RESEARCH PAPER

Development and Characterization of Buccal Tablets of Metformin Hydrochloride Using Mucoadhesive Polymers

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ABSTRACT

The present study was aimed at the development and characterization of mucoadhesive buccal tablets of Metformin Hydrochloride using different mucoadhesive polymers to achieve sustained drug release and improved patient compliance. Buccal tablets were prepared by direct compression method employing hydroxypropyl methylcellulose (HPMC K4M), carbopol 934P, sodium carboxymethyl cellulose, and polyvinylpyrrolidone as mucoadhesive polymers. The prepared formulations were evaluated for precompression parameters including angle of repose, bulk density, tapped density, Carr's index, and Hausner ratio. Post-compression evaluation included hardness, friability, thickness, weight variation, drug content uniformity, surface pH, swelling index, mucoadhesive strength, and in vitro drug release study. The results demonstrated that all formulations possessed satisfactory flow properties and complied with pharmacopoeial limits for physicochemical parameters. The surface pH values were found near neutral, indicating compatibility with buccal mucosa. Swelling index and mucoadhesive strength increased with increasing polymer concentration. In vitro drug release studies revealed sustained release behavior of metformin hydrochloride over an extended period. Among all formulations, formulation F5 exhibited optimum mucoadhesive properties and prolonged drug release profile due to higher polymer concentration. The study concluded that mucoadhesive buccal tablets of metformin hydrochloride could be considered a promising alternative to conventional oral dosage forms for sustained drug delivery and improved therapeutic efficacy in the management of Type 2 Diabetes Mellitus.

Keywords: Metformin hydrochloride; Buccal tablets; Mucoadhesive polymers; Sustained drug release; Buccal drug delivery system; Direct compression; Mucoadhesion; Controlled release.

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1. INTRODUCTION

Metformin Hydrochloride is one of the most widely prescribed first-line oral antihyperglycemic agents for the management of Type 2 Diabetes Mellitus due to its efficacy, safety profile, and cost-effectiveness. It belongs to the biguanide class of drugs and primarily acts by decreasing hepatic glucose production and improving insulin sensitivity in peripheral tissues. Despite its therapeutic advantages, metformin hydrochloride exhibits certain pharmacokinetic limitations such as incomplete gastrointestinal absorption, relatively short biological half-life, and the need for frequent administration, which may reduce patient compliance. [1,2]

Conventional oral dosage forms of metformin hydrochloride are associated with gastrointestinal side effects and variable bioavailability due to extensive absorption in the upper gastrointestinal tract. Buccal drug delivery systems have emerged as a promising alternative route for systemic drug administration because they bypass hepatic first-pass metabolism, improve bioavailability, and provide rapid onset of action.[3] The buccal mucosa is highly vascularized and relatively permeable, making it suitable for both local and systemic delivery of drugs.[4]

Mucoadhesive buccal tablets are designed to adhere to the mucosal surface for prolonged periods, thereby enhancing drug residence time and improving therapeutic efficacy. The incorporation of mucoadhesive polymers helps in maintaining close contact between the dosage form and buccal mucosa, resulting in controlled drug release and improved absorption.[5] Various natural and synthetic polymers such as hydroxypropyl methylcellulose (HPMC), carbopol, sodium carboxymethyl cellulose, chitosan, and polyvinylpyrrolidone have been extensively investigated for buccal drug delivery applications because of their excellent mucoadhesive and swelling properties.[6]

The formulation of buccal tablets offers several advantages including avoidance of enzymatic degradation in the gastrointestinal tract, reduced dosing frequency, enhanced patient compliance, and suitability for patients with swallowing difficulties.[7] Additionally, controlled release buccal systems can maintain therapeutic drug concentrations for extended durations, minimizing fluctuations in plasma drug levels.[8]

The development of metformin hydrochloride buccal tablets using mucoadhesive polymers may significantly improve the therapeutic performance of the drug by enhancing residence time and sustaining drug release. Characterization studies such as hardness, friability, surface pH, swelling index, mucoadhesive strength, drug content uniformity, and in vitro drug release are essential to evaluate the quality and performance of the prepared formulations.[9]

Recent advances in buccal drug delivery technology have focused on optimizing polymer combinations to achieve better adhesion, controlled drug release, and improved patient acceptability. The selection of suitable mucoadhesive polymers plays a crucial role in determining the physicochemical and bioadhesive characteristics of buccal tablets.[10] Therefore, the present study aims to develop and characterize buccal tablets of metformin hydrochloride using different mucoadhesive polymers for improved drug delivery and therapeutic effectiveness.

2. MATERIALS AND METHODS

Materials

Metformin Hydrochloride was obtained as a gift sample from a reputed pharmaceutical industry. Hydroxypropyl methylcellulose (HPMC K4M), carbopol 934P, sodium carboxymethyl cellulose (NaCMC), and polyvinylpyrrolidone (PVP K30) were used as mucoadhesive polymers. Microcrystalline cellulose (MCC PH-102) was used as diluent, magnesium stearate as lubricant, and talc as glidant. All chemicals and reagents used in the study were of analytical grade.[11,12]

Preparation of Buccal Tablets

Buccal tablets of metformin hydrochloride were prepared by the direct compression method using different concentrations of mucoadhesive polymers. The accurately weighed quantities of metformin hydrochloride, polymers, and excipients were passed through sieve no. 60 separately. The ingredients were mixed thoroughly in a mortar for 15–20 min to obtain a uniform blend. Magnesium stearate and talc were added at the final stage and mixed gently for 2–3 min.[13]

The prepared powder blend was compressed into tablets using a rotary tablet compression machine

equipped with flat-faced punches. The average weight of each tablet was maintained uniformly throughout the formulation batches.[14]

Evaluation of Precompression Parameters

Angle of Repose

The angle of repose was determined by the fixed funnel method. The accurately weighed powder blend was allowed to flow through a funnel to form a cone on a flat surface, and the angle of repose (θ) was calculated using the following equation.[15]

$$\tan\ \theta = \frac{h}{r}$$

Where,

h = height of powder cone

r = radius of powder cone

Bulk Density and Tapped Density

Bulk density and tapped density of the powder blend were determined by transferring a known quantity of powder into a graduated measuring cylinder. Bulk density was calculated before tapping, whereas tapped density was determined after 100 taps using a tapped density apparatus.[16]

$$\text{Bulk Density} = \frac{M}{V_b}$$

$$\text{Tapped Density} = \frac{M}{V_t}$$

Where,

M = mass of powder

Vb = bulk volume

Vt = tapped volume

Carr's Index and Hausner Ratio

Compressibility behavior of the powder blend was evaluated by Carr's index and Hausner ratio.[17]

$$\text{Carr's Index} = \frac{V_t - V_b}{V_t} \times 100$$

$$\text{Hausner Ratio} = \frac{V_t}{V_b}$$

Evaluation of Buccal Tablets

Physical Appearance and Thickness

Prepared buccal tablets were evaluated for color, appearance, and surface texture visually. Thickness of tablets was measured using a digital Vernier caliper.[18]

Hardness Test

Tablet hardness was determined using a Monsanto hardness tester. The force required to break the tablet diametrically was recorded in kg/cm².[19]

Friability Test

Friability of the tablets was evaluated using a Roche friabilator. Preweighed tablets were rotated at 25 rpm for 4 min, dedusted, and reweighed. Percentage friability was calculated using the following equation.[20]

$$\%F = \frac{W_1 - W_2}{W_1} \times 100$$

Where,

W1 = initial weight of tablets

W2 = final weight of tablets

Weight Variation Test

Twenty tablets from each formulation batch were weighed individually and average tablet weight was calculated. The percentage deviation from the average weight was determined according to pharmacopoeial standards.[21]

Drug Content Uniformity

Ten tablets were powdered, and a quantity equivalent to 100 mg of metformin hydrochloride was dissolved in phosphate buffer pH 6.8. The solution was filtered, suitably diluted, and analyzed spectrophotometrically at 233 nm using a UV-visible spectrophotometer.[22]

Surface pH Determination

The surface pH of buccal tablets was determined to evaluate possible mucosal irritation. Tablets were allowed to swell in phosphate buffer pH 6.8 for 2 h, and pH was measured using a digital pH meter by bringing the electrode in contact with the tablet surface.[23]

Swelling Index

Buccal tablets were weighed individually and placed in phosphate buffer pH 6.8. Tablets were removed at predetermined time intervals, excess surface water was removed carefully, and tablets were reweighed. Swelling index was calculated using the following equation.[24]

$$\text{Swelling Index} = \frac{W_t - W_0}{W_0} \times 100$$

Where,

Wt = weight of swollen tablet

W0 = initial weight of tablet

Mucoadhesive Strength

Mucoadhesive strength of buccal tablets was measured using a modified physical balance method employing freshly excised porcine buccal mucosa. The force required to detach the tablet from the mucosal surface was recorded as mucoadhesive strength.[25]

In Vitro Drug Release Study

In vitro drug release studies were carried out using USP dissolution apparatus type II (paddle method). Phosphate buffer pH 6.8 was used as dissolution

medium maintained at 37 ± 0.5°C with a paddle speed of 50 rpm. Samples were withdrawn at specified intervals, filtered, suitably diluted, and analyzed spectrophotometrically at 233 nm.[26]

3. RESULTS

Precompression Parameters of Powder Blend

The prepared powder blends showed good flow properties suitable for direct compression. The angle of repose values ranged from 24.15° to 28.42°, indicating good flow behaviour. Bulk density and tapped density values suggested adequate packing ability of the powder blend. Carr's index and Hausner ratio values were within acceptable limits, confirming good compressibility characteristics.[27]

Table 1: Precompression Parameters of Powder Blend

Formulation Code	Angle of Repose (°)	Bulk Density (g/cm³)	Tapped Density (g/cm³)	Carr's Index (%)	Hausner Ratio
F1	24.15 ± 0.12	0.42 ± 0.01	0.48 ± 0.01	12.50 ± 0.15	1.14 ± 0.02
F2	25.32 ± 0.15	0.43 ± 0.01	0.49 ± 0.02	12.24 ± 0.14	1.13 ± 0.01
F3	26.18 ± 0.11	0.44 ± 0.02	0.50 ± 0.01	12.00 ± 0.13	1.13 ± 0.01
F4	27.06 ± 0.16	0.45 ± 0.01	0.52 ± 0.01	13.46 ± 0.18	1.15 ± 0.02
F5	28.42 ± 0.14	0.46 ± 0.01	0.54 ± 0.02	14.81 ± 0.21	1.17 ± 0.02

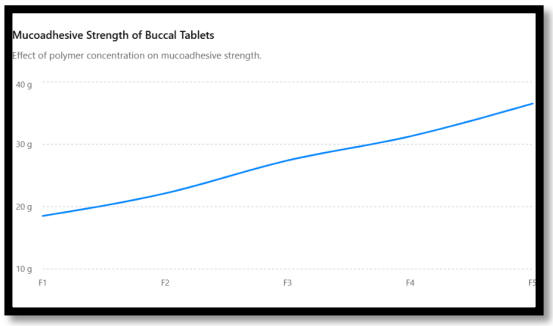
Post compression Parameters

The prepared buccal tablets were evaluated for various physicochemical characteristics including hardness, friability, thickness, weight variation, drug content, swelling index, surface pH, and mucoadhesive strength. All formulations complied with pharmacopoeial specifications.[28]

Table 2: Evaluation of Buccal Tablets

Formulation	Hardness (kg/c	Friability (%)	Thickness (mm)	Drug Content	Surface pH	Swelling Index	Mucoadhesive Strength (g)
	m²)			(%)		(%)	
F1	4.8 ± 0.12	0.71 ± 0.02	3.12 ± 0.04	96.42 ± 0.25	6.42 ± 0.03	58.24 ± 0.52	18.52 ± 0.35
F2	5.0 ± 0.14	0.68 ± 0.01	3.18 ± 0.03	97.15 ± 0.31	6.55 ± 0.04	64.12 ± 0.48	22.14 ± 0.41
F3	5.3 ± 0.11	0.63 ± 0.02	3.24 ± 0.05	98.26 ± 0.28	6.68 ± 0.02	71.42 ± 0.55	27.42 ± 0.36
F4	5.5 ± 0.16	0.58 ± 0.01	3.29 ± 0.04	99.12 ± 0.33	6.74 ± 0.03	76.85 ± 0.61	31.28 ± 0.42
F5	5.7 ± 0.13	0.54 ± 0.02	3.36 ± 0.03	99.64 ± 0.29	6.82 ± 0.02	82.46 ± 0.66	36.54 ± 0.45

Figure: Mucoadhesive Strength of Buccal Tablets- Effect of polymer concentration on mucoadhesive strength.



In Vitro Drug Release Study

The in vitro drug release study demonstrated sustained release behavior of metformin hydrochloride from buccal tablets over a prolonged period. Formulation F5 exhibited the maximum

sustained drug release due to the higher concentration of mucoadhesive polymer, which formed a strong gel barrier controlling drug diffusion.[30]

Table 3: In Vitro Drug Release Study

Time (h)	F1 (%)	F2 (%)	F3 (%)	F4 (%)	F5 (%)
1	22.15	18.42	16.25	14.62	12.84
2	38.24	34.18	30.56	27.48	24.36
3	52.68	47.25	43.12	39.24	35.42
4	66.42	60.18	55.26	50.32	46.18
5	78.54	72.46	67.28	62.15	58.64
6	91.24	86.12	81.36	76.54	72.18
7	98.42	95.24	91.28	88.42	84.36

4. DISCUSSION

The present investigation focused on the development and characterization of buccal tablets of Metformin Hydrochloride using different mucoadhesive polymers in order to enhance buccal residence time and provide sustained drug release. The prepared formulations exhibited satisfactory physicochemical and mucoadhesive properties, indicating the suitability of the selected polymers for buccal drug delivery applications.

The precompression parameters demonstrated acceptable flowability and compressibility of the powder blends. The angle of repose values below 30° suggested good flow characteristics, while Carr's index and Hausner ratio values confirmed efficient packing and compressibility behavior suitable for direct compression techniques. Similar findings have been reported for mucoadhesive buccal formulations prepared using hydrophilic polymers.[31]

Postcompression evaluation revealed that all formulations complied with pharmacopoeial limits for hardness, friability, weight variation, and drug content uniformity. The hardness values increased progressively with increasing polymer concentration due to enhanced interparticulate bonding and matrix formation by hydrophilic polymers. Friability values below 1% indicated adequate mechanical strength and resistance to abrasion during handling and transportation.[32]

The surface pH of all formulations was found to be near neutral, suggesting compatibility with buccal mucosa and minimizing the possibility of mucosal irritation. Maintenance of surface pH close to salivary pH is essential for patient comfort and prolonged retention of buccal dosage forms.[33]

Swelling behavior plays a crucial role in buccal adhesion and controlled drug release. The swelling index increased significantly with increasing concentration of mucoadhesive polymers due to higher water uptake and hydration capacity of the polymeric matrix. Hydration of polymers promotes chain relaxation and interpenetration with mucin, thereby enhancing mucoadhesion.[34] Formulation F5 exhibited maximum swelling index and mucoadhesive strength, which may be attributed to the higher concentration of carbopol and HPMC that possess strong bioadhesive properties.[35]

The mucoadhesive strength of the formulations increased proportionally with polymer concentration. This enhanced adhesion could be explained by the formation of secondary chemical bonds such as hydrogen bonding and van der Waals interactions between hydrated polymer chains and mucosal surfaces. Strong mucoadhesion is advantageous because it prolongs residence time at the site of absorption and improves drug bioavailability.[36]

The in vitro drug release study demonstrated sustained release characteristics of metformin hydrochloride from the buccal tablets. Formulations containing higher concentrations of mucoadhesive polymers exhibited slower drug release due to formation of a viscous gel barrier that restricted diffusion of the drug molecules. Formulation F5 showed the most prolonged release profile among all formulations, indicating efficient control of drug diffusion by the polymeric matrix. Similar sustained release behavior has been reported in buccal formulations prepared with hydrophilic swellable polymers.[37]

The results of the present study indicate that the combination of mucoadhesive polymers significantly influenced swelling behavior, adhesion strength, and drug release profile of buccal tablets. The optimized formulation demonstrated satisfactory physicochemical properties along with prolonged drug release, suggesting its potential utility as an alternative delivery system for metformin hydrochloride. Buccal delivery may enhance patient compliance by reducing dosing

frequency and avoiding gastrointestinal degradation and hepatic first-pass metabolism.[38-102]

5. CONCLUSION

The present study successfully developed and characterized mucoadhesive buccal tablets of Metformin Hydrochloride using different mucoadhesive polymers. The formulated buccal tablets exhibited satisfactory physicochemical properties including acceptable hardness, friability, weight variation, drug content uniformity, surface pH, swelling behavior, and mucoadhesive strength. The precompression parameters confirmed good flowability and compressibility of the powder blends, indicating suitability for direct compression method.

Among all formulations, formulation F5 demonstrated optimum mucoadhesive strength, maximum swelling index, and prolonged drug release profile due to the higher concentration of hydrophilic polymers. The in vitro drug release study confirmed sustained release behaviour of metformin hydrochloride over an extended period, which may improve therapeutic efficacy and reduce dosing frequency.

The findings of the study suggest that mucoadhesive buccal delivery systems can serve as a promising alternative to conventional oral dosage forms by enhancing residence time, minimizing gastrointestinal side effects, avoiding hepatic first-pass metabolism, and improving patient compliance. Therefore, the developed buccal tablets of metformin hydrochloride possess significant potential for effective management of Type 2 Diabetes Mellitus through sustained buccal drug delivery.

6. REFERENCES

1. Bailey CJ, Day C. Metformin: its botanical background. *Practical Diabetes International*. 2004;21(3):115-117.
2. Rojas LBA, Gomes MB. Metformin: an old but still the best treatment for type 2 diabetes. *Diabetology & Metabolic Syndrome*. 2013;5(1):6.
3. Shojaei AH. Buccal mucosa as a route for systemic drug delivery: a review. *Journal of Pharmacy and Pharmaceutical Sciences*. 1998;1(1):15-30.
4. Patel VF, Liu F, Brown MB. Advances in oral transmucosal drug delivery. *Journal of Controlled Release*. 2011;153(2):106-116.
5. Smart JD. The basics and underlying mechanisms of mucoadhesion. *Advanced Drug Delivery Reviews*. 2005;57(11):1556-1568.
6. Khairnar GA, Sayyad FJ. Development of buccal drug delivery system based on mucoadhesive polymers. *International Journal of PharmTech Research*. 2010;2(1):719-735.
7. Semalty A, Semalty M, Kumar G. Formulation and characterization of mucoadhesive buccal films of glipizide. *Indian Journal of Pharmaceutical Sciences*. 2008;70(1):43-48.
8. Perioli L, Ambrogi V, Rubini D, et al. Novel mucoadhesive buccal formulation containing metronidazole for periodontal disease. *Journal of Controlled Release*. 2004;95(3):521-533.
9. Nafee NA, Ismail FA, Boraie NA, Mortada LM. Mucoadhesive buccal patches of miconazole nitrate: in vitro/in vivo performance and effect of ageing. *International Journal of Pharmaceutics*. 2003;264(1-2):1-14.
10. Bhalodia R, Basu B, Garala K, Joshi B, Mehta K. Buccoadhesive drug delivery systems: a review. *International Journal of Pharmaceutical and Biomedical Research*. 2010;1(1):1-32.
11. Patel VM, Prajapati BG, Patel MM. Effect of hydrophilic polymers on buccoadhesive Eudragit patches of propranolol hydrochloride. *AAPS PharmSciTech*. 2007;8(1):E1-E8.
12. Chowdary KPR, Srinivas L. Mucoadhesive drug delivery systems: a review of current status. *Indian Drugs*. 2000;37(9):400-406.
13. Gupta A, Garg S, Khar RK. Measurement of bioadhesive strength of mucoadhesive buccal tablets. *Indian Drugs*. 1992;30(4):152-155.
14. Nafee NA, Boraie NA, Ismail FA, Mortada LM. Design and characterization of mucoadhesive buccal patches. *International Journal of Pharmaceutics*. 2003;264(1-2):1-14.
15. Aulton ME. *Pharmaceutics: The Science of Dosage Form Design*. 2nd ed. Churchill Livingstone; 2002.
16. Lachman L, Lieberman HA, Kanig JL. *The Theory and Practice of Industrial Pharmacy*. 3rd ed. Varghese Publishing House; 1987.
17. Banker GS, Anderson NR. Tablets. In: Lachman L, Lieberman HA, Kanig JL, editors. *The Theory and Practice of Industrial Pharmacy*. 3rd ed. Mumbai: Varghese Publishing House; 1987. p. 293-345.
18. Indian Pharmacopoeia. Government of India, Ministry of Health and Family Welfare. Ghaziabad: Indian Pharmacopoeia Commission; 2022.

19. Liberman HA, Lachman L, Schwartz JB. *Pharmaceutical Dosage Forms: Tablets*. Vol. 1. New York: Marcel Dekker; 1989.
20. United States Pharmacopoeia 30–National Formulary 25. Rockville: United States Pharmacopoeial Convention; 2007.
21. British Pharmacopoeia. London: Her Majesty's Stationery Office; 2019.
22. Beckett AH, Stenlake JB. *Practical Pharmaceutical Chemistry*. 4th ed. CBS Publishers; 2001.
23. Semalty A, Semalty M, Kumar G. Formulation and characterization of mucoadhesive buccal films. *Indian Journal of Pharmaceutical Sciences*. 2008;70(1):43-48.
24. Smart JD. Drug delivery using buccal-adhesive systems. *Advanced Drug Delivery Reviews*. 1993;11(3):253-270.
25. Khairnar GA, Sayyad FJ. Development of buccal drug delivery system based on mucoadhesive polymers. *International Journal of PharmTech Research*. 2010;2(1):719-735.
26. Shojaei AH. Buccal mucosa as a route for systemic drug delivery. *Journal of Pharmacy and Pharmaceutical Sciences*. 1998;1(1):15-30.
27. Aulton ME. Pharmaceutics: The Science of Dosage Form Design. 2nd ed. Churchill Livingstone; 2002.
28. Indian Pharmacopoeia. Government of India, Ministry of Health and Family Welfare. Ghaziabad: Indian Pharmacopoeia Commission; 2022.
29. Smart JD. The basics and underlying mechanisms of mucoadhesion. Advanced Drug Delivery Reviews. 2005;57(11):1556-1568.
30. Patel VF, Liu F, Brown MB. Advances in oral transmucosal drug delivery. Journal of Controlled Release. 2011;153(2):106-116.
31. Andrews GP, Laverty TP, Jones DS. Mucoadhesive polymeric platforms for controlled drug delivery. European Journal of Pharmaceutics and Biopharmaceutics. 2009;71(3):505-518.
32. Cilurzo F, Cupone IE, Minghetti P, Selmin F, Montanari L. Fast dissolving films made of maltodextrins. European Journal of Pharmaceutics and Biopharmaceutics. 2008;70(3):895-900.
33. Rathbone MJ, Drummond BK, Tucker IG. The oral cavity as a site for systemic drug delivery. Advanced Drug Delivery Reviews. 1994;13(1-2):1-22.
34. Peppas NA, Buri PA. Surface, interfacial and molecular aspects of polymer bioadhesion on soft tissues. Journal of Controlled Release. 1985;2(4):257-275.
35. Park H, Robinson JR. Mechanisms of mucoadhesion of poly(acrylic acid) hydrogels. Pharmaceutical Research. 1987;4(6):457-464.
36. Hassan EE, Gallo JM. A simple rheological method for the in vitro assessment of mucin-polymer bioadhesive bond strength. Pharmaceutical Research. 1990;7(5):491-495.
37. Nafee NA, Ismail FA, Boraie NA, Mortada LM. Design and characterization of mucoadhesive buccal patches containing cetylpyridinium chloride. Acta Pharmaceutica. 2004;54(3):199-212.
38. Sudhakar Y, Kuotsu K, Bandyopadhyay AK. Buccal bioadhesive drug delivery — a promising option for orally less efficient drugs. Journal of Controlled Release. 2006;114(1):15-40.
39. Salpe, H. G., Devhare, L. D., Ghugare, A. P., & Singh, N. (2016). Formulation and evaluation of hpmc coated diltiazem hcl tablet and its comparison with other marketed preparation. Research chronicle in health sciences, 3(1), 11-17.
40. Devhare, L., Hiradeve, S., & Bobade, T. (2017). Method Development & Validation For Determination Of Water Content. LAP LAMBERT Academic Publishing.
41. Devhare, L. D., Ghugare, A. P., Hatwar, B. P., Goupale, D. C., & Devhare, L. D. (2015). Method development for determination of water content from various materials by spectrophotometry and it's validation. International journal of drug delivery, 7(4), 233-240.
42. Tonde, T. U., Kasliwal, R. H., & Devhare, L. D. (2016). Quantitative estimation of bacoside a in polyherbal memory enhancer syrup for memory boosting activity using hptlc method. Research chronicle in health sciences, 2(6), 315-320.
43. Ghugare, A. P., Devhare, L., & Hatwar, B. P. (2016). Development and validation of analytical methods for the simultaneous estimation of Nimorazole and Ofloxacin in tablet dosage form. International Journal of Drug Delivery, 8, 96-98
44. Makhani, A. A., & Devhare, L. (2017). Development and validation of vierordt's spectrophotometric method for simultaneous estimation of Drotaverine and Nimesulide combination. Research chronicle in health sciences, 3(2), 22-28
45. Makhani, A. A., & Devhare, L. D. (2017). Development and validation of analytical methods for drotaverine and nimesulide combination. Research chronicle in health sciences, 3(3), 40-44.

46. Katole, G., & Devhare, L. (2018). Diluent and granulation study on Metformin Hydrochoride. LAP LAMBERT Academic Publishing.
47. Katole, G., & Devhare, L. D. (2020). Recent insight into some emerging natural resources with remarkable hepato protective potentials. International journal of pharmaceutical science and research, 5(1), 41-47.
48. Devhare, L. D., & Gokhale, N. (2021). Acid neutralizing capacity and antimicrobial potential of selected solvent extract from various indigenous plants. Journal of Advanced Scientific Research, 12(04), 175-179
49. Uplanchiwar, V. P., Raut, S. Y., & Devhare, L. D. (2021). Pharmacological assessment of antiulcer activity of gloriosa superba linn tubers in experimentally induced gastric ulcers. Journal of medical pharmaceutical and allied science, 10(3), 2852-2856.
50. Devhare, L. D., & Gokhale, N. (2022). Antioxidant and Antiulcer property of different solvent extracts of Cassia tora Linn. Research journal of pharmacy and technology, 15(3), 1109-1113.
51. Devhare, L. D., & Gokhale, N. (2023). A brief review on: phytochemical and antiulcer properties of plants (fabaceae family) used by tribal people of gadchiroli maharashtra. International journal of pharmaceutical sciences and research, 14(4), 1572-1593.
52. Devhare, L. D., & Gokhale, N. (2023). In silico anti-ulcerative activity evaluation of some bioactive compound from Cassia tora and Butea monosperma through moleculer docking approach. International journal of pharmaceutical sciences and research, 14(2), 1000-08.
53. Suruse, P. B., Jadhav, B. A., Barde, L. G., Devhare, L. D., Singh, S., Minj, K. H., & Suman, A. (2023). Exploring the potential of Aerva Lanata extract in a herbal ointment for fungal infection treatment. Journal of Survey in Fisheries Sciences, 10(1), 1922-1932.
54. Bodhankar, S. S., Devhare, L. D., Meshram, A. S., Moharkar, D. W., & Badwaik, C. B. (2023). Formulation and in vitro evaluation of dental gel containing ethanglic extract of Mimosa pudica. European Chemical Bulletin, 12(5), 1293-1299.
55. Shende, S. M., Bhandare, P., & Devhare, L. (2023). In-vitro: micropropagation of mint and investigate the antibacterial activity of mint extract. Eur. Chem. Bull, 12(5), 780-784.
56. Singh, S., Minj, K. H., Devhare, L. D., Uppalwar, S. V., Anand, S., Suman, A., & Devhare, D. L. (2023). An update on morphology, mechanism, lethality, and management of dhatura poisoning. Eur. Chem. Bull, 12(5), 3418-3426.
57. Devhare, L. D., Bodhankar, S. S., Warambhe, P., Uppalwar, S. V., Devhare, D. L., Uchibagle, S., & Shende, S. (2023). Important role of food and nutritional security during Covid-19: A survey. Eur. Chem. Bull, 12(5), 1363-1374.
58. Gnana, R. P. M., Devhare, L. D., Dharmamoorthy, G., Khairnar, M. V., & Prasidha, R. (2023). Synthesis, Characterisation, Molecular Docking Studies and Biological Evaluation of Novel Benzothiazole Derivatives as EGFR Inhibitors for Anti-breast Cancer Agents. International Journal of Pharmaceutical Quality Assurance, 14(3), 475-480.
59. Prasad, M., Suman, A., Srivastava, S., & Devhare, L. D. (2023). Butea monosperma stem bark extract partially reverses high fat diet-induced obesity in rats. Eur. Chem. Bull, 12(5), 4267-4273.
60. Thakare, V. M., Umare, S. A., & Devhare, L. D. (2023). Separation and purification of carboxymethyl cellulose from Spinacia Oleracea for use in pharmaceutical dosage form. Eur. Chem. Bull, 12(5), 4062-4080.
61. Suruse, P. B., Deshmukh, A. P., Barde, L. G., Devhare, L. D., Maurya, V. K., Deva, V., & Priya, N. S. (2023). Rimegepant embedded fast dissolving films: A novel approach for enhanced migraine relief. Journal of Survey in Fisheries Sciences,10(1), 2071-2084.
62. Pathak, N. R., Devhare, L. D., Sawarkar, K. R., Dubey, M., Trivedi, V., Thakre, A. R., & Thakare, V. M. (2023). Aclinial reveiew on pharmacological evaluation of Thiazolidine and Isatin in the new millenium as magic moieties. Eur. Chem. Bull, 12(5), 3410-3417.
63. Nikam Nikita, R., Vaishnavi, A., & Lalchand, D. (2023). Parenteral drug delivery approach: an overview. Journal of xidian university, 17(1), 386-400.
64. Shende, S. M., Meshram, B., Karemore, H., & Devhare, L. D. (2023). Development And Characterization of Glycerogelatin Suppositories For Enhanced Efficacy. European Journal of Pharmaceutical and Medical Research, 10(6), 522-528.
65. Shukla, M., Tiware, S. A., Desai, S. R., Kumbhar, S. T., Khan, M. S., Mavai, Y., & Devhare, L. D. (2023). Pharmacological Evaluation of Gloriosa Superba Linn Flower Extract For Antiulcer

Activity. Journal of Survey in Fisheries Sciences, 10(2), 463-470.

66. Tiwari, R., Mishra, J., Devhare, L. D., & Tiwari, G. (2023). AN UPDATED REVIEW ON RECENT DEVELOPMENTS AND APPLI-CATIONS OF FISH COLLAGEN. Pharma Times, 55(06), 28.

67. Polireddy, P., Malviya, V., Arora, S., Singh, M., pooja Tanaji, G., Devhare, L. D., & Dharmamoorthy, G. (2023). Assessment of Hepatoprotective Potential of Ecbolium Linneanum Extract on Experimental Animals. Journal of Coastal Life Medicine, 11, 884-890.

68. Devhare, L. D., Kumbhar, S. T., Chitrapu, P., Kundral, S., & Borkar, A. A. (2023). In-Silico Molecular Docking Study of Substituted Imidazo 1, 3, 4 Thiadiazole Derivatives: Synthesis, Characterization, and Investigation of their Anti-Cancer Activity. Journal of Coastal Life Medicine, 11, 1237-1245.

69. Sonule, M., Devhare, L. D., Babu, M. N., Gunjal, S. D., & Varalaxmi, S. (2023). Microemulgel-based Hydrogel of Diclofenac Sodium using Lipidium sativum as a Gelling Agent. International Journal of Drug Delivery Technology, 13(4), 1235-1239.

70. Shriram, B. K., Devhare, L. D., Mehrotra, A., Deokar, S. S., & Singh, S. P. (2023). Formulation and Evaluation of Mosquito Repellent Stick. International Journal of Drug Delivery Technology, 13(4), 1283-1286.

71. Tiwari, G., Gupta, M., Devhare, L. D., & Tiwari, R. (2024). Therapeutic and phytochemical properties of thymoquinone derived from Nigella sativa. Current Drug Research Reviews Formerly: Current Drug Abuse Reviews, 16(2), 145-156.

72. Singh, M., Malik, A., Devhare, D. L., Ruikar, D. B., Krishnan, K., Kumar, D. V., & Devnani, D. (2023). Comparative Case Study On Tuberculosis Patients Between Rural And Urban Areas. Journal of Survey in Fisheries Sciences, 10(2), 1-11.

73. Thakre, S. M., Kumar, D. V., Ahuja, A., Hamid, N., Thakre, A. R., Khan, M. S., & Devhare, L. (2023). Exploring the Influence of an Antifungal Medication on Patients Receiving Oral Hypoglycemic Therapy: Investigating the Interplay Between Medications. Journal of Coastal Life Medicine, 11, 1255-1262.

74. Adimulapu, A. K., Devhare, L. D., Patil, A., Chachda, N. O., & Dharmamoorthy, G. (2023). Design and Development of Novel Mini Tablet Cap Technology for the Treatment of Cardiovascular Diseases. International Journal of Drug Delivery. Technology, 13(3), 801-806.

75. Krishna, K. V., Jain, P. K., Devhare, L. D., Sharma, R. K., Bagade, O. M., Venkatesham, A., & Yogesh, P. K. (2023). A Study on Antidiabetic Potential of Dried Fruits Extract of Eucalyptus Globulus in Experimental Animals. Journal of Biomedical Engineering, 40(3), 99-110.

76. Priya, M. G. R., Prasanth, L. M. L., Devhare, L. D., Yazdan, S. K., & Gunjal, S. (2024). Synthesis, DNA Binding, Molecular Docking and Anticancer Studies of Copper (II), Nickel (II), and Zinc (II) Complexes of Primaquine-based Ligand. International Journal of Pharmaceutical Quality Assurance, 15(1), 69-75.

77. Choudhary, R. K., Beeraka, S., Sarkar, B. K., Dharmamoorthy, G., & Devhare, L. (2024). Optimizing Verapamil Hydrochloride In-situ Delivery: A Strategic Formulation Approach using Box-Behnken Design for Enhanced Performance and Comprehensive Evaluation of Formulation Parameters. International Journal of Drug Delivery Technology, 14(1), 61-70.

78. Kumar, K. K., Kiran, V., Choudhary, R. K., Devhare, L. D., & Gunjal, S. D. (2024). Design Development and Characterization of Nicardipine Solid Lipid Nano-Particulars. International Journal of Drug Delivery Technology, 14(1), 71-78.

79. Devhare, L. D., & Gokhale, N. (2023). Extraction. Phytochemical Screening and Comparative Pharmacological Evaluation of Some Indigenous Plants for Antiulcer Activity, 01-244.

80. Devhare, L. D., Naikwadi, A. S., & Arote, S. B. (2023). Aditya V, Hiteshkumar S. Agrawal. Pharmacy Practice. Pritam Publication, 1-200.

81. Devhare, L. D., & Nikam, N. (2023). Practical Handbook of Pharmacology-II. Pritam Publication, 1, 1-95.

82. Devhare, L., & Prasad, C. (2024). Prophylactic and curative activity of Withania somnifera on experimentally induced calcium oxalate nephrolithiasis. Journal of medical pharmaceutical and allied sciences, 13(4), 6687-6695.

83. Shende, S., Devhare, L., Prasad, C., Khobragade, A., & Khapne, A. (2024). Next-Generation Drug Delivery Strategies for Personalized Healthcare. Pharmaceutical Research - Recent Advances and Trends, 2, 28-62

84. Devnani, D., Prasad, K. K., Bongade, K., Verma, A., Choudhary, T., Posa, M. K., & Devhare,

D. L. (2024). Case Study On Rubella Virus. Journal of Advanced Zoology, 45(2). 1133

85. Lalchand D. Devhare, Ram Kumar Choudhary, Kiran Kumar Kurella, Falgunee Dasharath Ghadi, Jyoti Mundlia, Murali Krishna Kandukuri. (2024). Research Methodology and Biostatistics.IIP Publication.1-165

86. Kumar, Y. G., Dharmamoorthy, G., Devhare, L. D., Gunjal, S. D., & Deshpande, M. (2023). Toxicity Profile Study of Antihypertensive Drug Prazosin in Pregnant Wistar Rats. Journal of Advanced Zoology, 44, 64

87. Devhare, L. D.(2023) Extraction phytochemical screening and comparative pharmacological evaluation of some indigenous plants for antiulcer activity.Shodhganga.1-244

88. Konda V V S Krishna, Virendra Kumar Maurya, S. R. Fulmali, Praful N Giradkar, Lalchand D. Devhare (2023). A Textbook of Social and Preventive Pharmacy. Pritam Publication.1-201

89. Konda V V S Krishna, Amruta R. Patil, Anupama A. Kapadnis, Vinod M. Thakare, Lalchand D. Devhare. (2023). Textbook of Pharmacotherapeutics. Pritam Publication.1-166

90. Savita Shrikant Deokar Vedanshu R. Malviya, Biresh Kumar Sarkar, Lalchand D Devhare, Mangla Nand Singh.(2023). A Textbook of Novel Drug Delivery System. IIP Publication.1-230.

91. Chand, G., Devhare, L. D., & Hooda, T. (2024). Diverse Properties of Tinospora Cordifolia (Giloy, Heart Leaved Moonseed) world wild use for immunotherapies;boosting the body's defence and immune support . Emerging Paradigms for Antibiotic-Resistant Infections: Beyond the Pill. Sringer Nature. 471-486

92. Upreti, P., Devhare, L. D., Abdulmageed, L. H., Kumar, Y. G., Kumar, R., & Dharmamoorthy, G. (2024). Combatting Antibiotic Resistance: Leveraging Fecal Microbial transplantation for gut health. Emerging Paradigms for Antibiotic-Resistant Infections: Beyond the Pill. 211-232.

93. Chandani Prasad, Lalchand Devhare, Ashish Khobragade and Shubham Shende. (2025). Herbal Approaches To Skin Lightening: A Comprehensive Review. 16(1): 62-68.

94. Vyas S, Anitha KN, Mudduluru NB, Devhare LD. Quality by Design Approach to Nasal Mucoadhesive Microspheres: Enhanced Sumatriptan Succinate Delivery through Formulation and Characterization. International Journal of Drug Delivery Technology. 2024;14(3):1644-1651.

95. Deogade, S., Shende, S., Prasad, C., Dorlikar, M., Urade, P., & Devhare, LD. (2025). Autophagy: A Critical Review of Cellular Homeostasis and Pathophysiology. Asian Journal of Advanced Research and Reports, 19(2), 280-287.

96. Kumar, Y. G., Anitha, K. N., Verma, A., Agrawal, S. L., Motiram, N., Gawai, H. A. S., & Devhare, LD. (2025). Micro Needles Patch for Insulin: Transforming Drug Delivery in Diabetes Management. Journal of Neonatal Surgery, 14(2s).

97. Spandana, C. H. V. L. D., Anitha, K. N., Muddagoni, J., Gawai, N. M., Chauhan, V., Sawarkar, H. A., & Devhare, LD. (2025). Phytopharmaceutical Interventions in Neurodegenerative Disorders: Emerging Trends and Prospects. Journal of Neonatal Surgery, 14(2s).

98. Lalchand D. Devhare, Ram Kumar Choudhary, Kiran Kumar Kurella, Falgunee Dasharath Ghadi, Jyoti Mundlia, Murali Krishna Kandukuri. Textbook of Research Methodology and Biostatistics. IIP Publication, 2024, Volume 1, Pages 1-165.

99. Lalchand D. Devhare Konda V V S Krishna, Virendra Kumar Maurya, S. R. Fulmali, Praful N Giradkar. A Textbook of Social and Preventive Pharmacy. Pritam Publication. 2023, Volume 1, Pages 1-201.

100. Lalchand D. Devhare Konda V V S Krishna, Amruta R. Patil, Anupama A. Kapadnis, Vinod M. Thakare. Textbook of Pharmacotherapeutics. Pritam Publication. 2023, Volume 1, Pages 1-166.

101. Savita Shrikant Deokar Vedanshu R. Malviya, Biresh Kumar Sarkar, Lalchand D Devhare, Mangla Nand Singh. A Textbook of Novel Drug Delivery System. IIP Publication. 2023, Volume 1, Pages1-230.

102. Prasad, C., Devhare, LD., Khobragade, A., & Shende, S. Herbal Approaches To Skin Lightening: A Comprehensive Review. International Journal of Pharmaceutical Sciences and Research, 2025; Vol. 16(1): 62-68.