and adjuvants, such as antioxidants or stabilizers, is likely to occur and results in the formation of radiolytic products. The radiolytic products formed upon irradiation may be present at significant levels such that they could migrate into food and affect the odor, taste, or safety of the irradiated food. For example, it is well known that certain adjuvants are prone to degradation during polymer processing. During irradiation they would be expected to degrade preferentially over the polymer and result in the formation of radiolytic products in the polymer that could potentially migrate into food. Therefore, the migration of both base polymers and adjuvants, as well as migration of their radiolytic products, must be evaluated in the premarket safety assessment of new packaging materials, especially at high dose levels and in the presence of oxygen (Marcondes et al., 2003).

8.3.6.1 Irradiating New Materials

The FDA's safety assessment relies on evaluating probable consumer exposure to a food contact substance, including all constituents or impurities as a result of the proposed use, and on the available toxicological information. It is important to understand that the safety assessment focuses on those substances that would be expected to become components of food as a result of the proposed use of the food contact substance. The FDA's toxicological assessment is based on a tiered approach, and therefore the recommended toxicological data depend on the exposure estimates for the radiolytic products and other migrants from the proposed use. The FDA recommends that all data and information be generated in accordance with the available guidance documents. The identities, residue and migration levels, and consumer exposures to the radiolytic products that are generated in the packaging materials may be of concern depending on the regulatory status of the substances, as well as the presence or absence of oxygen. The formation of radiolytic products depends on irradiation conditions that include the absorbed dose, the dose rate, the amount of oxygen in the atmosphere, the temperature, the time after irradiation, and the food simulant. To evaluate the fate of the components of irradiated new packaging materials in comparison to nonirradiated materials, one can develop an appropriate testing protocol that might involve an irradiation experiment designed to simulate the actual application conditions for determining the effects of irradiation on the packaging materials. After irradiation, the test materials can be analyzed for radiolytic products or other migrants, as applicable, using methods and techniques that may require various analytical instruments. Any analytical methods used in the analysis for radiolytic products in an irradiated test specimen should give some consideration to identification and quantification of an unknown migrant (ASTM D6954, 2004).

8.3.7 Testing of Bottles

Bottles for juice, soda, and water are available in different sizes and shapes. They are tested for structural rigidity to ensure that they won't experience any cracking when filled or fold over when stacked. They are also subjected to burst testing to identify the point of failure when filled with fluid. Dimensional measurements are performed to ascertain trouble-free passing of bottles through production lines. Structural integrity is ensured by checking consistency through thickness measurements at various points. Since bottles are often shipped on pallets and stored by placing them on top of each other, it is necessary to perform a top-load test to assess their rigidity and identify their ability to withstand stacking forces. These tests are normally performed on a digital force tester equipped with compression plates to exert a force on the top of the bottle. The tester is programmed to move its crosshead down depending on the bottle height so that it will apply a force enough to make contact with the bottle top. The next step involves compressing the bottle down to a set displacement point and recording the force reading at that point. The initial bottle height and force reading at that displacement point must lie within a tolerance range prescribed by the quality department to give assurance to the users that the bottles deliver the desired function for the fluid they hold (Aarnio & Hamalainen, 2008).

8.3.8 Testing of Seals

The seals applied on packaging for cereal, potato chips, cookies, and yogurt are thoroughly tested to ensure their ability to deliver the desired performance. These seals may be pressure sealed or adhered together. If the seal used for sealing the bag material is much stronger than the bag material, the bag will rip open despite the seal, causing the food to fall out of the bag. The strength of the seal is determined by peel testing, which involves pulling the seals apart. This test provides valuable data to determine the bag's structural integrity during the application of forces.

8.3.8.1 Peel Tests

A testing system like the Lloyd LS1 testing machine is required to perform the peel tests. A common test involves cutting a strip 4 inches long and 1 inch wide in the middle. This testing procedure is called a T-Peel. The ends are secured in the grips to pull the sample apart at a preset test speed, thereby allowing the material to be pulled apart uniformly. Average peel and maximum force are the common results. Average peel is also termed seal strength or peel strength (Urbanek et al., 2011).

8.3.8.2 Burst Strength Testing

This is performed to evaluate the integrity of the entire bag. It involves compressing the sealed bag between two plates and taking the maximum force reading before bursting. This test ascertains that the products remain fresh and are not ruptured by the force exerted during stacking or packing together of the bags. Packaging testing is done with the Lloyd Material Tester (Urbanek et al., 2011).

8.3.8.3 Flexure Testing

Flexure testing is the most common, cost-effective, and reliable packaging material strength test for brittleness flexure. Methods cover the determination of flexural properties of unreinforced and reinforced plastics in three- and four-point bends (Urbanek et al., 2011).

8.3.8.4 Compression Testing

Packaging materials behave differently in compression than they do in tension, so we perform tests that simulate the conditions the packaging material will see in actual use. Top-load compression testing evaluates the package performance of materials, providing an indication of final packaging performance in storage and transport to help refine the final packaging material selection (Urbanek et al., 2011).

8.3.8.5 Tensile Testing

The packaging material is subjected to linear stress until failure or a critical attribute is attained. The testing is carried out on many types of packaging materials to gather information about yield strength, ultimate tensile strength, modulus of elasticity (stiffness), and elongation from various methods (Urbanek et al., 2011).

8.3.8.6 Puncture and Impact Testing

The ability of film and packaging materials to withstand penetration forces is assessed through puncture and impact testing. The rate of energy delivered affects material properties; multiple packaging material test methods help define material properties under controlled conditions. In concert with puncture and impact testing, tear testing helps characterize the energy required to propagate a tear in packaging material (Urbanek et al., 2011).

8.3.8.7 Barrier Properties

To characterize adsorption, dissolution, diffusion, and desorption of packaging materials, package testing for OTR and water vapor transmission rate can help to plan the optimal packaging material choice for specific applications to maximize preservation and prolong the shelf life of the product.

8.3.8.8 Conditioning and Testing in Controlled Atmosphere

The environmental chamber is designed to stimulate temperatures and humidities of encountered conditions. The measured performance of many packages is affected by the conditioning and testing atmospheres. For example, paper-based products are strongly affected by their moisture content: relative humidity needs to be controlled. Plastic products are often strongly affected by temperature.

Conditions of 23°C (73.4°F) and 50% relative humidity are common. Often the package is conditioned to the specified environment and tested under those conditions. This can be done in a conditioned room or in a chamber enclosing the test. With some testing, the package is conditioned to a specified environment, then is removed to ambient conditions and quickly tested. The test report needs to state the actual conditions used. It is important to know the effects of the full range of expected conditions on package performance.

8.3.8.9 Degradation of Package

Laboratory tests can help to determine the shelf life of a package and its contents under a variety of conditions. This is particularly important for foods, pharmaceuticals, and some chemicals. The testing is usually product specific: The mechanisms of degradation are often different. Exposures to expected and elevated temperatures and humidities are commonly used for shelf-life testing. The ability of packaging to control product degradation is frequently a subject of laboratory and field evaluations.

Packages can degrade with exposure to temperature, humidity, time, sterilization (steam, radiation, gas, etc.), sunlight, and other environmental factors. For some types of packaging, it is common to test for possible corrosion of metals, polymer degradation, and weather testing of polymers. Several types of accelerated aging of packaging and materials can be accomplished in a laboratory.

Exposure to elevated temperatures accelerates some degradation mechanisms. An Arrhenius equation is often used to correlate certain chemical reactions at different temperatures based on the proper choice of Q_{10} coefficients. As with any laboratory testing, validating field trials are important. Some of the relevant tests are as follows:

- ASTM D3045 – Standard Practice for Heat Aging of Plastics Without Load
- ASTM F1640 – Standard Guide for Packaging Materials for Foods to Be Irradiated
- ASTM F1980 – Standard Guide for Accelerated Aging of Sterile Medical Device Packages
- ASTM G151 – Standard Practice for Exposing Non-metallic Materials in Accelerated Test Devices That Are Laboratory Light Sources

8.3.8.10 Vacuum Testing

Vacuum chambers are used to test the ability of a package to withstand low pressures that might be encountered. This could be in an air shipment or high-altitude truck shipment. A laboratory vacuum places controlled stress on a sealed package to test the strength of seals, the tendency for leakage, and the ability to retain sterility. Some of the relevant tests are as follows:

- ASTM D4991 – Standard Test Method for Leakage Testing of Empty Rigid Containers by Vacuum Method
- ASTM D6653 – Standard Test Methods for Determining the Effects of High Altitude on Packaging Systems by Vacuum Method
- ASTM F2338 – Standard Test Method for Non-destructive Detection of Leaks in Packages by Vacuum Decay Method (Johnson, 1995)

8.3.8.11 Shock and Impact Testing

Both primary (consumer) packages and shipping containers have a risk of being dropped or being impacted by other items. Package integrity and product protection are important packaging functions (Aarnio & Hamalainen, 2008). Tests are conducted to measure the resistance of packages and products to controlled laboratory shock and impact. Testing also determines the effectiveness of package cushioning to isolate fragile products from shock. Instrumentation is used to measure the shock transmitted to a cushioned product. Some of the relevant tests are as follows:

- ASTM D880 – Standard Test Method for Impact Testing for Shipping Containers and Systems
- ASTM D1596 – Standard Test Method for Dynamic Shock Cushioning Characteristics of Packaging Materials
- ASTM D3332 – Standard Test Methods for Mechanical-Shock Fragility of Products, Using Shock Machines
- ASTM D5265 – Standard Test Method for Bridge Impact Testing
- ASTM D5276 – Standard Test Method for Drop Test of Loaded Containers by Free Fall
- ASTM D5487 – Standard Test Method for Simulated Drop of Loaded Containers by Shock Machines
- ASTM D6344 – Standard Test Method for Concentrated Impacts to Transport Packages
- ASTM D6537 – Standard Practice for Instrumented Package Shock Testing for Determination of Package Performance

8.3.8.12 Package Insulation

Many packages are used for products that are sensitive to temperature. The ability of insulated shipping containers to protect their contents from exposure to temperature fluctuations can be measured in a laboratory. Ovens, freezers, and environmental chambers are commonly used for this and other types of packaging. Digital temperature data loggers are used to measure temperatures experienced in different distribution systems. These data are sometimes used to develop unique laboratory test methods for that distribution system.

Relevant tests are as follows:

- ASTM D3103 – Standard Test Method for Thermal Insulation Performance of Distribution Packages
- ISTA 7E – Testing Standard for Thermal Transport Packaging Used in Parcel Delivery System Shipment

8.3.8.13 Thermal Shock

Some packages, particularly glass, can be sensitive to sudden changes in temperature: thermal shock. This method of testing involves rapid movement from cold to hot water baths and back (Aarnio & Hamalainen, 2008). The relevant test is:

- ASTM C149 – Standard Test Method for Thermal Shock Resistance of Glass Containers

8.3.8.14 Vibration Testing

A vibration tester is used to simulate vibrating frequencies to which packaged products are subjected during shipments. Vibration is encountered during shipping (vehicle vibration, rough roads, etc.) and movement on conveyors. Potential vibration damage may include fractures and fatigue damage; loose wires, screw caps, and so on; bruises on soft products (fruit, etc.); surface abrasion; and so on.

The ability of a package to withstand these vibrations and to protect the contents can be measured by several laboratory test procedures. Some allow searching for the particular frequencies of vibration that have potential for damage. Modal testing methodologies are sometimes employed. Others use specified bands of random vibration to better represent complex vibrations measured in field studies of distribution environments (Aarnio & Hamalainen, 2008).

Relevant tests are as follows:

- ASTM D999 – Standard Test Methods for Vibration Testing of Shipping Containers
- ASTM D3580 – Standard Test Methods for Vibration (Vertical Linear Motion) Test of Products
- ASTM D4728 – Standard Test Method for Random Vibration Testing of Shipping Containers
- ASTM D5112 – Standard Test Method for Vibration (Horizontal Linear Sinusoidal Motion) Test of Products
- ASTM D7387 – Standard Test Method for Vibration Testing of Intermediate Bulk Containers (IBCs) Used for Shipping Liquid Hazardous Materials (Dangerous Goods)

8.3.8.15 Compression Testing

Compression testing relates to stacking or crushing of packages, particularly shipping containers. It usually measures the force required to crush a package, stack of packages, or unit load. Packages can be empty or filled as for shipment. A force–deflection curve is used to obtain the peak load or other desired points. Other tests use a constant load and measure the time to failure or to a critical deflection. Dynamic compression is sometimes tested by shock or impact testing with an additional load to crush the test package. Dynamic compression also takes place in stacked vibration testing (Aarnio & Hamalainen, 2008). Relevant tests are as follows:

- ASTM Standard D642 – Test Method for Determining Compressive Resistance of Shipping Containers, Components and Unit Loads
- ASTM Standard D4577 – Test Method for Compression Resistance of a Container under Constant Load
- ASTM Standard D7030 – Test Method for Short-Term Creep Performance of Corrugated Fiberboard Containers Under Constant Load Using a Compression Test Machine

8.3.8.16 Large Load Testing

Large pallet loads, bulk boxes, wooden boxes, and crates can be evaluated by many of the other test procedures previously listed. In addition, some special test methods are available for these larger loads. Relevant tests are as follows:

- ASTM D5414 – Standard Test Method for Evaluation of Horizontal Impact Performance of Load Unitizing Stretch Wrap Films
- ASTM D5415 – Standard Test Method for Evaluating Load Containment Performance of Stretch Wrap Films by Vibration Testing
- ASTM D6055 – Standard Test Methods for Mechanical Handling of Unitized Loads and Large Shipping Cases and Crates
- ASTM D6179 – Standard Test Methods for Rough Handling of Unitized Loads and Large Shipping Cases and Crates

8.3.8.17 Test Protocols for Shipping Containers

Shipping containers are often subjected to sequential tests involving a combination of individual test methods. A variety of standard test schedules or protocols are available for evaluating transport packaging. They are used to help determine the ability of complete and filled shipping containers in various types of logistics systems. Some test the general ruggedness of the shipping container, while others have been shown to reproduce the types of damage encountered in distribution. Some test the type and severity of damage based on formal studies of the distribution environment: instrumentation, data loggers, and observation. Test cycles with these documented elements better simulate parts of certain logistics shipping environments (Aarnio & Hamalainen, 2008).

Relevant tests are as follows:

- ASTM D4169 – Standard Practice for Performance Testing of Shipping Containers and Systems
- ASTM D7386 – Standard Practice for Performance Testing of Packages for Single Parcel Delivery Systems

Procedures are as follows:

- Procedure 1A: Packaged Products Weighing 150 lb (68 kg) or Less
- Procedure 1B: Packaged Products Weighing over 150 lb (68 kg)
- Procedure 1C: Extended Testing for Individual Packaged Products Weighing 150 lb (68 kg) or Less
- Procedure 1D: Extended Testing for Individual Packaged Products Weighing over 150 lb (68 kg)
- Procedure 1E: Unitized Loads
- Procedure 1G: Packaged Products Weighing 150 lb (68 kg) or Less (Random Vibration)
- Procedure 1H: Packaged Products Weighing over 150 lb (68 kg) (Random Vibration)
- Procedure 2A: Packaged Products Weighing 150 lb (68 kg)
- Procedure 2B: Packaged Products Weighing over 150 lb (68 kg)
- Procedure 2C: Furniture Packages
- Procedure 3A: Packaged Products for Parcel Delivery System Shipments 70 kg (150 lb) or Less (standard, small, flat or elongated)
- Procedure 3B: Packaged Products for Less-Than-Truckload (LTL) Shipment
- Procedure 3E: Unitized Loads of Same Product
- Procedure 3F: Packaged Products for Distribution Centre to Retail Outlet Shipment 100 lb (45 kg)
- Procedure 3H: Performance Test for Products or Packaged-Products in Mechanically Handled Bulk Transport Containers
- Project 3K: Fast Moving Consumer Goods for the European Retail Supply Chain

8.4 LIFE CYCLE ASSESSMENT (LCA) OF PACKAGING MATERIALS

Life cycle assessment (LCA) is a tool used to evaluate the environmental impacts associated with a product—including both goods and services—throughout its entire life cycle. By adopting a systems-based approach, LCA can effectively trace and assess environmental effects, helping to identify key areas for improvement while avoiding the shifting of burdens from one stage to another. Its strengths lie in systematic data management, detailed process analysis, and meaningful interpretation of results. LCA methods have been widely applied in the packaging sector, including comparing reusable plastic crates and recyclable cardboard boxes to determine the more environmentally friendly option for transportation; assessing eco-design strategies in food packaging by altering materials, formats, and recycling rates to measure potential environmental benefits; and evaluating the environmental impact of biodegradable packaging in scenarios involving food waste, as well as for dry packaging without food contamination (Su et al., 2020).

8.4.1 LCA of Bio-based Packaging Solutions

Bioplastic bottles continue to have a lower environmental impact in areas such as particulate matter emissions, land use, ozone depletion, and human toxicity across recycling scenarios. At the end-of-life stage, human toxicity significantly decreases for bioplastics due to the minimal impact associated with composting. However, when it comes to terrestrial eutrophication and acidification, bioplastics are the most environmentally taxing, largely due to the effects of feedstock cultivation (Cappiello et al., 2022).

In terms of climate change, bioplastic bottles consistently perform better than PET bottles, multilayer cartons, and HDPE bottles, thanks in part to the relatively low greenhouse gas emissions during PLA production compared to fossil-based materials. Introducing biocomposting as a disposal method increases the impact on terrestrial eutrophication (Vendries et al., 2020). Mechanical recycling emerges as a more environmentally favorable disposal option than composting.

Incorporating recycling into the life cycle of PLA-based products can enhance their overall environmental performance. Recycling and incineration with energy recovery are both effective in substantially reducing the environmental footprint of bio-based packaging. A key challenge in recycling is the difficulty of accurately distinguishing between bio-based and fossil-based polymers. The variability in PLA 3D printing waste, for instance, significantly affects the quality of the recycled material (Beltrán et al., 2021).

This issue can potentially be addressed through distributed recycling, which enables the processing of well-sorted waste streams. For lightweight polymers like ABS and PLA, distributed recycling helps reduce inefficiencies in the collection and transportation of large volumes. Although this study does not assess the environmental impact of food waste, it's important to note that composting can support higher food waste recovery, contributing to additional environmental benefits (Vendries et al., 2020).

8.4.2 Life Cycle Assessment of Plastic Packaging

An LCA of plastic is a comprehensive method used to evaluate the environmental impacts associated with each stage of a plastic product's life – from raw material extraction to disposal. This approach considers the entire journey of plastic, including the extraction of fossil fuels, manufacturing processes, transportation, usage, and end-of-life options such as recycling, incineration, or landfilling. By analyzing these stages, LCA helps identify where the most significant environmental burdens occur and offers insights into how to reduce them. One of the primary concerns in plastic production is the reliance on nonrenewable resources such as petroleum, which contributes heavily to greenhouse gas emissions during extraction and refinement. The manufacturing phase further adds to the environmental load through energy-intensive processes and chemical usage (Meister et al., 2022). When plastics are used in products, their impact often depends on factors like durability, application, and whether they are reused or single-use items. At the end-of-life stage, disposal methods play a crucial role in determining environmental performance. While recycling can reduce the demand for virgin materials and lower emissions, it is often hindered by contamination, sorting challenges, and degradation of plastic quality over time. Incineration, though capable of energy recovery, can release harmful emissions unless properly managed. Landfilling, although common, contributes to long-term pollution and resource loss. Emerging alternatives such as bioplastics are being assessed through LCAs to determine whether they offer true environmental advantages, but results vary depending on feedstock sourcing and waste treatment methods (García-Velásquez & van der Meer, 2022). Overall, LCA highlights that improving the sustainability of plastics requires a systems-based approach. This includes developing efficient recycling infrastructure, designing for reuse, reducing reliance on fossil fuels, and educating consumers on responsible disposal. Additionally, policy support and innovation in materials science are crucial to drive change across the entire value chain. Through LCA, businesses, governments, and researchers can make informed decisions aimed at reducing the environmental footprint of plastic while maintaining its functional benefits in modern society.

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9 Safety in Packaging

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9.1 INTRODUCTION

The primary purpose of food packaging is to maintain the safety, wholesomeness, and quality of food throughout the supply chain. Packaging is an essential part of processing, storing, and distributing foods. Packaging must protect against a variety of threats including microorganisms, insects, and rodents. An important consideration, namely, the nature and composition of the specific packaging material and its potential effect on the intrinsic quality and safety of the packaged food as a consequence of the migration of components from the packaging material into the food, needs to be looked into. Environmental factors such as oxygen and water vapor will spoil foods if they are allowed to enter packages freely. Packaging can become a shelf-life limiting factor; this may be as a result of migration of chemical compounds from the packaging into the food or the migration of food components into the packaging. The migration of potentially toxic compounds from the packaging material to food is a major safety concern in the selection and use of plastic materials for food packaging. Recent trends in food packaging techniques are the result of consumer demands toward mildly processed food products with enhanced shelf life and convenience. Novel and innovative packaging techniques fulfil the manufacturer and consumer demands without compromising food safety and quality characteristics. However, current research is shifting to the development of packaging techniques like active packaging, which actively contributes to the preservation and safety of foods. Such packaging interacts directly with the food and the environment to extend shelf life and/or improve quality. Different groups within the food chain, that is, manufacturers, retailers and distributors, and consumers, offer slightly different perspectives of shelf life, reflecting the aspect of greatest importance and significance to them. For consumers, it is imperative that products are safe and the quality meets their expectations. Legislation regarding food contact materials (FCMs) is intended to ensure that no components of FCMs likely to endanger health or food quality are transferred into foods. All packaging materials of plastic origin should meet or surpass the prescribed overall migration and color migration limits. Monitoring migration from packaging materials is mandatory to ensure the safety of the product. The degree of migration of a substance depends on the nature of the migrant (chemical), the nature of the material(s) from which it can be released, and the nature of the food with which it comes into contact.

Packaging is a system for preserving the safety and quality of food products throughout the whole supply chain to the consumer by:

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1. Providing physical strength to the product against tampering
2. Maximizing the shelf life of the product
3. Carrying important information on the label (as per regulation) relating to preparation, safety, and nutrition
4. Providing the date and the location of manufacture for traceability

9.2 SELECTION OF PACKAGING MATERIAL

A sensible choice of packaging materials can be made based on the prediction of changes in food. The rate and magnitude of such changes can be minimized by the selection of the correct packaging materials. The deterioration of packaged foods largely depends on the occurrence of transfers between the internal environment of the package and the external environment, which is exposed to the hazards of storage and distribution. The moisture and oxygen transfer play a major role in food deterioration, for example, transfer of moisture vapor from a humid atmosphere into a dried product, or transfer of an undesirable odor from the external atmosphere into a high-fat product, or development of oxidative rancidity if the package is not an effective oxygen (O_2) barrier. Sometimes, flavor compounds can be absorbed by some types of plastic packaging materials (a phenomenon referred to as scalping), particularly reported in fruit juices, and chemical contaminants can migrate from the packaging material into the food (e.g., plasticizers from plastic < l m). In addition to the ability of packaging materials to protect and preserve foods by preventing or minimizing the transfers referred to, packaging materials must also protect the product from mechanical damage and prevent or minimize misuse by consumers (including tampering) (Robertson, 2009). Types of food safety problems associated with packaging are given in Table 9.1. Some packaging materials can act as efficient insulators against fluctuations in ambient temperatures and do not allow mass transfer between the package and its environment, and this prolongs the shelf life of the food (Baner & Piringer, 2008). The complex, sensible approach to food processing, preservation, packaging, and distribution improves the quality and safety of the food products.

The advancement of an analytical approach to food packaging is strongly recommended, and to achieve this success, a good understanding of food safety and quality is required. Food safety requires that the food is free from harmful physical, chemical, and microbial contaminants at the time of consumption. Packaging is directly related to food safety in two ways:

1. First, if the packaging material does not provide a suitable barrier around the food, microorganisms can contaminate the food and make it unsafe. In this situation, microorganisms present in the food but posing no risk because of the initial absence of moisture or O_2 may subsequently be able to grow and present a risk to the consumer. However, microbial contamination can also arise if the packaging material permits the transfer of moisture or O_2 from the atmosphere into the package.
2. Second, the migration of potentially toxic compounds from some packaging materials to the food, in addition to migration of other components from packaging materials, although not harmful to human health, may adversely affect the quality of the product (Robertson, 2009).

TABLE 9.1
Types of Food Safety Problems Associated with Packaging

Safety Problems	Consequences
Microbial contamination;	Seal rupture, leaking cans, and incomplete glass finishes allows contamination by pathogenic and spoilage microorganisms. Loss of integrity; quantity and quality loss.
Microbial contamination; toxin production – anaerobiosis	Low oxygen environment resulting from product or microbial respiration can lead to toxin formation by anaerobic pathogenic microorganisms.
Recycled packaging – migration	Contamination of post-consumer packaging is transferred to foods after recycling. Improper cleaning and processing increases migration rate.
Insect contamination	Some insects can bore through many common packaging materials and improperly sealed packs.
Exploding pressurized containers; broken containers; tampering; improper handling	Soft drinks, beer in glass, etc.; cuts, lacerations. Transfer of package components to foods.
Chemical contamination and environmental contamination	Environmental toxicants can permeate films Examples include preservatives used in wooden pallets, diesel exhaust.
Foreign objects	Glass shards, metal pieces.
Inadequate processing	Underprocessing can lead to food poisoning.
Conventionalaseptic	Loss of integrity or insufficient sterilization of packaging can lead to food spoilage.
Aroma and nutrient sorption by polymers	Light exposure, oxygen transfer, loss of nutritional and sensory quality.

9.3 DETERIORATIVE REACTIONS IN FOODS

Knowledge about the nature of the reactions and the factors that control the rates of these reactions is necessary to minimize the changes occurring in foods during storage, that is, while packaged (Robertson, 2009). The packaging provides protection from three major classes of external influences as given in Table 9.2.

Preservation is a means of protecting a product, usually against chemical, physical, and microbiological deterioration. It is important to understand the differences between biotic deterioration, which refers to changes in a food product brought about either by a biological function (e.g., ripening of fruit, respiration of vegetables) or attack by microorganisms (e.g., molds, bacteria, and yeasts) and abiotic deterioration, which is brought about by chemical or physical agents (e.g., atmospheric O_2, moisture, light, odors, and temperature). Both biotic and abiotic deterioration can lead to food spoilage.

Packaging can be used to provide a barrier to those agents that lead to food spoilage. Deteriorative reactions in foods are influenced by two factors, the nature of the food and its surroundings:

TABLE 9.2
Chemical, Biological, and Physical Influences

External Influences	Role in Safety
Chemical protection	Acts as a chemical barrier and minimizes compositional changes triggered by environmental influences such as moisture (gain or loss), exposure to gases (typically oxygen), or light (visible, infrared, or ultraviolet [UV]).
Biological protection	Acts as a barrier to microorganisms (pathogens and spoiling agents), insects, rodents, and other animals, thereby preventing disease and spoilage. In addition, biological barriers maintain conditions to control senescence (ripening and aging).
Physical protection	Protects food from mechanical damage and cushioning against the shock and vibration encountered during distribution. Protects against abrasions and crushing damage and from various hazards.

1. Intrinsic parameters that are an inherent part of the food include water activity (a_w), pH, oxidation reduction potential (E_h), O_2 content, and product formulation, including the presence of any preservatives or antioxidants.
2. Extrinsic parameters, the factors that control the rates of deteriorative reactions, include temperature, RH, gas atmosphere, and light; packaging can, to varying degrees, influence the impact of these factors on the rates of deteriorative reactions, depending on the specific packaging material (Brown & Williams, 2003).

9.3.1 Sensory Issues in Packaging

The major quality attributes of food are its sensory qualities such as texture, flavor, color, appearance, and nutritive value, and these attributes can all undergo undesirable changes during processing and storage. With the exception of nutritive value, the changes that can occur in these attributes are readily apparent to the consumer, either before or during consumption. Packaging can affect the rate and magnitude of many of these quality changes. For example, effective O_2 barrier packages prevent the development of oxidative rancidity, flavor compounds can be absorbed by some plastic polymers but not by others, and the particle size of many food powders can increase (i.e., particles can clump) if the package is a poor moisture barrier (Brown & Williams, 2003).

9.3.2 Microbial Contamination in Packaging

Microorganisms can make both desirable and undesirable changes to the quality of foods, depending on whether they are introduced as an essential part of the food preservation process or subsequently grow to produce food spoilage. Every microorganism has a limiting a_w value below which it will not grow, form spores, or produce toxic compounds. Water activity can influence each of the four main growth-cycle phases by its effect on the germination time, the length of the lag phase and the growth rate phase, the size of the stationary population, and the subsequent death rate. Whether a microorganism survives or dies in a low a_w environment is influenced by intrinsic factors that are also responsible for its growth at higher a_w. These factors include water-binding properties, pH, nutritive potential, E_h, and the presence of antimicrobial compounds. Microbial growth and survival are not entirely ascribed to reduced a_w but are also attributable to the nature of the solute. The main extrinsic factors relating to a_w that influence microbial deterioration in foods include O_2, temperature and chemical treatments. These factors can combine in a complex way to encourage or discourage microbial growth (Brown & Williams, 2003).

Controlling the presence of microorganisms on surfaces of packaging materials is fundamental to achieving food safety standards and improving the overall quality (i.e., texture, flavor, and aroma) and shelf life of fresh produce. The literature data on the contamination levels of packaging materials are fewer. However, they demonstrated that packaging materials can be contaminated by spoilage and pathogenic microorganisms (Suominen et al., 1997). The cell loads normally detected for mesophylic aerobic bacteria ranged between 10^3 and 10^6 cfu/cm^2 for packages of recycled materials and between 10^2 and 10^5 cfu/cm^2 for products based on virgin fibers (Suominen et al., 1997). The wide variability of microbes is mainly due to the differences in physicochemical features of packaging materials and in logistics such as transportation. It was reported that the spore-forming bacteria (*Bacillus*, *Geobacillus*, *Alicyclobacillus*, and *Clostridium*) and molds (*Aspergillus niger*, *A. cinnamomeus*, and *Cladosporium herbarum*) prevail on packaging microbiota (Binderup et al., 2002; Turtoi & Nicolau, 2007). However, there is a chance that packaging materials contain yeast and other spoilage bacteria. The use of appropriate packaging is essential to protect fresh food from contamination and spoilage. The use of cardboard, compared to plastic, can significantly reduce the potential of microbial transferring from packaging to fruits (Patrignani et al., 2016). However, Regulation (EC) No 852/2004 on materials and articles intended to come into contact with food stipulates that

> the packaging must not be a source of food contamination, but the real contribution of the packaging material in product contamination is not very simple due to the unpredictable level of the naturally occurring fruit and packaging microflora. In addition, the survival, growth or death of microorganism on the packaging materials, and consequently their role in cross contamination of packed fruits, are affected by environmental conditions, including relative humidity, storage temperature and nutrient availability.
>
> *(DeCandia et al., 2015; Erickson et al., 2015; Siroli et al., 2014)*

The intrinsic factors of fruit species and variety (i.e., pH, acidity, sugar content, and so on), as well as ripening and the presence of wounds and exudates, highly affect the growth of microorganisms on fruit surface (Heaton & Jones, 2008).

9.4 FOOD AND FOOD PACKAGING INTERACTIONS

Chemicals used in manufacturing plastic containers are highly toxic, mainly as carcinogens. They are known to have effects on the nervous system, blood, kidneys, and so on. There are many additives (e.g., plasticizers) added to plastics at the time of production to facilitate manufacture and use; these additives are known to be harmful, and they may interact with the food (Kirwan & Strawbridge, 2003).

Interactions between packaging and foods can be classified into four types:

1. *Migration or transfer of package components to the food during storage or preparation*: Migration can have both quality and toxicological significance. There are many chemicals involved in the manufacture of packaging materials, and some of these have the potential to migrate into food. Some chemicals can cause potential harmful effects to humans. It has been reported that food has been contaminated by the migration of chemicals from packaging that is in direct contact with food (primary packaging). However, it is recognized that migration or contamination may occur less frequently from secondary, tertiary, and even quaternary packaging (such as corrugated carton, pallets, and containers).

   The chemical components in packaging such as printing inks (e.g., photo-initiators such as benzophenone) may transfer to food contact surfaces via the "set-off" process. This is a direct transfer of chemicals from the external surface of the packaging to the food contact surface during stacking and storage of packaging. The chemicals may then migrate into food. Migration may also result in the transfer of potentially toxic substances to foods, and this transfer can also occur via evaporation and then leach into food via the gaseous phase. The recycled packaging materials contain chemicals such as ink components and recycled fibers that may persist and ultimately migrate into food (Abdullahi, 2014).

   The type of packaging material used largely determines the potential for, and extent of, migration of chemicals into food. For apparently inert materials such as stainless steel, ceramic, or glass, chemicals lining the inner surface and in direct contact with the food could lead to contamination, and migration may still occur from closures or sealants containing plasticizers. Chemical migration is more likely to occur from materials such as plastics, elastomers, paper, and board (Abdullahi, 2014; Hotchkiss, 1997). Migration of potentially toxic components becomes a regulatory concern. The exception is for active packaging, which may be intended to release substances into the food with beneficial effects, such as antioxidants or preservatives.
2. *Permeability of the food container to fixed gases and water vapor*: Fixed gases and water vapor can permeate packages made from plastics or thin foils except glass or metal containers. The degree of plastic permeability depends on the type or nature of packaging material, and the permeation rates vary over three orders of magnitude.
3. *Sorption and/or permeation by organic vapors*: Continuous polymer films are permeable to organic vapors in a similar manner to fixed gases. Transfer of organic vapors across polymeric food packaging could have two adverse consequences. First, packaged foods that are exposed to undesirable volatile odors pick up the odor during storage or shipment. Plastics can sorb or transfer sufficient aroma compounds to be detected by human senses.

The second type of problem can occur when the desirable aroma compounds associated with a particular food are reduced by being sorbed into or permeated through the package, which is called flavor scalping.

4. *Interaction between foods and food packaging results from the transparency of many food packages to light*: Light, particularly in the shorter wavelengths, can catalyze adverse reactions such as oxidation in foods when the food surface is exposed to light. This may lead to loss of nutrients, discoloration, or the development of off-odors (Hotchkiss, 1997).

9.4.1 Factors Affecting Migration

Chemical migration occurs for smaller-sized molecules and ions below 1,000 Dalton. Migration of chemicals from packaging materials into the food depends on the composition and properties (e.g., polarity) and the functional properties of the packaging material (e.g., crystallinity, permeability), nature and extent of contact, nature of the food, temperature of contact, duration of contact, and mobility of the chemicals in the packaging. Many packaging chemicals are lipophilic (meaning they have a greater ability to dissolve in fats) and can therefore more readily migrate into fatty foods at higher rates and levels. The degree and rate of chemical migration into food depends on the product filling conditions, storage conditions, shelf life, and product–pack ratio (Abdullahi, 2014; Robertson, 2009). Damaged packaging material could potentially lead to greater chemical migration through changes in ambient oxygen, moisture, light, and temperature and deteriorate the product easily (Robertson, 2009). Mineral hydrocarbons, including petroleum jelly, liquid paraffin, white oil, hard paraffin, and microcrystalline wax, may be used in certain polymers as processing aids (Brown & Williams, 2003). The overview of substances migrating from FPM is given in Table 9.3.

TABLE 9.3
Overview of Substances Migrating from FPM

Type	Class of Substance	Substance	FPM/Use
IAS	Plastic monomers	Vinyl chloride	PVCs
	6-Aminohexanoic acid	Polyamides	6-Aminohexanoic acid
	Acrylamide	Polyacrylamides	Acrylamide
	Caprolactam	Polyamide	Caprolactam
	2-Hydroxy-6-naphthoic acid	Polyesters	2-Hydroxy-6-naphthoic acid
	p-Hydroxybenzoic acid	Polyesters	p-Hydroxybenzoic acid
	Metals	Aluminum	Aluminum foil
	Photo-initiators	2-Isopropylthioxanthone	Paper/cardboard
	Dyes		Paper/cardboard
	Antioxidants		Plastic polymers
	Water/fat repellents	Perfluorinated acids, etc.	Paper/cardboard
	Plastifiers	Bisphenol A, phthalates	Plastic polymers
NIAS	Mineral oils	MOSH/MOAH	Recycled paper/cardboard

The monitoring of this migration is an important integral part of ensuring food safety. Human exposure to chemicals from packaging and other materials in contact with food may occur as a result of migration from the packaging materials into foodstuffs. The intensity and danger of the chemical migrants depend on their quantity and characteristics and also the length of contact time and temperature of exposure, with the highest levels observed where there was a direct contact between the film and food, and fat content on the contact surface in food (Brown & Williams, 2003).

Food and beverages can be very aggressive products and may interact strongly with materials when they comes in contact. For example, acidic food can corrode metals; fats and oils can swell and leach plastics; and beverages can disintegrate unprotected paper and carton board. In fact, no FCM is completely inert, and so it is possible for their chemicals to migrate into the packaged food. All packaging materials, which include metals, glass, ceramics, plastics, rubber, and paper, can release minute amounts of their chemical constituents when they touch certain types of foods. This release of chemicals to the food is known technically as migration.

9.4.2 Substances Migrating from FPM into Food

9.4.2.1 Plastic Containers

Chemicals used in manufacturing plastics containers are carcinogens that are highly toxic (Abdullahi, 2014). They damage kidneys and so on. There are many additives (e.g., plasticizers) added to plastics at the time of production to facilitate manufacture and use; these additives are known to be toxic, and they may interact with the food (Kirwan & Strawbridge, 2003). The contents of the PET bottle and its storage temperature both appear to influence the rate and magnitude of leaching of organic and inorganic compounds from PET bottle into food. For an example, exposure of PET bottles at temperature ranges between 37°C and 47°C for 30 days shows significant increase in the concentration of SO_4, NO_3–, NH, chemical oxygen demand (COD), electrical conductivity (EC), and total dissolved salt (TDS) with increase of sunlight exposure time. The concentrations of Cl^-, F^-, and pH decrease with increase in sunlight exposure time. The concentration of EC and TDS increases due to leaching of ions and metals from plastic to the water (Muhamad et al., 2011). Mineral water (in a PET bottle) concentrated with silica and stored under darkness for 30 days revealed mutagenic activity in salmonella strain TA 98. The mutagenic activity was twice as high for the same samples exposed to sunlight (40°C average) for 30 days (Bach et al., 2012). Leaching of toxic chemical pollutants, such as bisphenol A (BPA), phthalates, and antimony, from reusing plastic materials with poor cleaning system was reported. It facilitates pathogenic organisms, which spreads infectious diseases. This practice can cause serious health problems due to some carcinogenic agents and cross contamination by microorganisms (Abdullahi, 2014).

9.4.2.2 BPA in PET Bottles

BPA is used to produce certain types of plastic that are used in thousands of formulations for myriad products. Containers made with these plastics may expose people to small amounts of BPA in food, and it is reported that food and drinks stored in plastic containers can contain trace amount of BPA, a synthetic chemical that interferes with the body's natural hormonal messaging system. BPA is capable of interfering with the action of estrogen, an important regulator of reproduction and development. BPA exposure in the general population comes primarily from consumption of food and beverages. Particularly, the repeated reuse of such bottles, which get dinged up through normal wear and tear and while being washed, increases the chance that chemicals will leak out of the tiny cracks and crevices into water (Abdullahi, 2014). It was reported that extremely toxic heavy metals (Pb, Cd, and Al) were detected above the toxicity levels in locally packaged powdered milk marketed in Dakahlia, Egypt. The researchers related high concentrations of these toxic metals to contamination during handling, storage, marketing, and leaching from containers (Salah et al., 2013). The Food Safety and Standards Authority of India (FSSAI) limits for heavy element contents in plastics for use in contact with food, pharmaceuticals, and drinking water (as per IS 9833: 1981) are given in Table 9.4.

9.4.2.3 Metal Cans

Metal cans used in packaging foods to preserve and protect its content resist any chemical reactions and provide physical protection to withstand the handling and processing conditions. Mechanical damage to cans caused by poor handling, such as denting, can result in cracking of the internal lacquer. This will allow the product to gain access to the underlying metal and may result in quite rapid localized corrosion, depending on the can and the nature and composition of the product. Occasionally, internal corrosion may result from an unusually aggressive reaction between the can and its contents, causing the lacquer to peel away from the can surface (Bev et al., 2003). Monomers such as bisphenol A and bisphenol F and their diglycidyl ethers migrate from can lacquers into canned foods; these migrants have potential health hazards (Brown & Williams, 2003). Aluminum foil is used in cooking. The increase in cooking temperature causes more leaching, which provides an easy channel for the metal to enter the human body. The leaching is also highly dependent on the pH value of the food solution and ingredients used in foods like salt and spices. Aluminum foil is not suitable for cooking, especially with acidic food. It is also

TABLE 9.4
Limits of Heavy Element Contents in Plastics for Food Contact

S. No.	Heavy Element (% by mass, *Max.*)	Limit
1	Lead	0.01
2	Arsenic	0.005
3	Mercury	0.005
4	Cadmium	0.10
5	Zinc	0.20
6	Selenium	0.01
7	Barium	0.01
8	Chromium	0.025

possible that excessive consumption of food baked with aluminum foil may carry a serious health risk (Bassioni et al., 2012).

Glass is an FPM entirely made from natural raw materials, which are toxicologically inert. The major constituents, namely sodium/potassium silicates, are nontoxic and chemically highly inert. The transfer of silicates and cations into food is marginal and even if it occurs is toxicologically irrelevant. Practically no traces of problematic migrants originating from the glass are found in glass-bottled food products (Hayashi et al., 2011). Cases of concern related to migration of chemicals such as 2-ethylhexanoic acid into food have been associated with glass FPMs only if these were combined with other materials, that is, in metal lids. The problems of polymers and adhesives used in lids have been solved, however, by the use of alternative processes in their production (Elss et al., 2004).

9.4.2.4 Paper and Cardboard

Paper and cardboard are used as FPMs. Generally paper and cardboard are coated with plastic polymers since they have weak barrier functions in order to avoid the transfer of chemical compounds between the food and the outside world. Therefore, many paper- or cardboard-containing FPMs face the same problems as the plastic polymers. Similar conclusions can be drawn for adhesives used for gluing of paper or cardboard. The latter also contains plastic polymer-like materials in addition to solvents; many of them are of organic nature. Furthermore, polyfluorinated acids and related compounds are used for coating paper to provide resistance to oil and moisture (Zafeiraki et al., 2014). Recently, the increasing use of recycled paper or cardboard as the only or a partial constituent of FPMs has led to special concerns. This is due to the contamination of recycled paper with a variety of chemicals, mostly derived from printing inks.

9.4.2.5 Printing Ink Migration

According to International Regulations and Guidelines on Printing Inks, the printed surfaces shall not come into direct contact with food, so they do not transfer their constituents to food that can endanger human health, affect the composition of food, or bring about a deterioration in the organoleptic characteristics thereof (Abdullahi, 2014). PIs are used as catalyzers for inks and lacquers that are cured with UV light, and they can easily contaminate foodstuffs by mass transference (Sanches-Silva et al., 2009). Types of printing ink migration to food are given in Table 9.5.

TABLE 9.5
Types of Printing Inks Migration

Migration Type	Description
Direct migration	Direct migration from print to the food, in a situation where the food is in direct contact with the print
Through migration	Penetration through the substrate to the reverse side of the print
Set-off migration	Set-off from the print to the reverse side while being stored in a pile or reel
Gas-phase migration	Volatilization and condensation of components after heating

Benzophenone is one of the most commonly used PIs, which is mostly used in UV-cured inks for which drying times are much shorter than for conventional solvent- or water-based coatings (Pastorelli et al., 2008). Migration of PIs such as benzophenone and 4-methylbenzophenone into food has been shown in recent years to be a problem. It was reported that the level of the migration of the PI 2-isopropylthioxanthone (ITX) into different kinds of food was found to be above 50 ppb in 10% of the samples, with the highest levels at 357 ppb in orange juice and 208 ppb in baby food (Rothenbacher et al., 2007). It is known that UV radiation may cause photodegradation of dyes and pigments in print. For instance, 4,4-bis-(dimethyl-amino) benzophenone (Michlers ketone) is a possible degradation product from violet dyes or pigments (Pedersen et al., 2012).

9.5 RECENT ADVANCES IN FOOD PACKAGING TECHNOLOGIES

Novelty and recent trends in food packaging techniques are the result of consumer demands toward mildly processed food products with enhanced shelf life and convenience (Dobrucka & Cierpiszewski, 2014). Novel and innovative packaging techniques fulfil the manufacturer and consumer demands without compromising food safety and quality characteristics (Dainelli et al., 2008). Innovative food packaging eliminates the rising issues of food-borne microbial outbreaks. The use of packaging with antimicrobial effects along with retention of food quality improves the safety and marketability of the food (Appendini & Hotchkiss, 2002). Innovations in packaging started earlier in the form of packaging machinery, various packaging materials, metallic cans, aseptic packaging, flexible packaging, aluminum foils, and flexographic printing. Recently, advancement in packaging technology appeared as intelligent and active packaging (oxygen and moisture scavengers, antimicrobial emitters, respiration controllers, and aroma/odor absorbers) (Majid et al., 2016). The emerging changes in the packaging industry will strengthen the economy by improving food safety and quality and by minimizing product losses (Vanderroost et al., 2014).

9.5.1 Active Packaging

Active packaging prolongs the storage life and enhances the safety and quality of food by altering the internal condition of the food package (Kruijf et al., 2002). Active packaging is used as a substitute to conventional food processing techniques (high thermal treatments, brining, acidification, dehydration, and additive preservation) (Lopez-de-Dicastillo et al., 2011). A recent advancement in the use of active packaging is the infusion of antimicrobial agents in polymer materials (Suppakul et al., 2003). These polymeric matrices have the potential of emitting active agents (antioxidants and antimicrobials) and scavenging compounds for undesirable food components (ethylene, oxygen, and water) (Flores et al., 2007). Controlled delivery of active agents into the food via packaging films for extended periods of storage and distribution restricts the safety issues and the development of undesirable flavors produced as a result of directly incorporating additives into the food (Peltzer et al., 2009). At the same time, use of artificial antioxidative agents like butylated hydroxytoluene, thioester, and organophosphate compounds as active packaging additives is limited due to toxicity as a result of their migration into the food products (Gomez-Estaca et al., 2014). At least four types of food safety and regulatory issues related to active packaging of foods need to be addressed. First, food contact approval must be established before any form of active packaging is used. Second, it is important to consider environmental regulations covering active-packaging materials. Third, labeling shall meet the laws and regulations to avoid consumer confusion. Fourth, it is important to consider the effects of active packaging on the microbial ecology and safety of foods (Majid et al., 2016).

9.5.2 Intelligent Packaging

Intelligent packaging monitors and indicates the internal condition of the food package to enhance food quality characteristics and safety. Intelligent packaging includes time–temperature regulators, ripeness monitors, biosensors, and radio frequency indicators and regulators (Restuccia et al., 2010). Intelligent packaging providing detailed knowledge throughout the supply chain maintains food quality by finding critical points with the use of attached sensors, indicators, and incorporated or printed labels onto packaging material (Dainelli et al., 2008). Radio frequency identification (RFID) is radio-wave-based system that wirelessly tracks items, which offers traceability. Application of RFID in the food industry has emerged as a gateway, starting from monitoring of food to its traceability in order to enhance food safety and improve supply chain effectiveness (Majid et al., 2016).

9.5.3 Nanopackaging

Nanotechnology is an innovative technique that is introducing the latest enhancements in food packaging by providing mechanical and barrier properties, detecting pathogens, and introducing intelligent and active packaging, keeping in consideration food quality and safety aspects. The nanoclay particles act as an impermeable barrier, and they enhance the shelf life and quality of foods by hindering the process of diffusion. The problem of oxidation and flavor of beer in plastic bottles due to packaging has also been tackled by the process of nanotechnology. Use of nanocrystals incorporated in plastic bottles prevents the loss of carbon dioxide from and infusion of oxygen into the bottles and extends the shelf life of beer by 18 months. It was found that the carbon nanotubes resulted in cellular damage in *Escherichia coli* by puncturing cells and eventually leading to their death (Majid et al., 2016).

The safety concerns related to smart packaging should be addressed based on the following three important considerations:

1. *Labeling*: Proper labeling should be done as per regulation in order to prevent misuse and misunderstanding by the consumers or downstream users, for example, to prevent sachets from being eaten (Majid et al., 2016).
2. *Migration*: The migration of active and intelligent substances based on their toxicity should be kept in consideration, and their migration process should meet food legislation. Monitoring the phenomena of migration means to

adapt some mass transfer modeling tools and migration tests other than those applied or recommended for conventional plastics, as they cannot be adapted to active and intelligent systems. It is very important to determine the adequacy of analytical methods used in migration studies to detect as well as quantify to which components the consumer would be exposed, and at what level, to ensure the safety of active packaging. Potential migration outside the packaging is considerably reduced as the systems do not require migration testing as there will be a "functional barrier" (Restuccia et al., 2010).

3. *Efficient packaging*: Most importantly, in a few cases the claimed function of food packaging can give rise to safety concern as for any food preservation technology, for example, releasing a preservative or absorbing oxygen and/or water in a suitable way for preventing microbial growth without inducing antimicrobial resistance or pathogen overgrowth, or giving reliable information on the presence of pathogenic bacteria for direct indicators (Dainelli et al., 2008).

Food contact approval will often be required because active packaging may affect foods in two ways. Active packaging substances may migrate into the food (antioxidants, antimicrobials, etc.) or may be removed from it (moisture, ethylene, and oxygen). Migrants may be intended or unintended. Intended migrants include antioxidants, antimicrobial preservatives, and ethanol, which require regulatory approval in terms of their identity, concentration, and possible toxicology effects. Unintended migrants include various metal compounds that achieve their active purpose inside packaging materials but do not need to, or should not, enter foods. Food additive regulations require identification and quantification of any such unintended migration (Majid et al., 2016).

9.6 REGULATORY FRAMEWORK FOR FOOD PACKAGING

To protect consumers against potential health hazards of substances that migrate into food, India, the EU, the United States, and many other countries have introduced strict regulations. In India, the Food Safety and Standards Regulations, 2011, has laid several requirements for food packaging and labelling. FCMs must comply with these regulations, and to ensure them, testing of food packaging materials is required. It is also necessary to determine the toxicological profile of each chemical present in packaging material.

9.6.1 Regulations in India

The food and packaging regulations in India are governed by Food Safety and Standards (Packaging and labelling) Regulations, 2011, 1.1.2.

9.6.1.1 Packaging Requirements

1. A utensil or container made of the following materials or metals, when used in the preparation, packaging, and storing of food, shall be deemed to render it unfit for human consumption:

   a. Containers that are rusty
   b. Enamelled containers that have become chipped and rusty
   c. Copper or brass containers that are not properly tinned
   d. Containers made of aluminum not conforming in chemical composition to IS:20 specification for cast aluminum and aluminum alloy for utensils or IS:21 specification for wrought aluminum and aluminum alloy for utensils
2. Containers made of plastic materials should conform to the following Indian Standards Specification:
   - *IS: 10146* – Polyethylene for contact with foodstuffs
   - *IS: 10142* – Styrene polymers for contact with foodstuffs
   - *IS: 10151* – Polyvinyl chloride (PVC) for contact with foodstuffs
   - *IS: 10910* – Polypropylene for contact with foodstuffs
   - *IS: 11434* – Ionomer resins for contact with foodstuffs
   - *IS: 11704* – Ethylene acrylic acid (EAA) copolymer specification
   - *IS: 12252* – Poly alkylene terephthalates (PET) for food contact
   - *IS: 12247* – Nylon 6 polymer for food contact
   - *IS: 13601* – Ethylene vinyl acetate (EVA) specification
   - *IS: 13576* – Ethylene methacrylic acid (EMAA) specification
   - *Note*: Tin and plastic containers, once used, *must not* be reused for packaging edible oils and fats.

General packaging requirements for canned products are as follows:

- All containers shall be securely packed and sealed.
- The exterior of the cans shall be free from major dents, rust, perforations, and seam distortions.
- Cans shall be free from leaks.

Packaging requirements for specific groups of products such as milk and milk products, edible oil/fat, fruit and vegetable products, canned meat products, and drinking water (both packaged and mineral water) are also described in FSSAI regulations. All packaging materials of plastic origin shall pass the prescribed overall migration and color migration limits.

9.6.1.2 Labeling Requirements

- *Name of the food*: The name of the food shall include the trade name or a description of food contained in the package.
- *List of ingredients*: Except for single ingredient foods, a list of ingredients shall be declared on the label.
- *Nutritional information*: Nutritional information or nutritional facts per 100 g or 100 ml or per serving of the product shall be given on the label.
- *Declaration regarding vegetarian or nonvegetarian*: If the food contains any ingredient in part or whole from animal origin (meat, fish, and poultry eggs), a declaration is to be made by a symbol and a color code stipulated for this purpose to indicate the product as nonvegetarian food. The symbol shall consist of a black-color-filled circle. Similarly, for vegetarian food a similar symbol with gray-color circle and square will be displayed.

- *Declaration regarding food additives*: For food additives falling in the respective classes and appearing in lists of permitted food additives, the class titles shall be used together with the specific names or recognized international numerical identifications.
- *Addition of colors and/or flavors*: When a statement regarding the addition of colors and/or flavors is displayed on the label in accordance with regulation 2.2.2(5)(ii) and regulation 3.2.1 of the Food Safety and Standards (Food Product Standards and Food Additive) Regulation, 2011, addition of such colors and/or flavors need not be mentioned in the list of ingredients. Also, in addition to the foregoing statement, the common name or class name of the flavor shall also be mentioned on label.
- *Name and complete address of the manufacturer*: When food is manufactured or packed or bottled by a person or a company under the written authority of some other manufacturer or company, under its brand name, the label shall carry the name and complete address of the manufacturing or packing or bottling unit as the case may be, and also the name and complete address of the manufacturer or the company.
- *Net quantity*: Quantity by weight or volume or number or drained weight (liquid medium) shall be declared on every package of food.
- *Lot/code/batch identification*: A mark of identification by which the food can be traced in manufacture and identified in distribution shall be given on the label.
- *Date of manufacture or packing*: The month and the year of manufacture, packing, or prepacking shall be given if the "Best Before Date" of the products is more than 3 months. The date, month, and year shall be mentioned on the label for short shelf life of less than 3 months.
- *Best before and use by date*: The month and year up to which the product is best for consumption, shall be printed on the label in capital letters in the following manner:

  BEST BEFORE....MONTHS AND YEAR

  OR

  BEST BEFORE......MONTHS FROM PACKAGING

  OR

  BEST BEFORE.......MONTHS FROM MANUFACTURE

  (*Note*: Blanks should be filled up.)

- *Country of origin for imported food*: The country of origin of the food shall be declared on the label of food imported into India.
- *Instructions for use*: Instructions for use, including reconstitution where applicable, shall be included on the label if necessary to ensure correct utilization of the food.

9.6.2 Regulations of the European Community

The food and packaging regulations are governed by the European Parliament in the universal regulations for EU countries and also by numerous agencies and organizations that monitor correct manufacturing techniques, such as the European Food Standards Agency (EFSA). EFSA is a separate organization following the European Commission as well as other EU member states to examine emerging issues in food production. According to the European Parliament and the council's framework, the basic community legislation (EC 1935/2004) covers all FCMs in Article 3. It defines FCMs and articles and sets basic requirements for them:

- Materials and articles, including active and intelligent materials and articles, shall be manufactured in compliance with GMP.
- The labeling, advertising, and presentation of a material or article shall not mislead the consumers. (Parliament and Council Regulation (EC) 1935/2004 of October 27, 2004.)

As per IS and EU, in general, the limits of overall migration are specified as 10 mg/dm^2 and/or 60 mg/L in food simulants for different types of materials. Apart from the overall migration of plastic constituents into food simulants, there should not be any color migration into the simulant apparent to the naked eye. Although the instructive value is within the limit, if the color migration is clearly visible, such materials are not suitable for food contact applications. Some plastics like PVC, polystyrene, polyacrylonitrile, and nylon-6 whose monomers are toxic should be tested separately for the monomer content in the plastic as well as monomers migrating into foods. The limits of different monomers in the polymers are 0.1, 0.2, 11, and 10 ppm, respectively. As per plastic regulation (EU) 10/2011, for multilayer films (e.g., three-layer films), if the layers do not contain an aluminum foil (layer) in between, then only the layer that is in immediate contact with food needs to be tested for migration. Otherwise, all three layers should be tested separately (European Commission, 2009).

9.6.3 Regulations of the United States

In the United States, regulations affecting food packaging products and materials are dictated by US FDA regulatory requirements affecting each individual substance used in a given packaging material. The FDA recommends the following approach to determine the regulations that apply to individual packaging material substances and the path to achieving compliance with its regulations:

- Consult 21 CFR (Code of Federal Regulations) 174–179 to determine if a substance used in a packaging material is a regulated indirect additive. Regulated additives can include adhesives and components of coatings, paper and paperboard components, polymers, and irradiation used in the production process and handling of food.
- Consult 21 CFR 182–186 to determine if a substance used in a food packaging material is listed as "generally recognized as safe" (GRAS).

- Consult 21 CFR 181to determine if a substance used in a food packaging material is listed as "prior sanctioned."
- Consult the FDA's listing of Threshold of Regulation Exemptions to determine if a substance falls below the threshold of regulation and is therefore exempt.
- Consult the FDA's listing of Food Contact Substance (FCS) Notifications to determine if the FDA has previously been notified about a separate use of a given substance.

If a manufacturer determines that a specific food packaging product or material substance does not meet the foregoing regulations or listings, a manufacturer can either submit a threshold of regulation exemption request, satisfy the criteria necessary for GRAS status, or submit an FCS notification. The FDA's FCS notification route is generally the preferred method for obtaining agency clearance for previously unused or new food packaging substances.

9.6.4 Regulations of Australia and New Zealand

The Australia–New Zealand Food Standards Code or the New Zealand Food Regulation 1984 specify details of materials permitted to be added to or used to produce food packaging materials. However, the effect of New Zealand Food Act 1981 Section 9 (4) (C) is that the packaging used must not cause food to be unsafe or tainted (Nielsen, 2017). Therefore, it is the responsibility of food manufacturers and sellers to ensure that their products are safe and that they comply with relevant legislation. In practice, packaging suppliers will need to ensure their products are suitable for the intended use. Compliance with recognized institutional food standards such as those of Europe or the US FDA would be reasonable evidence that the materials are suitable for food use.

9.7 SUMMARY

Food packaging products and materials are an important element in the overall effort to provide consumers worldwide with safe and nutritious food. Interactions between food and packaging materials and migration of chemical constituents from packaging materials to food are a major safety concern in the selection and use of plastic materials for food packaging. However, packaging manufacturers must be prepared to deal with a complex global regulatory landscape, in which individual jurisdictions have adopted different regulatory frameworks for the review and approval of food packaging materials.

Manufacturers seeking worldwide acceptance of their food packaging products and materials will benefit from a thorough understanding of all of the substances used in their products and materials and a detailed analysis of the regulations and standards applicable to those substances. The ideal situation is to package products in materials that will protect foods only for the maximum shelf life desired or found in the marketplace. This concern provides a stimulus to the packaging industry in order to present numerous innovative techniques to tackle the legal and regulatory requirements along with the changing needs of the food industry and consumers.

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