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Original Article

The International Natural Product Sciences Taskforce (INPST) and the power of Twitter networking exemplified through #INPST hashtag analysis

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Abstract

Background

The development of digital technologies and the evolution of open innovation approaches have enabled the creation of diverse virtual organizations and enterprises coordinating their activities primarily online. The open innovation platform titled "International Natural Product Sciences Taskforce" (INPST) was established in 2018, to bring together in collaborative environment individuals and organizations interested in natural product scientific research, and to empower their interactions by using digital communication tools.

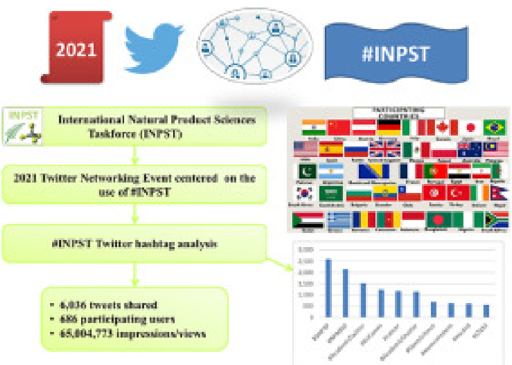
Methods

In this work, we present a general overview of INPST activities and showcase the specific use of Twitter as a powerful networking tool that was used to host a one-week “2021 INPST Twitter Networking Event” (spanning from 31st May 2021 to 6th June 2021) based on the application of the Twitter hashtag #INPST.

Results and Conclusion

The use of this hashtag during the networking event period was analyzed with Symplur Signals (https://www.symplur.com/), revealing a total of 6,036 tweets, shared by 686 users, which generated a total of 65,004,773 impressions (views of the respective tweets). This networking event's achieved high visibility and participation rate showcases a convincing example of how this social media platform can be used as a highly effective tool to host virtual Twitter-based international biomedical research events.

Graphical abstract



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Keywords

Natural products; Open innovation; Social media; Hashtag analysis; Twitter research; Digital tools

Abbreviations

COVID-19, Coronavirus Disease 2019; DHPSP, Digital Health and Patient Safety Platform; FDA, Food and Drug Administration; HIV/AIDS, Human Immunodeficiency Virus/ Acquired ImmunoDeficiency Syndrome; INPST, International Natural Product Sciences Taskforce; ICNPU-2019, The 4th International Conference on Natural Products Utilization from Plants to Pharmacy Shelf, 2019; LDCs, Least Developed Countries; MDPI, Multidisciplinary Digital Publishing Institute; ROS, Reactive Oxygen Species; SARS-

CoV-2, Severe Acute Respiratory Syndrome Coronavirus 2; STEM, Science Technology Engineering and Mathematics

Introduction

Significance of natural products and natural product research

Nature offers multiple solutions to almost all the challenges faced by mankind. In particular, natural products represent a sustainable bioresource with the potential to treat and manage various diseases and disorders (Durazzo et al., 2018a; Durazzo and Lucarini, 2021, 2019; Ghareeb et al., 2020; Uhrin et al., 2018). Globally, a fast and dynamically growing body of evidence is continuously emerging from computational level to the clinical level, enabling translational aspects and diverse applications of a wide range of bioactive natural products (Apoorva et al., 2021; Bankar et al., 2011; Bansal et al., 2021; Dangar and Patel, 2021; Igoli et al., 2014a, 2014b; Madaan et al., 2022; Marzocco et al., 2021; Okoh et al., 2021; Singla, 2021; Singla et al., 2021a, 2021b, 2021c; Singla et al., 2021d). Plants, animals, and microbes serve as natural resources and goldmines for therapeutics, supplements, and nutraceuticals discovery (Capó et al., 2021; Dai et al., 2021; Durazzo et al., 2018b, 2020; Mirończuk-Chodakowska et al., 2021; Santini et al., 2018; Santini and Novellino, 2014, 2017, 2018; Santini et al., 2017; Singla and Dubey, 2019; Singla et al., 2019; Wink, 2015; Yang et al., 2019a). Not only do the traditional medicinal systems rely on natural products, but the modern medicinal systems also heavily rely on using multiple natural product scaffolds for drug development, in an unmodified state or for-property optimization achieved by modifying the starting natural product scaffold (Atanasov et al., 2015; Chaturvedi et al., 2020; Ravula et al., 2021; Tewari et al., 2021). For clinical purpose, there are already a lot of highly successful natural product-based medicines, including but not limited to antibacterials such as streptomycin (Waksman and Schatz, 1945), antifungals such as amphotericin B (Cavassin et al., 2021), antimalarials such as artemisinin (Wang et al., 2019b), anticancer agents such as vinca alkaloids (Ehrhardt et al., 2011), camptothecin (Wang et al., 2021), and paclitaxel (Rowinsky et al., 1995), or antidiabetic agents such as acarbose (Kumar Singla et al., 2016; Tupas et al., 2020). Chemical modification of natural product molecules has also yielded multiple clinically relevant drugs such as caspofungin (Walsh et al., 2004), artemether (Hien et al., 1996), or etoposide (Cragg and Pezzuto, 2016; O'Dwyer et al., 1985). As a reflection of the high significance of natural products for the discovery and development of new pharmaceuticals, a high number of natural products or their derivatives are currently in clinical trials for a range of diverse diseases (Ahmad et al., 2021; Lima et al., 2021; Nile and Kai, 2020; Singla et al., 2022a, 2022b). Moreover, multi-component natural product mixtures are also studied to explore their therapeutic potential and used clinically (Wink, 2015). Examples of botanical drugs based on such complex mixtures of natural products approved by the United States Food and Drug Administration (FDA) include sinecatechins (marketed as Veregen® by Fougera Pharmaceuticals Inc.), an extract of green tea leaves [*Camellia sinensis* (L.) Kuntze] approved for the treatment of genital and anal warts in 2006, and crofelemer (marketed as Mytesi™ by Napo Pharmaceuticals), an oligomeric proanthocyanidin-enriched extract from the latex of the Dragon's blood tree (*Croton lechleri* Müll.Arg.)

that was approved for human immunodeficiency virus/ acquired immunodeficiency syndrome (HIV/AIDS)-related diarrhea in 2012 (Chenetal., 2008; Crutchleyetal., 2010; Kleindletal., 2017). Natural products are also been intensively investigated for prevention or treatment of coronavirus disease 2019 (Devpuraetal., 2021; Lordanetal., 2021; Silveiraetal., 2020; Singlaetal., 2021b; Wangetal., 2020b). Aside of medicinal plants, many mushrooms are also exhibiting therapeutic potential, and for example in China numerous medicinal mushrooms have been included in the Chinese Pharmacopoeia (Daietal., 2021). Along this line, it is important to underline that multiple herbal preparations are used in complementary and alternative medicine around the world. For example, plants with antioxidant phytoconstituents, such as phenolics, carotenoids, allicin, mustard oil and vitamins C and E, are widely employed as phytopharmaceuticals and nutraceuticals and help prevent diseases caused from an overdose of reactive oxygen species (ROS) including cancer, cardiovascular and neurodegenerative health conditions (Wink,2022). To reduce the financial strain on the public from poorer countries undergoing rapid (economic) development (LDCs), it is essential to focus on such sustainable resources for therapeutic management as they will be cost-effective, accessible, and in most cases safe (Chaturvedietal., 2018; Heinrichetal., 2021; Singlaetal., 2021d; Suryanarayana Rajuetal., 2015).

In addition to therapeutic uses, natural products and materials have many other (non-medical) applications in different areas. Cellulose nanofibers with improved photothermal stability, for example, have potential in the fields of coating and packaging (Dengetal., 2022). Rice husk can be applied as a green coagulant (Tanetal., 2022), and hydrophobically modified agarose as hydrogels (Evansetal., 2022). Sweeteners (Pawaretal., 2013; Yeungetal., 2019d), biosurfactants (Liuetal., 2022), bioremediators (Xueetal., 2022), adsorbents (Etimetal., 2016), biofuels (Murilloetal., 2021; Sirigerietal., 2019), fuel cells (Chenetal., 2018), carbon electrodes (Xietal., 2021), carbon fertilizers (Xiangetal., 2021), paper industry uses (Haunreiteretal., 2021), cosmeceuticals (Alvesetal., 2020), and pesticides (Yangetal., 2021; Zaccardellietal., 2020) are just a couple of examples out of the broad spectrum applications of various natural products and materials.

Scientific open innovation in the era of digital communications

The traditional approach for the generation of industrial innovation (including the development of new products and services) has been relying on internal resources and company employees. A newer concept, "open innovation", moved the focus on a more substantial reliance on innovation generated externally, and its interaction with the company´s resources (Chesbroughand Crowther,2006; Hodson,2016). The open innovation concept has an advantage that it can tap into newly developed technologies and ideas without the need to entirely depend on own resources and expertise, the maintenance of which is complex and costly. In this model of innovation generation, industrial entities move their priority out of intellectual property protection to pursue external collaboration-oriented strategies, whereby collaborating partners could be other companies, academic units, or the general public as a whole. In analogy to the industrial approach where the concept was first created, the "Open Innovation in Science" approach in academia emerges as a set of practices with the focus shifted to openness and collaborative, interactive, integrated, and often interdisciplinary work involving more vital interaction with external parties from academia, industry, and society (Becketal., 2020), realized for example by creating collaborative networks and research infrastructures in the perspective of interoperability (Dwyer et al., 2021). In the arena of medical and pharmaceutical research, which is of relevance to the focus of the open innovation platform described in the present manuscript, a recent total-scale literature analysis identified 384 scientific papers dealing with open innovation, with the first publications starting to appear in the literature in the middle of the 2000s (Yeung et al., 2021a). The later analysis also revealed that, so far, most research on open innovation in the arena of medical and pharmaceutical research was done in North America and Europe, and that the pharmaceutical sector was the most active industrial stakeholder.

Digital communication tools have the potential to empower significantly open innovation approaches. Historically, some of the first applications of open innovation took place exactly in the area of information technologies and computer technologies (in addition to the above-mentioned pharmaceutical industry sector) (Chesbrough and Crowther, 2006). With the use of digital communication tools, open innovation practitioners can reach quickly and easily large audiences of relevant stakeholders, which is of high importance for the application of key open innovation techniques such as crowdsourcing (Wazny, 2018). Moreover, digital technologies have enabled the emergence of a variety of virtual organizations that coordinate their activities primarily online, one of which is the International Natural Product Sciences Taskforce (INPST) (Atanasov et al., 2021; Camarinha-Matos and Afsarmanesh, 2005) that we present in detail in the current manuscript.

The International Natural Product Sciences Taskforce (INPST), an open innovation platform to invigorate the natural product research field

The International Natural Product Sciences Taskforce (INPST) was initiated in the early 2018, aiming to bring together in a collaborative environment individuals and organizations interested in natural products science, and empower them through the application of open innovation approaches and digital communication tools (for both networking and dissemination of credible scientific information). Envisaging the diverse applications of natural products in many areas of industry and healthcare, new natural product-related scientific findings could be of high importance in addressing some key societal problems, such as the search for new medicines, the establishment of innovative technologies that are friendlier to the environment, and the development of better food and dietary supplements. Along this line, both the continuous exploration of the existing natural biodiversity is of benefit, but also cultivated biodiversity, involving improvements mediated through modern genetic techniques, which allow to specifically increase the content of substances of high nutritional and even pharmaceutical interest (Sabbadini et al., 2021).

As the major entry point for accessing INPST-curated content, INPST website (https://inpst.net/ ↗) has been established. The INPST platform integrates several social media channels (Table 1) and presents in diverse subsections, contents that might be of interest to the visitors, including links to relevant conferences, job offers, publications, funding opportunities, and special issues of scientific journals. The INPST has attracted strong attention, and over 1500 people from more than 50 countries have joined the platform as members or email subscribers as of April 2021. In addition, large audiences have followed the major INPST social media channels (Facebook, Twitter, ResearchGate, and LinkedIn), as detailed in Table 1.

Table 1. Major INPST social media channels.

Social media	Audience (as of April 2021)- Pre INPST Networking Event	Audience (as of January 2022) Post INPST Networking Event	Web address
Facebook	7672	8171	https://www.facebook.com/INPST/
Twitter	3113	4084	https://twitter.com/_INPST
ResearchGate	561	889	https://www.researchgate.net/project/International-Natural-Product-Sciences-Taskforce-INPST
LinkedIn	573	725	https://www.linkedin.com/company/international-natural-product-sciences-taskforce/

Aside from the INPST email list and social media channels, another tool for direct communication between INPST members and web visitors was provided through the INPST forum tool (https://inpst.net/other-topics-and-announcements/). Representative examples of different INPST-based activities (Table2) are aligned with the multiple dissemination and outreach activities. INPST-based networking has proven to be an excellent catalyst for new collaborative integrated scientific research (Banachetal., 2018; Horbanczuketal., 2019; Jozwiketal., 2018; Ruscicaetal., 2021; Tanchevaetal., 2020; Tewarietal., 2020; Tzvetkovetal., 2019; Yangetal., 2019b; Zhubi-Bakijaetal., 2021), including joint work conducting meta-analysis of the published literature (Durazzoetal., 2021a, 2021b; Yeungetal., 2018, 2019a, 2020a; Yeungetal., 2019b, 2020b, 2020c; Yeungetal., 2019c, 2021c, 2019d), and the preparation of scientific collaborative review publications (Khanetal., 2020; Lietal., 2021; Mondaletal., 2021, 2019; Tewarietal., 2018; Vaccaetal., 2019; Wangetal., 2022, 2018, 2019a; Wangetal., 2021) utilizing broadly-international collaborative work. In the latest example of collaborative work type, a special mention deserves a 2021 article from *Nature Reviews Drug Discovery* entitled "Natural products in drug discovery: advances and opportunities," in which the International Natural Product Sciences Taskforce was used for the first time as an author group designation (Atanasovetal., 2021).

Table 2. Representative examples of different categories of INPST-based activities.

Category	Example	Weblink
Conference support	ICNPU-2019: The 4th International Conference on Natural Products Utilization from Plants to Pharmacy Shelf, supported by INPST (29 May – 01 June 2019, Albena resort, Bulgaria)	https://inpst.net/4th-international-conference-on-natural-products-utilization-from-plants-to-pharmacy-shelf-supported-by-inpst/

Category	Example	Weblink
News entries dissemination	INPST collaborative work analyzes about 300,000 scientific papers to outline trends in antioxidants research	https://inpst.net/antioxidant-phytochemicals-takeover-scientific-attention-replacing-antioxidant-vitamins-and-minerals/
Research project features	Multitarget peptide-fragment hybrids for the treatment of neurodegenerative diseases	https://inpst.net/multitarget-peptide-fragment-hybrids-for-the-treatment-of-neurodegenerative-diseases/
Popularization of scientific publications	Marine natural products	https://inpst.net/marine-natural-products/
Funding announcements	Government of Ireland International Education Scholarship Programme	https://inpst.net/government-of-ireland-international-education-scholarship-program/
Online lectures	SARS-CoV-2 and COVID-19: Basic knowledge on a novel pandemic (Special Online Lecture by Prof. Thomas Efferth, on 9th of March 2021)	https://inpst.net/sars-cov-2-and-covid-19-basic-knowledge-on-a-novel-pandemic/
Job offers	Non-academic Executive Director at Natural Product Research center (at Trinity College Dublin, Ireland)	https://inpst.net/non-academic-executive-director-at-natural-product-research-center-at-trinity-college-dublin-ireland/
Collaborative research calls	Collaboration call: Root of *Althea officinalis* (marsh-mallow)	https://inpst.net/collaboration-call-root-of-althea-officinalis-marsh-mallow/
Award announcements	INPST Young Scientist Award 2019	https://inpst.net/inpst-young-scientist-award-2019/
Blogging	Pomegranate for heart health and the science behind it	https://inpst.net/blog/pomegranate-for-heart-health-and-the-science-behind-it/
Dissemination of journal special issues	Natural Products and Their Applications	https://inpst.net/crbiotech-special-issue-natural-products-and-their-applications/

Twitter as a tool for science communication and networking

Twitter represents one of the comparably large social media platforms with an estimated more than 300 million monthly active users (https://www.statista.com/↗). The major feature of the platform is that it enables users to share publicly short messages (tweets), with the current characters limit (since 2017) for a single tweet being 280 characters (Bootetal., 2019). Furthermore, tweets can optionally include hyperlinks to other content on the web, photo images, short video clips, and hashtags (broadly used tags in social media used to label and grouping together thematically linked social media posts).

Twitter represents a social media platform widely used by scientists (Soragni and Maitra, 2019) and the general public. It empowers scientists to disseminate their research both to their peers (who are also the users of the platform) and directly to the general public (without the need for involvement of journalists or science communication professionals). Moreover, Twitter represents a fertile ground for networking of professionals and finding new collaboration partners, with multiple examples in the scientific literature of fruitful research partnerships starting through Twitter interactions (Baker, 2015; Doxtader et al., 2019; Guralnick et al., 2016; Lurie et al., 2020).

Hashtags, which were mentioned above as one of the commonly used tweet components, are designed as keyword-terms (usually thematically related to the content of the tweet) that are missing spaces (in case the term consists of several words) and have a hash sign (#) in front (particular example: #NaturalProducts). Hashtags afford tagging and thematic grouping of tweets and hashtag analysis has been widely used as a research tool that allows different quantifications (Cheung et al., 2018; Gardhouse et al., 2017; Grabbert et al., 2019; Kudchadkar and Carroll, 2020). In this context, relevant visibility parameters associated with tweets that could be analyzed, include retweets (re-shares) and impressions (views). Consequently, in this work, we aimed to evaluate visibility-associated features of the INPST Twitter networking event 2021 (detailed in the next section) by #INPST Twitter hashtag analysis.

Methodology

The use of the #INPST hashtag was assessed through a one-week event, highlighted and promoted as "2021 INPST Twitter Networking Event", which spanned from 31st May 2021 to 6th June 2021. Twitter users were encouraged to use the #INPST hashtag, while doing any relevant scientific communication on Twitter. Contributions that were being encouraged included: showcasing individual research, collaboration calls, job postings, journal special issue announcements, networking messages, conference announcements, Twitter polls, seminar announcements, links of relevant new publications, and job searches. Readers can refer to https://inpst.net/inpst-twitter-networking-event-2021/ for more details. Utilization of the hashtag #INPST through the study period was analyzed with the aid of Symplur Signals (https://www.symplur.com/).

Results and discussion

A total of 6036 tweets were posted by 686 users in that one-week networking event, generating a total of 65,004,773 impressions (views of the respective tweets). Of these 6036 tweets, 4272 tweets (70.8%) contained links, while only 319 tweets (5.28%) contained different attached images. Strategic usage of links, related hashtags, and images are in general relevant in strengthening tweets' visibility (Mishori et al., 2019). Mishori and the team, in their study published in 2019, have covered seven hashtags such as #ilooklikeasurgeon, #WomenInMedicine, #SheLeads2017, #seeitbeit, #BlackMenInMedicine, #QuoteHer, and #diversityinmedicine, and analyzed them for one year. For each tweet, the volume of tweets recorded on a monthly basis (Mishori et al., 2019) was less than the tweets yielded in our one week #INPST campaign. This indicates that the tweets number obtained in the conducted “2021 INPST Twitter Networking Event” was comparably higher than weekly tweets reported in the literature for many other hashtags with biomedical significance.

Out of the 686 Twitter users who posted #INPST-containing tweets, 399 (58.2%) made only one tweet during the networking event period; 95 (13.8%) posted two tweets, while 192 (28.0%) users made three or more tweets. This suggested that close to two hundred users have regularly used the hashtag #INPST while promoting their scientific content on Twitter. It has been observed that during the one week of this hashtag networking event, new users kept on joining in the tweeting and sharing (Fig. 1A). On the first day, only 211 Twitter users joined the networking event, and the participant number gradually increased in the next few days, reaching 686 users by the last day of the networking event. During the study period, new tweets number also gradually increased, with daily tweet numbers in the range 814–1200 (Fig. 1B). On the first day of the networking event 996 tweets and 11.6 million impressions were recorded. Each day, there was an increase of around 10 million of new impressions, and by the end of the networking event week, there were more than 65 million impressions (Fig. 1C). For comparison, in a one-year period (from 1st of March 2021 to 1st of March 2022), there have been 49,300 tweets using the hashtag #INPST that have been shared by 4209 users and generated 610,157,622 impressions. Considering that there are around 52 weeks in a year, it becomes obvious that the “2021 INPST Twitter Networking Event” that took place in one single week (from 31st May 2021 to 6th June 2021) generated hugely increased weekly activity reflected in the number of shared tweets (6036 tweets in a single week) participating users (686 users) and generated impressions (65,004,773 impressions). In a previous study, a Twitter campaign focused on the hashtag #DHPSP was executed for five weeks, yielding a total of 151,984,378 impressions (Kletecka-Pulker et al., 2021). Benjamin and Royer in 2018, have performed analytics of a six months-interval to track the significance of the @AACAnatomy Twitter account. Total impressions gained by the posts from that account were calculated to be 60,510 from September 2016 to February 2017 (Benjamin and Royer, 2018). These comparative data illustrate that the #INPST networking event, with its 65,004,773 impressions (views) achieved very high visibility in just one week in comparison to other biomedical Twitter-based campaigns. Similar conclusions can be also reached by comparing to the Spanish pro-vaccine Twitter campaign focused on the hashtag #yomevacuno, which was monitored for two weeks (between 14 December and 28 December 2020) and yielded 915,736 impressions (Herrera-Peco et al., 2021).

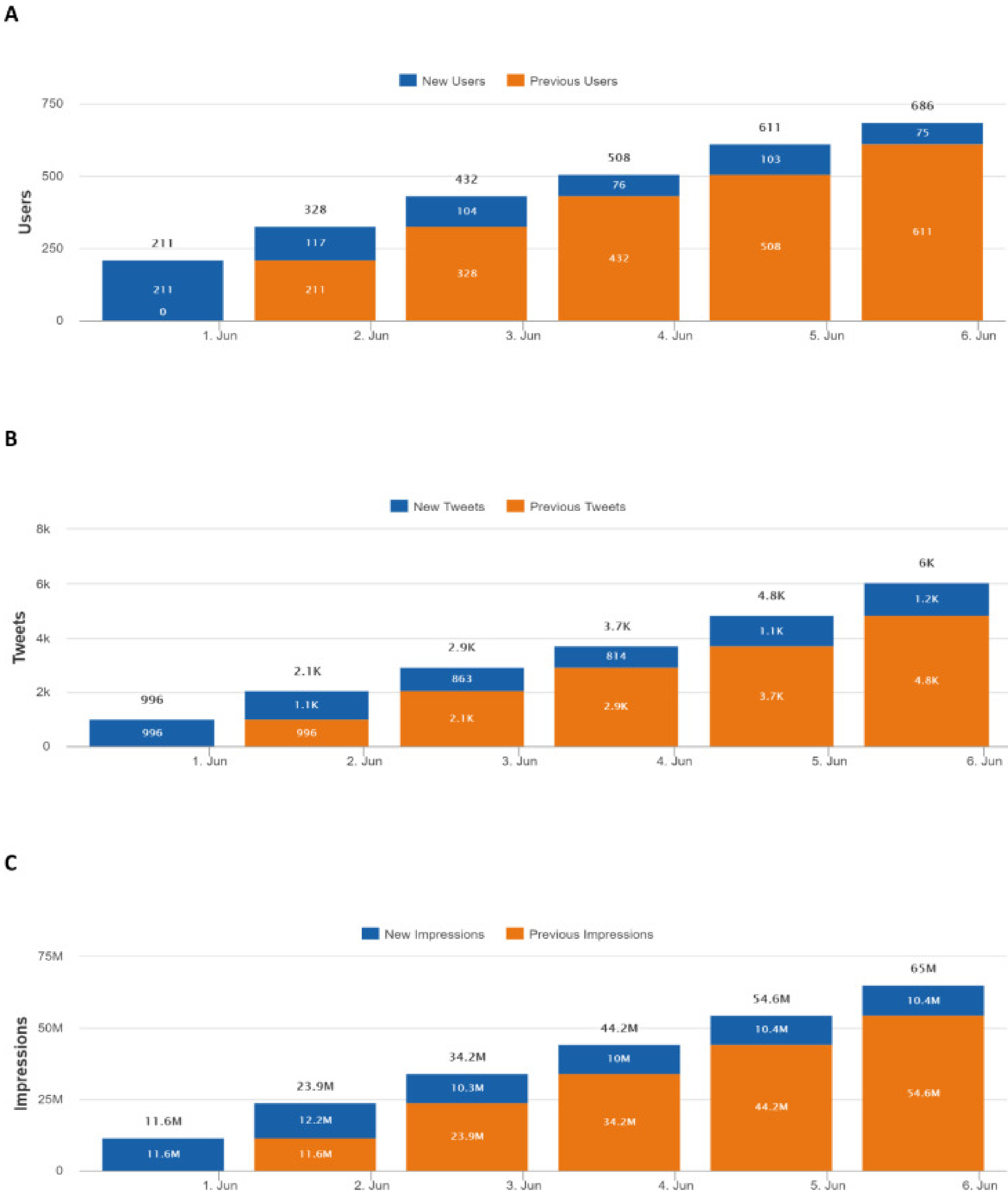

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Fig. 1. Cumulative increase in the number of #INPST-posting users (A), #INPST-containing tweets (B), and impressions/views (C) during the networking event timeline (31st May to 6th June 2021).

Further, as *per* the user information publicly available on Twitter, the top 5 locations of the users who had used the #INPST hashtag while posted during the one-week networking event was the United

States (73 users), India (38), the United Kingdom (22), Canada (18), and Spain (14). Although English remains the most frequently used language with 4068 of the tweets being in English, other languages such as Japanese (26 tweets), Romanian (14), Welsh (10), and Slovenian (6) are also noteworthy. During the one-week #INPST networking event, the most widely shared tweet featured the publication "Big impact of nanoparticles: analysis of the most cited nanopharmaceuticals and nanonutraceuticals research", and gathered 66 retweets, 6 quoted tweets and 69 likes (Fig. 2). Furthermore, Twitter Analytics revealed that this tweet generated 23,426 impressions and 211 engagements (equaling the total number of times a user has interacted with a Tweet, including all clicks, retweets, replies, follows, and likes). The article featured in this tweet was published in Current Research in Biotechnology (Elsevier) in 2020. As per the Google Scholar record dated January 18 2022, this article has been cited a total of 25 times. Although, the follow-up time was too short to investigate whether the visibility-boost achieved through Twitter during the #INPST networking event might translate into more widespread readership and increasing citation rate for this paper, it is interesting to mention that previous works have indicated that on average widely tweeted manuscripts receive more citations (Luc et al., 2021).

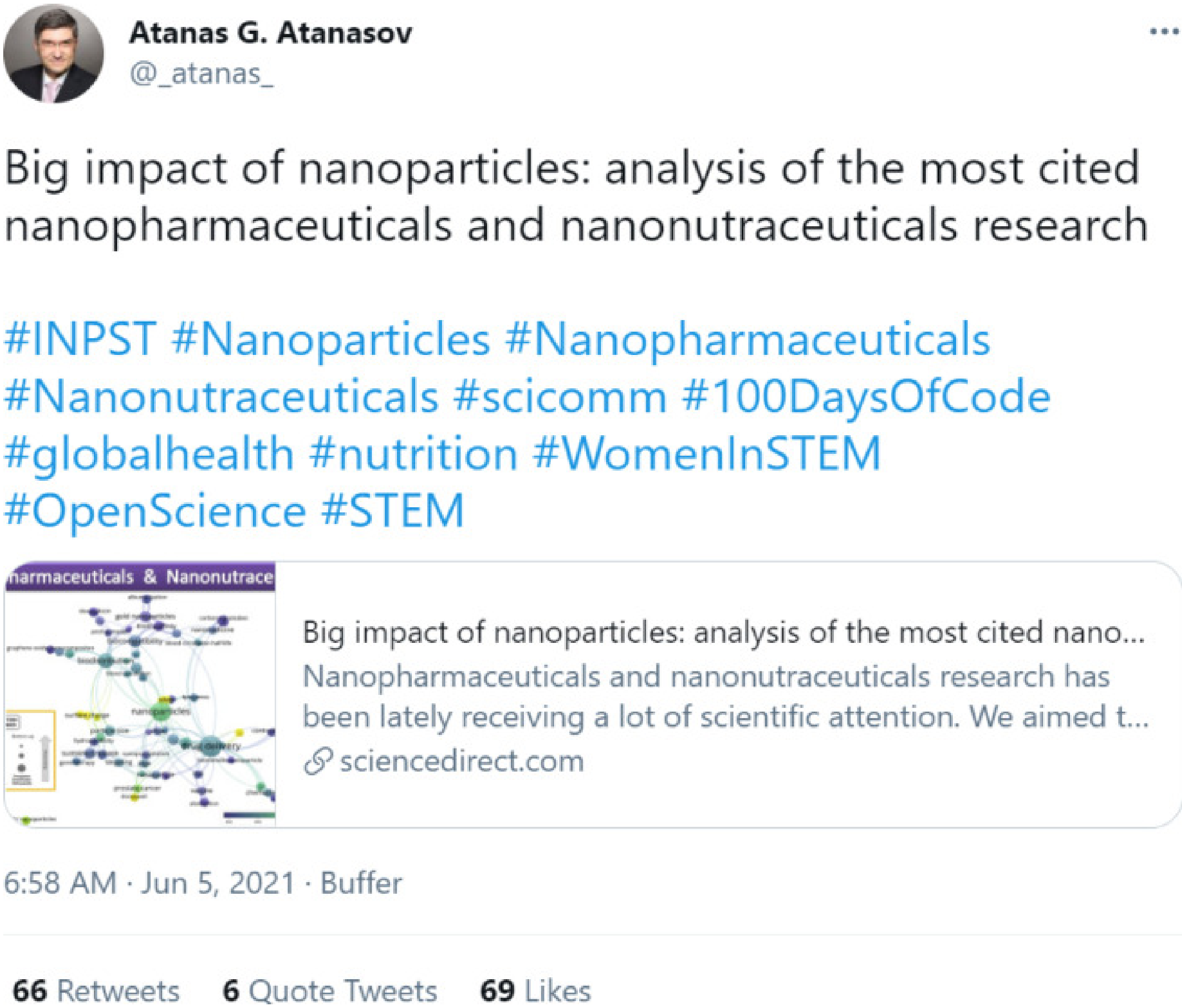

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Fig. 2. The most shared tweet of the #INPST Twitter networking event.

The most frequently used words, which were found in the #INPST tweets shared during the networking event, were also analyzed. The top 10 words were “read”, “twitter”, “research”, “paper”, “natural”, “event”, “analysis”, “review”, “published”, and “networking” (Fig.3). All of these words have meanings that can be linked to the scope of the #INPST Twitter networking event and scientific research in general. The frequency of these words is quite high, ranging from 200 to more than 400 uses.

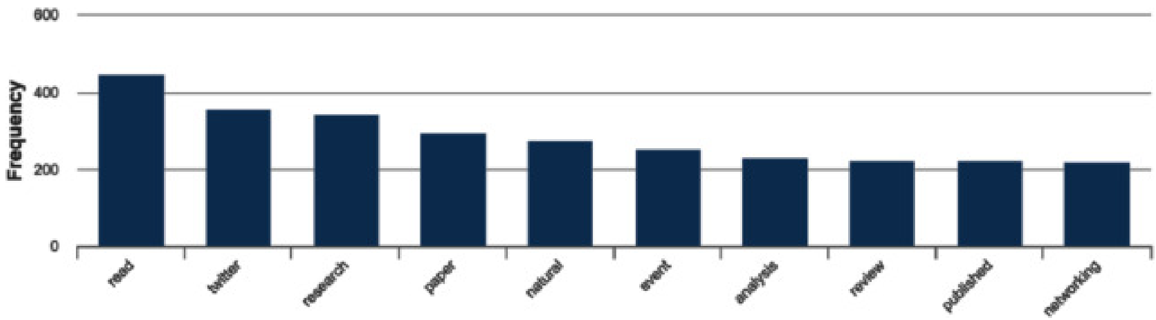

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Fig. 3. . Top 10 words of the #INPST tweets posted during the networking event.

As the co-hashtag usage also influences the visibility of tweets, we additionally analyzed the hashtags that were co-occurring with #INPST. The top 10 hashtags that co-occurred with #INPST were also all related and relevant to the focus of the Twitter networking event (Fig. 4). The hashtag #DHPSP (an acronym for Digital Health and Patient Safety Platform) is officially registered with the Symplur Healthcare Hashtag Project and meant to be used with tweets related to "digital health, open innovation, patient safety, personalized medicine" (Kletecka-Pulker et al., 2021). #NPMND is a hashtag officially registered with the Symplur Healthcare Hashtag Project and is meant to be used with tweets related to "cancer, diabetes, metabolic disorders, natural products, neurological disorders, obesity, pain, Parkinson's disease" (Singla, 2021). #AcademicTwitter, is a widely used hashtag to label various academy-related Twitter discussions (Fuller and Potvin, 2020; Gomez-Vasquez and Romero-Hall, 2020). #SciComm hashtag is used with tweets related to "Medical Education, scientific communication, scientific posters" (Kaczmarczyk, 2015). #cancer is broadly used in tweets related to cancer. #AcademicChatter is dedicated to broader academic community chatting (Davies, 2021; Stillwell, 2021). #OpenScience is a hashtag from the accounts @_open_science_ and @openscience, and is related to "promoting the discussion/dissemination of open science, equality, inclusivity, and fairness". #womeninstem is a hashtag related to "gender equity, gender parity, STEM, women in healthcare, women in medicine, women in research, women in science" (Woolston, 2015). #meded is linked to medical education (Jaswal et al., 2021), and #STEM is related to science and technology related communications (abbreviation from science, technology, engineering, and mathematics). Thus, all the co-hashtags in the top 10 list were related to science and health.

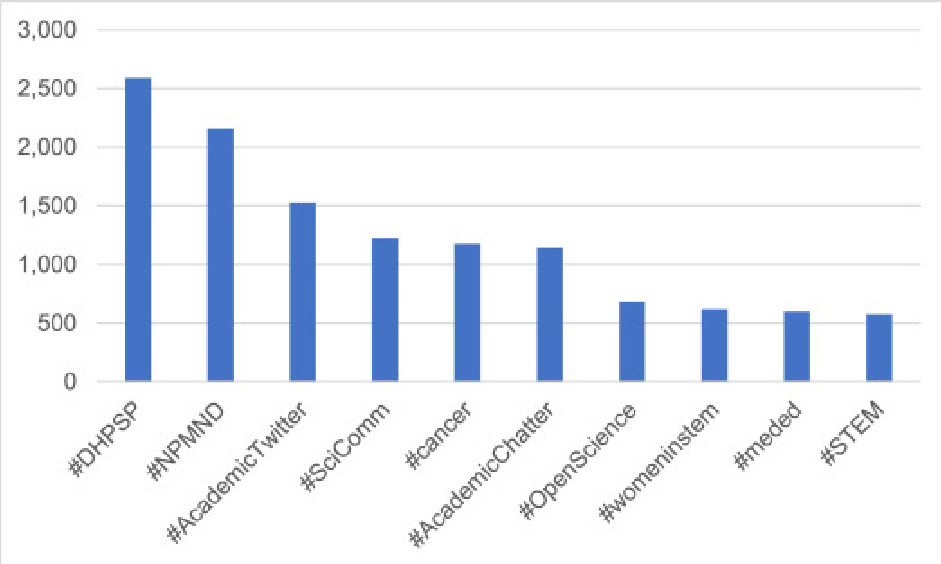

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Fig. 4. Top 10 hashtags co-occurring with #INPST.

Special issues in various journals have also been widely promoted during the #INPST networking event. Among the three most shared images (Fig.5), two illustrations (left and right) are related to journal special issues. At the same time, the third (in the center) presents an overview of a specific drug discovery research project, "Multitarget peptide-fragment hybrids for the treatment of neurodegenerative diseases“ lead by Dr. Nikolay T. Tzvetko. The first special issue (the image on the left) is entitled “Plant-Derived Functional Foods, Nutraceuticals, and Cosmeceuticals: From Basic to Applied Science.” This special issue is being handled by the guest editor, Dr. Hari Prasad Devkota for the journal, *Applied Sciences*, MDPI publisher. The second special issue was about “Pharmacology of Plant Polyphenols in Human Health and Diseases”. This special issue was handled by five guest editors, including Dr. Hari Prasad Devkota, Dr. Atanas G. Atanasov (the founder of INPST and the #INPST hashtag), Dr. Keshav Raj Paudel, Dr. Namrita Lall, and Dr. Michał Tomczyk, for the journal *Frontiers in Pharmacology* (Frontiers Publisher).

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Fig. 5. The three most shared images during the #INPST Twitter Networking Event 2021 (with 27, 20, and once again 20 retweets, for the images displayed left, center-bottom, and right, respectively).

Other journal special issues promoted during the event (edited by Dr. Anupam Bishayee were "Molecular Mechanisms Underlying Cancer Prevention and Intervention with Bioactive Food Components" (in *Cancers*), "Molecular insights into natural compounds in oncoprevention and oncotherapy" (in *Pharmacological Research*), and "Molecular pharmacology of anticancer natural products" (in *Phytomedicine*). Additionally, a special collection E-book at the interface of Frontiers in Plant Science, Frontiers in Pharmacology and Frontiers in Physiology, entitled "Lignans: Insights into Their Biosynthesis, Metabolic Engineering, Analytical Methods and Health Benefits" was published in early 2021. It was edited by Christophe F Hano, Albena T. Dinkova-Kostova, Norman G Lewis, John R Cort, and Laurence B. Davin, and has been viewed more than 18,700 times to date (https://www.frontiersin.org/research-topics/9159/lignans-insights-into-their-biosynthesis-metabolic-engineering-analytical-methods-and-health-benefit#overview↗) (Hanoetal., 2021).

In their randomized-controlled trial "Three Facts and a Story", Tapper and co-workers have also evaluated the use of Twitter for research dissemination, finding a significant increase in engagement for the papers published in the *Journal of Hepatology*, if relevant tweets featuring these papers were posted on Twitter (Tapperetal., 2021). Exploring another application of the social media platform, Bennett and co-workers have utilized Twitter to identify COVID-19 vaccine-associated hematological adverse events (Bennettetal., 2022). Further, Eibensteiner and co-workers have utilized the Twitter poll analysis methodology to assess the people's willingness to vaccinate against COVID-19 (Eibensteineretal., 2021). As yet another application of Twitter, Lyu etal. have utilized the social media platform to identify topics and perform sentiment analysis in public for COVID-19 vaccine-related discussions (Lyuetal., 2021). Kwok and co-workers did the same but focused only on Australian users and by machine learning analysis (Kwoketal., 2021). As further examples of Twitter hashtag-based studies, Kauffman and colleagues have analyzed the role of Twitter in online radiology education by assessing the hashtag #RadEd (Kauffmanetal., 2021), and Robertson etal. have analyzed the hashtags #RadialFirst and #RadialForNeuro on Twitter referring to transradial access for neurointerventional procedures (Robertsonetal., 2021). While Twitter-applications have the limitation that they just reach this segment of the population who are users of the platform, the above-described research studies leave no scope for doubting for the value of Twitter use and Twitter-based analysis for the scientific community. Moreover, since social media platforms are a fertile ground for the dissemination of science and health-related misinformation (Yeungetal., 2021b, 2022), scientists-driven activities and events hosted on social media platforms such as Twitter can benefit the general public by providing credible and easy-accessible science-based information. Nevertheless, it should be noted that using specifically Twitter for scientific communication-based initiatives such as the here-described #INPST networking event has one important limitation: Twitter is not popularly used in some countries, which results in excluding a large group of researchers in Asia, particularly in China, who are engaging in natural product research. Envisaging this limitation, it might be recommended that for better international coverage future events from that kind might be executed with the simultaneous use of several diverse social media platforms to better reach and involve scientists located in different countries.

Conclusions

This study demonstrated how Twitter networking event attracted a large number of scientists across the world to showcase their scientific content and gained high visibility for the participants and the INPST platform as a whole, as clearly demonstrated especially by the archived high number (65,004,773) of impressions/views archived in just a single week. This work sets an example of how Twitter can be used as a highly efficient and fascinating channel to host virtual campaigns, disseminate credible scientific information, and host virtual international biomedical research events. Importantly, such digital networking events also provide platform for intensifying of interactions between scientists from different parts of the world, which might potentially yield the formation of new scientific collaborations benefiting future biomedical research. The wider implications of this analysis relate to the potential of better understanding scientific communication both within the scientific community as well as with the wider public enabling a better understanding of science.

CRediT author statement

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Availability of data and materials

All the key information is already available in the manuscript; still, the authors are ready to provide any further data if the inquiry will be routed through journal and affiliation authorities, and follow the standard process.

Ethical approval and consent to participate

Not applicable.

Human and animal rights

Not applicable.

Consent for publication

Authors duly provide the consent for publication.

Conflict of Interest

Authors Dr. Rajeev K. Singla and Shailja Singla have an honorary-based associations with the iGlobal Research and Publishing Foundation (iGRPF), New Delhi, India. Dr. Bernd Fiebich is associated with

VivaCell Biotechnology GmbH. RKS, SS and BF along with the remaining authors, declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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