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Multilingual analysis of public discourse on opioid and non-opioid analgesics through social media: a cross-sectional infodemiological study

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ABSTRACT:

Background: The global opioid crisis has intensified concerns regarding misuse, overdose-related mortality, and the associated social and economic burden of both prescribed and illicit opioids. Social media platforms provide large volumes of real-time data that enable the capture of public perceptions, emerging risks, and shifts in discourse. This study analyzes a decade of conversations on X to characterize temporal trends, identify thematic patterns, and compare the evolution of public discourse in English and Spanish on opioids and other analgesics.

Methods: A cross-sectional analysis was conducted of all posts on X between 2014 and 2024 containing generic names of opioid analgesics, non-opioid analgesics, and opioid antagonists approved by national regulatory agencies. Following data collection, tweets were filtered by language and underwent normalization, cleaning, and lemmatization. Topic modeling was performed using Latent Dirichlet Allocation, applying online training with mini-batches to manage the size of the corpus.

Results: A total of 1,874,907 tweets were analyzed. Major opioids consistently generated the highest volume of discourse in both languages. Topic modeling revealed linguistic divergences: English-language tweets focused on personal experiences with opioids, the opioid crisis, and the pharmaceutical industry, whereas Spanish-language tweets emphasized therapeutic use, self-medication, alternatives for chronic pain, and emerging concerns regarding opioid potency.

Conclusions: Analysis of X represents a sensitive and dynamic tool for monitoring public discourse on opioids and other analgesics. The findings reveal relevant linguistic and cultural differences in narratives surrounding these medications, as well as temporal patterns aligned with epidemiological, media, and regulatory changes. Continuous social media monitoring enables early detection of shifts in risk perception and public attention, providing key insights for health communication, the identification of emerging risks, and the design of interventions tailored to specific sociocultural contexts.

Keywords: Analgesic, Opioid, Social Media, Chronic Pain, Public Health Surveillance, Infodemiology, Epidemic, Fentanyl, Oxycodone.

1. BACKGROUND:

The opioid crisis represents one of the most pressing global public health challenges, raising growing concern among healthcare professionals, researchers, and policymakers. In recent decades, the misuse of opioids—both prescription and illicit—has led to a dramatic increase in overdose mortality, the incidence of drug-related infectious diseases, and the broader social and economic burden associated with dependence and disability[1,2]. In the United States, for example, overdose mortality rates have risen exponentially since the 1990s, initially driven by the misuse of prescription opioids such as oxycodone and hydrocodone, and more recently exacerbated by the increasing availability and lethality of fentanyl, with annual deaths exceeding 80,000 in recent years[3,4]. Globally, opioids are implicated in more than 70% of drug-related deaths, with overdoses accounting for over 30% of these fatalities[4].

Analgesic medications used in pain management can be broadly classified into four main categories: major opioids, minor opioids, non-opioid analgesics, and opioid antagonists, in accordance with the principles of the analgesic ladder and contemporary clinical pharmacology[5]. Major opioids, such as morphine and fentanyl, are used to treat severe pain but are associated with a high risk of dependence and overdose, particularly in the case of fentanyl, whose potency is estimated to be 50 to 100 times greater than that of morphine[6,7]. Minor opioids, such as tramadol and codeine, are commonly prescribed for moderate pain, although prolonged use may also lead to dependence[8,9]. Non-opioid analgesics, including paracetamol and nonsteroidal anti-inflammatory drugs, are typically used as first-line treatments for mild to moderate pain and are essential components of multimodal analgesia strategies[10,11]. Finally, opioid antagonists, such as naloxone, are used to reverse opioid effects—particularly in overdose situations—through competitive displacement at opioid receptors[12].

Over the past decade, pain management has undergone a profound transformation, characterized by a progressive reduction in opioid prescribing and an increasing promotion of non-opioid alternatives driven by regulatory changes and updated clinical guidelines[11,13-17]. This therapeutic shift raises an important question: to what extent are

these changes in clinical practice and health policy reflected in public discourse and digital conversations surrounding pain management.

The systematic use of user-generated data from digital environments to study health-related phenomena has given rise to the field of digital epidemiology, which complements traditional surveillance systems by enabling real-time analysis of behaviors, perceptions, and experiences expressed online. Within this framework, numerous studies have used social media to monitor patterns of substance use, detect early warning signals of health risks, and analyze the dissemination of information related to drugs, treatments, and public policies[18–21]. In this context, the analysis of data from platforms such as X (formerly Twitter) has emerged as a valuable tool for examining public perceptions and social dynamics related to opioid use[22]. These platforms provide large volumes of real-time information, allowing researchers to assess the frequency, evolution, tone, and context of discussions about these medications, as well as to identify shifts in discourse in response to key events such as overdoses, regulatory changes, or media coverage[23,24].

In recent years, several studies have applied data mining, sentiment analysis, and topic modeling techniques to examine the opioid crisis. For example, Carabot et al. (2023) analyzed Twitter posts and found that patients dominated the conversation, while healthcare professionals generated higher engagement[22]. Similarly, Ahmad et al. (2025) used advanced language models to characterize risk perceptions in YouTube comments with high accuracy[25]. However, the existing literature presents important limitations in the digital analysis of public discourse on analgesics and pain management. Many studies have focused on short time periods, single-language contexts, or isolated substances, limiting a broader comparative and longitudinal understanding of discourse dynamics[26–28].

Monitoring multilingual public discourse on opioids is essential to understand how public opinion evolves, how emerging risks are identified, and how sociocultural dynamics shift across different contexts. In a landscape shaped by policies restricting opioid prescribing, promoting non-opioid alternatives, and expanding preventive measures such as access to naloxone, there is an urgent need for tools that capture how these interventions are debated and reinterpreted in digital environments[29]. Analyzing conversations over a decade marked by the evolution of the opioid crisis can provide critical insights to

improve public health communication, strengthen social pharmacovigilance, and inform the design of context-sensitive policies[30–32].

In this context, the present study addresses several limitations identified in previous research by providing a longitudinal analysis over a full decade, adopting a comparative multilingual approach (English and Spanish), and examining multiple pharmacological categories of analgesics in an integrated manner. Specifically, this study aims to analyze the evolution of discourse on X regarding opioids and other analgesics in both English and Spanish from 2014 to 2024, with the following objectives: (1) to identify temporal trends in mentions of different drugs; (2) to compare predominant discourse patterns across languages; (3) to identify the most frequently associated topics in public debate; and (4) to explore how social perceptions vary according to the type of medication (major opioids, minor opioids, non-opioid analgesics, and opioid antagonists).

By doing so, this approach enables the early detection of changes in public narratives that may anticipate shifts in risk perception, usage behaviors, or acceptance of regulatory policies. Moreover, the analysis of social media discourse allows for the identification of communication gaps and provides valuable insights to strengthen infodemiological surveillance systems and public health communication strategies.

2. METHODS:

2.1. Study Design and Data Collection:

This study, based on social media data mining and topic modeling using unsupervised learning, focuses on the analysis of tweets related to opioid and non-opioid analgesics used for pain management. The aim is to identify thematic patterns and compare their temporal evolution and linguistic differences between English and Spanish. The data collection period extended from January 1, 2014, to December 31, 2024. All tweets containing any of the selected keywords—corresponding to the generic names of the included medications in both English and Spanish—approved by the Food and Drug Administration (FDA), the Spanish Agency of Medicines and Medical Devices (AEMPS), or both, were retrieved. The data collection procedure applied consistent search criteria and extraction parameters throughout the entire study period to ensure temporal comparability of the corpus.

The following keywords (i.e., terms appearing in tweet content) were used, classified by pharmacological group: Major opioids: (1) buprenorphine; (2) fentanyl; (3) hydromorphone; (4) methadone; (5) morphine; (6) oxycodone; (7) oxymorphone; (8) tapentadol. Minor opioids: (9) codeine; (10) hydrocodone; (11) tramadol. Non-opioid analgesics: (12) celecoxib; (13) dexketoprofen; (14) paracetamol. Opioid antagonists and modulators: (15) naloxone; (16) naltrexone, and their equivalents in Spanish.

The selection focused on opioids predominantly used outside hospital settings to capture social discourse in community contexts, excluding substances mainly used in perioperative or highly controlled clinical settings due to their limited presence in spontaneous social media conversations. Additionally, only generic names were used to avoid geographic variability, semantic ambiguity, and false positives associated with trade names, thereby improving the consistency and reproducibility of the analysis[33,34]. Queries were constructed using standardized active substances in accordance with International Nonproprietary Names (INN) and validated against official regulatory sources (FDA and AEMPS), ensuring terminological equivalence between English and Spanish.

Inclusion criteria for tweets were: (1) publicly available posts; (2) containing the selected keywords; (3) published between January 1, 2014, and December 31, 2024; and (4) written in English or Spanish. A total of 1,874,907 tweets were collected. Extracted variables included date and time of creation, public username, tweet text, geolocation, and engagement metrics ("likes" and "retweets"). Data were obtained using the Tweet Binder Application Programming Interface (API), which provides access to 100% of public tweets matching the search criteria[35]. Geographic information was derived from metadata available for each tweet through the API, including user-declared location and, when available, geographic coordinates associated with the tweet.

2.2. Content Analysis and Data Processing:

First, a descriptive analysis of absolute frequencies was conducted to quantify the total volume of tweets by pharmacological group and language, aggregating data by year of publication to identify longitudinal trends in digital discourse. Subsequently, an unsupervised learning approach using Latent Dirichlet Allocation (LDA) was applied to identify thematic patterns in a bilingual corpus of English and Spanish tweets related to the use and perception of opioid and non-opioid analgesics. LDA was selected after

evaluating alternative techniques such as Non-negative Matrix Factorization (NMF), Hierarchical Dirichlet Process (HDP), and K-means clustering on embeddings, due to its mathematical simplicity, high interpretability, and widespread use in natural language processing of large unstructured datasets—particularly in short-text corpora such as social media—where it provides an appropriate balance between computational efficiency and interpretability[36–38]. Previous literature supports its robustness and application in the analysis of social media conversations[39–41].

Prior to model implementation, a data preprocessing pipeline was applied to optimize LDA performance. Tweets were first classified by language and separated into English and Spanish corpora. Preprocessing was conducted independently for each language using language-specific stopword lists, lemmatization models, and tailored cleaning rules (e.g., handling of diacritics in Spanish), ensuring semantic coherence and avoiding artificial mixing between languages. Text normalization included the removal of URLs, hashtags, non-alphabetic characters, stopwords, duplicate terms, and non-standard characters (e.g., emojis), followed by lowercasing and lemmatization. This process allowed the absorption of orthographic variations and informal language typical of social media, reducing textual noise and improving computational consistency. Bag-of-Words matrices were then generated, applying frequency thresholds to remove extremely rare or overly frequent terms that could distort topic extraction. This resulted in a clean and homogeneous corpus suitable for LDA modeling.

To determine the optimal number of topics, Cluster Validity Indices (CVI) were used—metrics commonly applied in unsupervised learning to evaluate clustering quality[42]. The silhouette coefficient was selected due to its ability to assess inter- and intra-cluster distances and optimize thematic coherence, complemented by semantic coherence metrics to evaluate the interpretability and linguistic consistency of the resulting topics. This combination enabled the selection of a topic number that maximized coherence while minimizing redundancy.

Once the optimal model was identified, topics were analyzed using a mixed quantitative–qualitative approach[43]. For each topic, the highest-probability words (top-n words) and the most representative tweets (i.e., those with the highest probability of belonging to the topic) were examined to assess semantic coherence and facilitate interpretation. Two researchers independently assigned descriptive thematic labels to each topic based on this

information, resolving discrepancies through discussion and consensus, in line with established practices in topic modeling studies in the social and health sciences[44]. Finally, topics were compared across languages and pharmacological categories and ranked according to the total number of tweets assigned to each topic to identify the predominant themes in each language.

3. RESULTS

3.1. Total Count of Tweets:

A total of 1,594,615 tweets mentioning the selected drugs were analyzed across different languages over the study period, including 1,074,863 tweets in English and 519,752 in Spanish. As shown in Figure 1, major opioids accounted for the highest number of posts in both languages (679,080 tweets in English and 301,571 in Spanish), followed by minor opioids and opioid antagonists (269,257 and 116,689 tweets, respectively) in English, and by non-opioid analgesics and minor opioids (132,542 and 79,957 tweets, respectively) in Spanish.

In comparison, non-opioid analgesics generated a considerably lower volume of activity in English (9,837 tweets), while opioid antagonists showed the lowest activity in Spanish (5,682 tweets). Overall, opioids (both major and minor) generated a substantially higher proportion of conversations on Twitter than non-opioid groups, reflecting greater public interest in these medications.

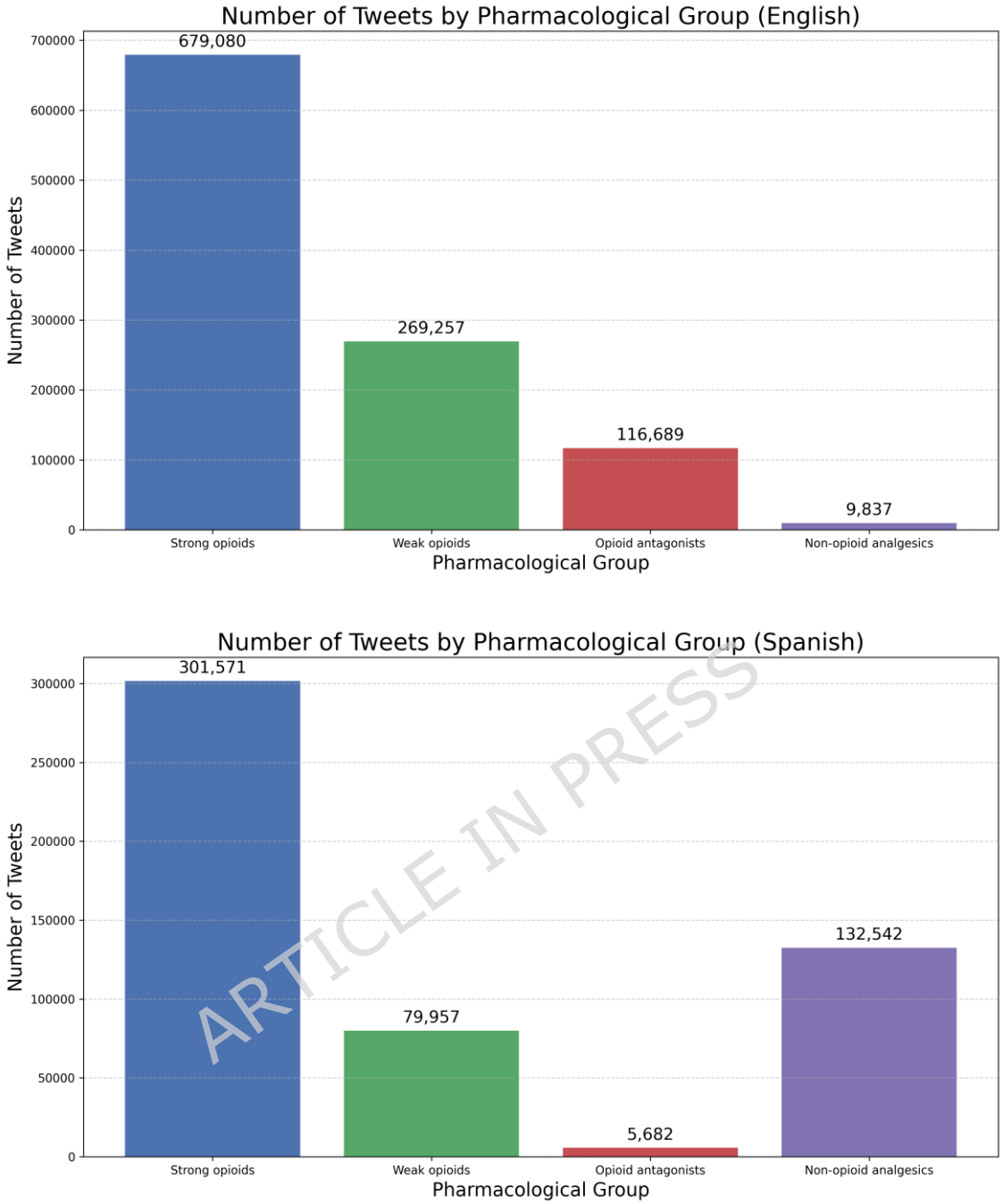


Figure 1. Upper panel: Number of tweets in English by pharmacological group published between January 1, 2014, and December 31, 2024. Lower panel: Number of tweets in Spanish by pharmacological group published between January 1, 2014, and December 31, 2024.

3.2. Number of Tweets per Year:

The temporal analysis revealed that most pharmacological groups, as shown in Figure 2, exhibited a relatively stable evolution in the number of publications throughout the

observation period, with moderate fluctuations in recent years and no abrupt changes in the overall trend, except for major opioids.

Regarding tweets in English, major opioids consistently accounted for the highest volume of tweets across the entire period, showing an upward trend from 2014 to 2023, followed by a slight decline in 2024. Minor opioids ranked second in frequency and displayed a more gradual yet sustained increase over time, except for a decrease between 2023 and 2024. In contrast, opioid antagonists and non-opioid analgesics maintained substantially lower levels of conversation, with no significant temporal variation.

For tweets in Spanish, the temporal evolution followed a similar pattern, characterized by the predominance of major opioids and a particularly pronounced upward trend between 2016 and 2023. Non-opioid analgesics constituted the second most frequently mentioned group and showed a sustained increase over the study period, especially between 2018 and 2022. Minor opioids also exhibited a progressive increase until 2020, followed by stabilization in subsequent years. Opioid antagonists, by contrast, maintained a consistently low and stable volume of publications throughout the entire period.

Furthermore, to contextualize potential biases arising from variations in the overall activity volume of the platform, a complementary analysis based on normalized metrics was conducted (annual proportions relative to the total number of tweets and rates per unique user). The results were consistent with the trends observed in the absolute counts. Additional analyses are provided in the supplementary material (see Additional Files 1 and 2) to enhance the transparency and reproducibility of the findings.

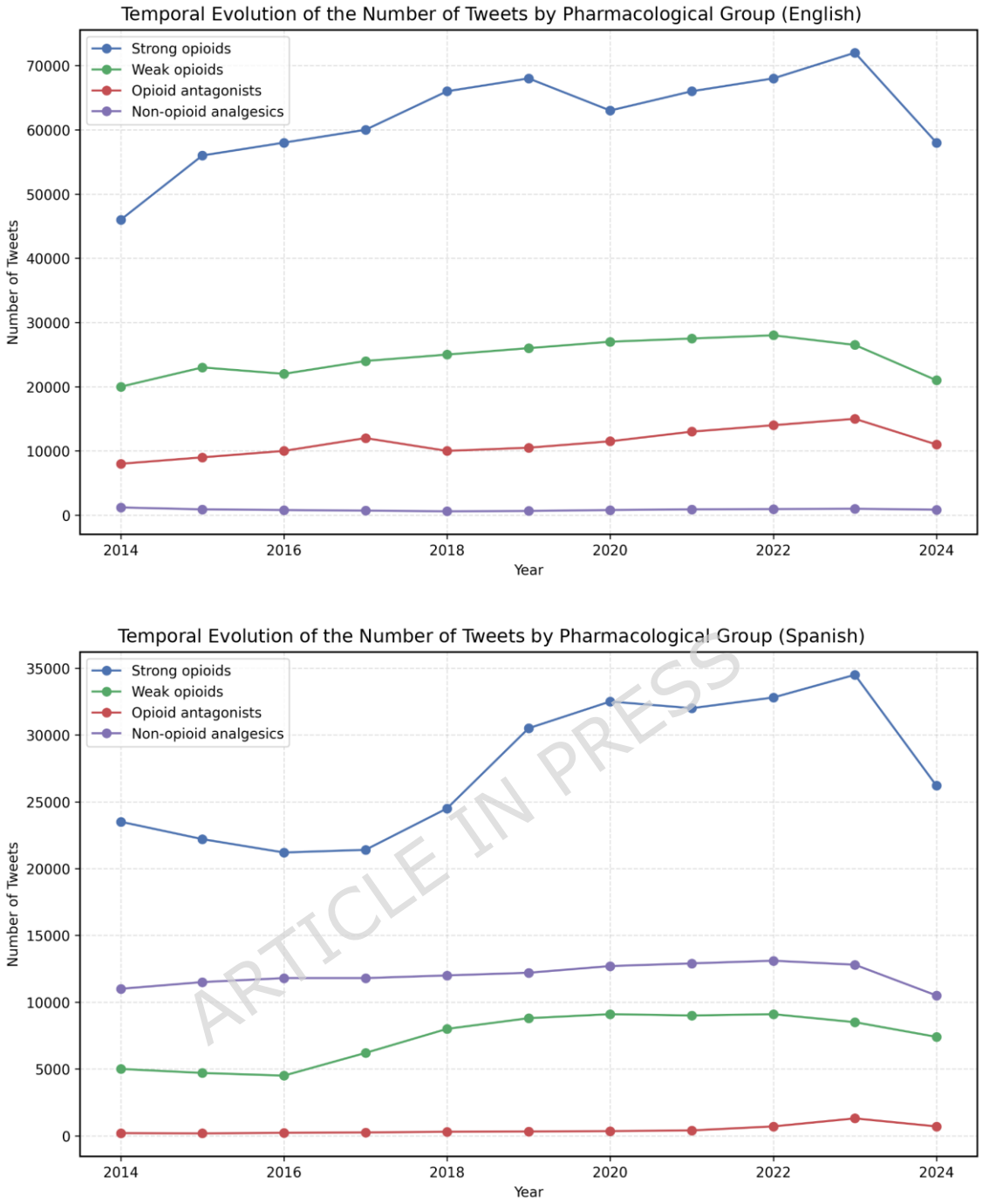


Figure 2. Biannual frequency of tweets in English (upper panel) and Spanish (lower panel) by pharmacological group. Each color represents a pharmacological group, as indicated in the legend.

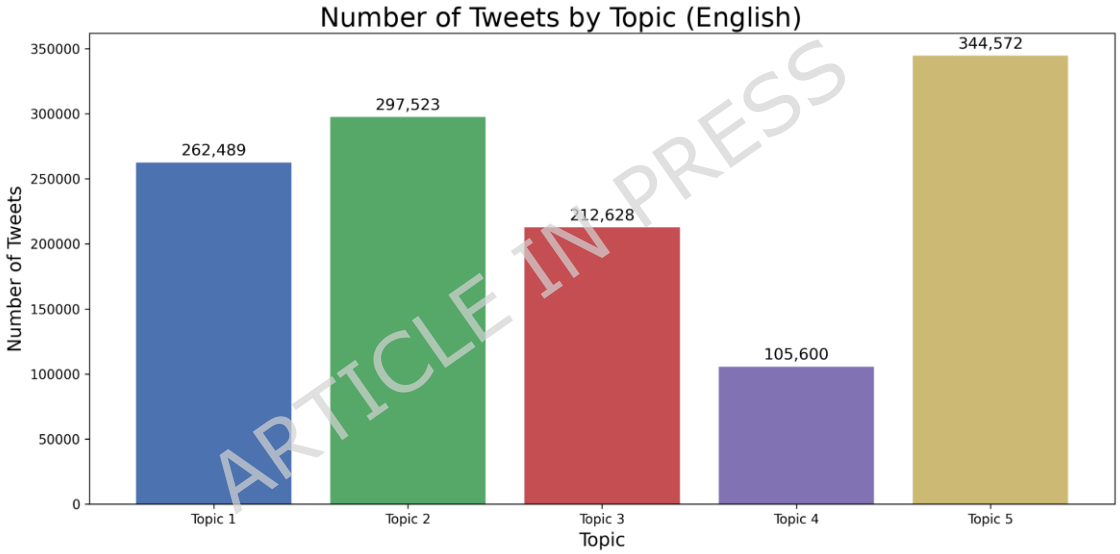
3.3. Topic Modeling:

3.3.1 Main Topics and Number of Associated Tweets:

The analysis identified five main topics in each language, ranked according to the total number of associated tweets (Figure 3).

In English, the predominant topics focused on personal perceptions and individual experiences related to opioid use (Topic 5), followed by discussions on the opioid crisis and the responsibility of the pharmaceutical industry (Topic 2), and tweets associated with the therapeutic use and analgesic efficacy of opioids (Topic 1). To a lesser extent, conversations addressed overdose, mortality, and public responses to the opioid epidemic (Topic 3), as well as the regulation of opioid and non-opioid analgesics (Topic 4).

In Spanish, the analysis revealed a different thematic distribution. Alternatives to opioids for chronic pain management emerged as the most frequent topic (Topic 5), followed by tweets related to therapeutic use and self-medication (Topic 4), personal perceptions and experiences regarding opioid and non-opioid analgesic use (Topic 2), opioid-related lethality (Topic 3), and, lastly, illicit opioid trafficking and consumption (Topic 1).



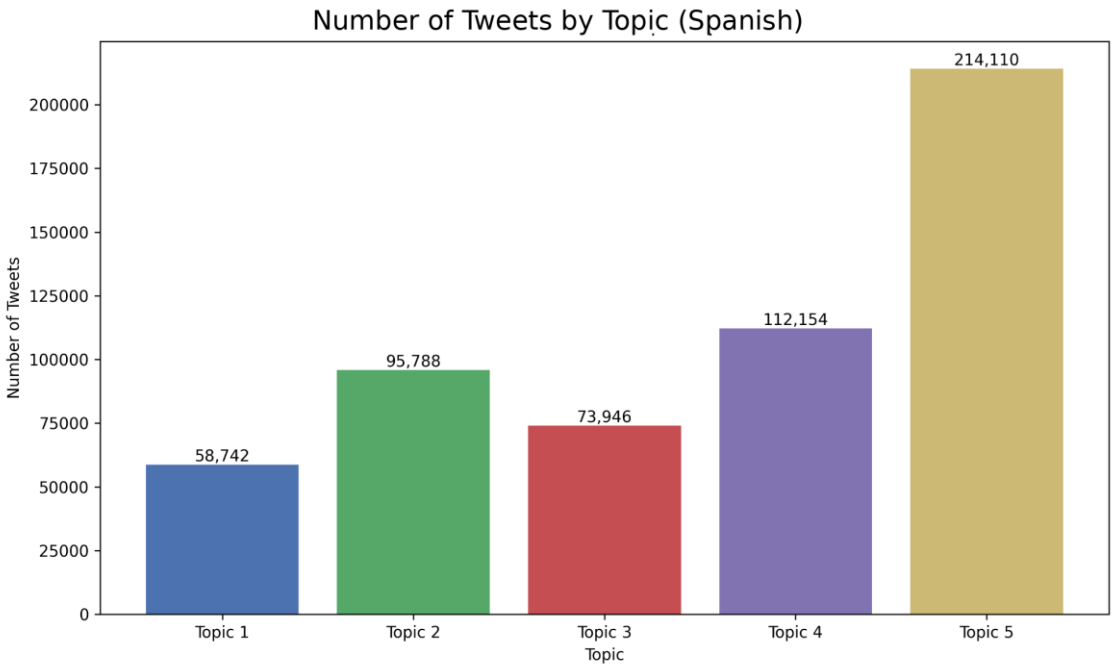


Figure 3. Upper panel: Tweets by topic in English. Lower panel: Tweets by topic in Spanish.

3.3.2. Number of Tweets per Year for Each Main Topic:

In English-language tweets, the temporal evolution of the different topics showed distinct patterns over the study period (Figure 4, upper panel). Conversations focused on personal perceptions and individual experiences (Topic 5) remained relatively stable, with moderate fluctuations but no abrupt changes between 2014 and 2024. In contrast, discussions related to the opioid crisis and the pharmaceutical industry (Topic 2) exhibited a progressive increase from 2014 onward, peaking in 2023 before a slight decline in the final year. Mentions of the therapeutic use and analgesic effectiveness of opioids (Topic 1) also showed an overall upward trend for most of the period, followed by a more pronounced decrease after 2023. References to overdose and mortality (Topic 3) increased initially but displayed a progressive decline from 2016 onward. Finally, the topic related to the regulation of analgesic use (Topic 4) was the least dynamic, with low-magnitude fluctuations and a slight reduction toward the end of the period.

For Spanish-language tweets, shown in the lower panel of Figure 4, the temporal trajectories of the topics followed a different pattern. Mentions related to alternatives to opioids for chronic pain management (Topic 5) increased steadily between 2016 and

2020, followed by a period of stability and a slight decline from 2022 onward. Therapeutic use and self-medication with analgesics (Topic 4) remained relatively stable, with no major year-to-year changes. Perceptions and personal experiences related to analgesics (Topic 2) showed gradual growth from 2016 onward, whereas discussions on opioid trafficking and consumption (Topic 1) exhibited more marked fluctuations without a clear trend. Lastly, tweets referring to lethality associated with opioid use (Topic 3) displayed an irregular pattern, with a pronounced peak in 2019 followed by a sustained decline.

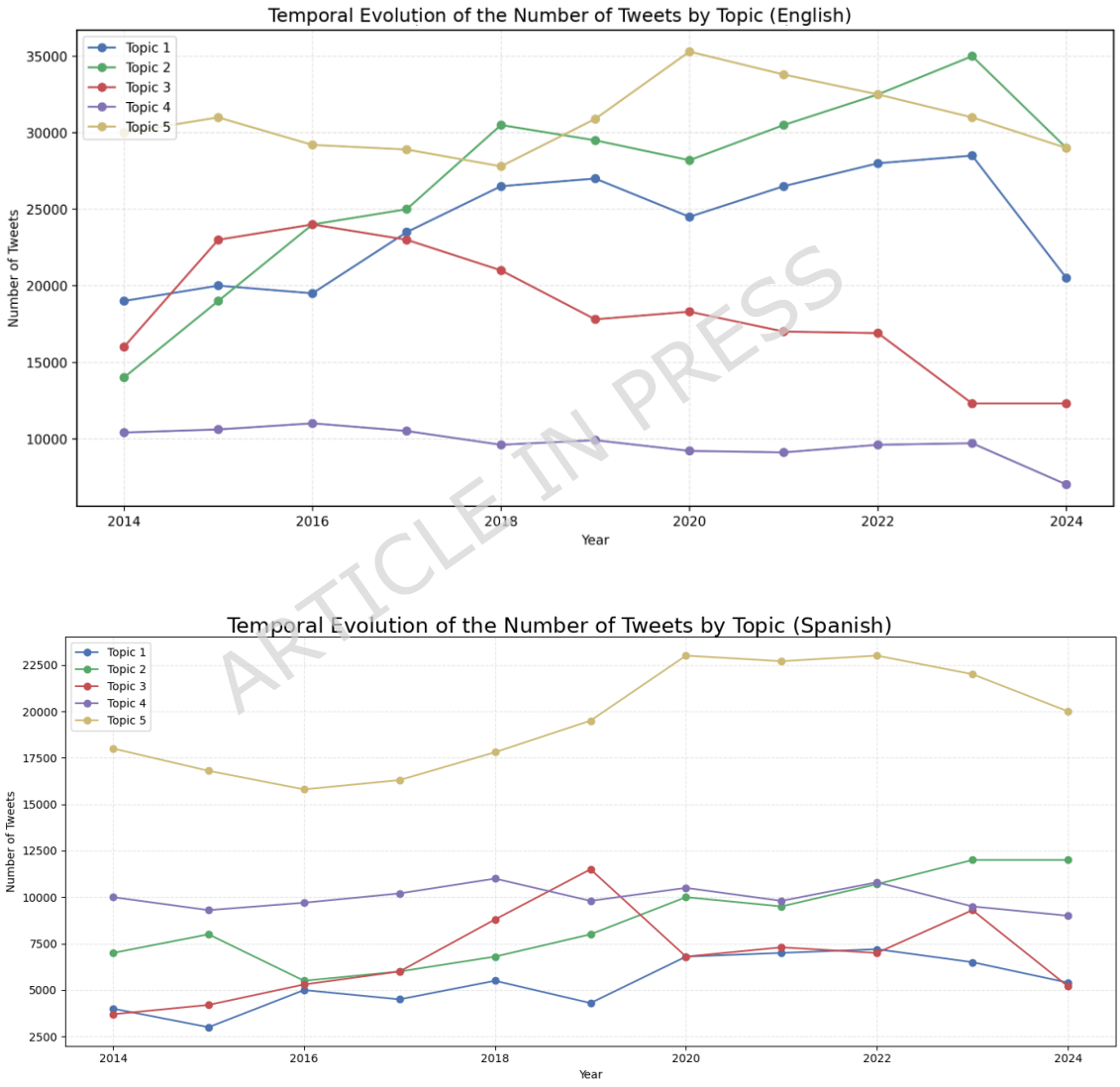


Figure 4. Upper panel: Temporal evolution by topic per year in English. Lower panel: Temporal evolution by topic per year in Spanish.

3.4. Temporal Evolution of Tweets related to Fentanyl and Oxycodone:

The analysis of the temporal evolution of tweets related to fentanyl and oxycodone reveals a progressive increase in the volume of publications in both languages throughout the study period, reflecting growing public attention toward these potent opioids. As shown in Table 1, in English-language tweets, mentions of fentanyl increased from 9,037 tweets in 2014 to a peak of 22,766 in 2023, followed by a moderate decline in 2024. A similar upward trend was observed in Spanish-language tweets, although with lower absolute values, rising from 657 tweets in 2014 to a maximum of 13,285 in 2023, and subsequently decreasing in 2024. Comparison between languages indicates that tweet volumes were consistently higher in English across the entire period; however, both languages exhibited a comparable ascending trend with a shared peak in 2023 followed by a decline in 2024.

Regarding oxycodone, the temporal pattern in English-language tweets showed moderate fluctuations over the study period. In 2014, 15,893 tweets were recorded, followed by a notable increase in 2015 to 19,220 tweets. Subsequently, the volume declined in 2016 and remained relatively stable in 2017. From 2018 onward, mentions resumed an upward trend, reaching a peak in 2023 with 19,953 tweets. A slight decrease was observed in 2020, and a more pronounced decline occurred in 2024, with 16,069 tweets. In Spanish-language tweets, the initial volume was substantially lower, starting at 2,041 tweets in 2014. A marked decrease was observed in 2015, with similar levels maintained in 2016 and 2017. From 2018 onward, mentions increased progressively, followed by a slight decline in 2020. Tweet activity rose again in 2021 and 2022, peaking in 2023 with 4,651 mentions, before declining to 2,627 tweets in 2024.

Temporal Evolution of Tweers About Fentanyl and Oxycodone

Year	Fentanyl (English)	Oxycodone (English)	Fentanyl (Spanish)	Oxycodone (Spanish)
2014	9,037	15,893	657	2,041
2015	13,792	19,220	1,575	976
2016	14,995	17,392	4,064	968
2017	15,775	17,472	4,131	856
2018	17,719	18,140	6,399	1,203
2019	19,539	18,765	10,697	1,724
2020	18,905	18,604	9,384	1,526
2021	20,115	19,591	10,186	2,288
2022	21,866	19,803	10,745	2,572
2023	22,766	19,953	13,285	4,651
2024	19,330	16,069	10,184	2,627

Table 1. Temporal evolution of tweets about fentanyl and oxycodone in English and Spanish (2014–2024).

4. DISCUSSION

This study analyzed 1,594,615 tweets published between 2014 and 2024 that mentioned opioid and non-opioid analgesics, as well as opioid antagonists, in English and Spanish, enabling a comprehensive characterization of the temporal and thematic evolution of digital discourse surrounding these drugs. The multilingual approach adopted further allows for the comparison of digital narratives across distinct linguistic and epidemiological contexts, facilitating the identification of cultural and regional differences in the social perception of analgesic use. Overall, the findings reveal four main results: first, conversations on X are clearly dominated by opioids—particularly high-potency opioids—which generated the highest volume of posts in both languages throughout the study period, whereas non-opioid analgesics and opioid antagonists received considerably less attention; second, clear thematic differences were observed between English- and Spanish-language discourse, with English-language tweets primarily focusing on personal experiences related to opioid use and on debates surrounding the opioid crisis and the responsibility of the pharmaceutical industry, whereas Spanish-language conversations more frequently addressed the therapeutic use of analgesics, self-medication practices, and non-opioid alternatives for chronic pain management; third, the temporal evolution of posting volume showed an overall upward trend over the past decade, particularly for strong opioids, with sustained growth between 2014 and 2023 followed by a slight decline in 2024; and finally, mentions of fentanyl and oxycodone increased progressively in both languages, peaking in 2023 before showing a moderate decline in 2024.

The findings indicate that conversations on X related to analgesics are predominantly concentrated on strong opioids, which constitute the pharmacological group with the highest volume of posts in both languages. This observation is consistent with the prominent role these drugs occupy in international public health debates, particularly in the context of the opioid crisis[45–46]. Similarly, the higher proportion of tweets published in English may reflect the strong influence of the epidemiological landscape of the United

States—the primary epicenter of this crisis—where public, political, and media discourse surrounding opioid use is substantially more intense[47–49].

Furthermore, the greater frequency of mentions of both strong and weak opioids is consistent with their well-established association with adverse events, misuse, and significant social burden, all of which contribute to their heightened visibility in both traditional media and digital platforms[50,51]. In contrast, non-opioid analgesics—despite representing first-line therapy in many clinical guidelines for pain management—and opioid antagonists, which are essential for overdose reversal and harm-reduction strategies, receive markedly less attention. Evidence suggests that messages focused on preventive interventions, such as naloxone use, tend to receive less dissemination and media attention than those centered on risk, alarm, or mortality associated with the opioid epidemic[52–54]. This pattern has been documented in multiple studies, which show that public and media narratives tend to prioritize perceived danger and immediate health impact, whereas preventive and therapeutic strategies—such as community naloxone distribution and harm-reduction programs—receive comparatively limited visibility[55–57]. However, these dynamics must be interpreted within the broader context of global heterogeneity in opioid prescribing patterns and access, as outside the United States the availability, regulation, and types of opioids used may differ substantially, thereby influencing both clinical use and abuse potential[58–61].

The temporal evolution observed in the data closely parallels key epidemiological milestones associated with opioids over the past decade. The sustained increase in mentions of strong opioids in English between 2014 and 2023 coincides with the intensification of the opioid crisis in the United States, characterized by successive "waves"—initially driven by prescription opioids, followed by heroin, and more recently by illicit fentanyl—which have generated recurrent peaks in public attention, media coverage, and regulatory pressure[45,62]. These dynamics are mirrored in social media activity, where interest increases during periods of crisis expansion or following major policy announcements, followed by phases of stabilization or decline, as observed in the decrease recorded in 2024.

In parallel, international clinical guidelines have increasingly promoted the preferential use of non-opioid strategies and multimodal analgesia approaches, reserving opioids for specific clinical situations and encouraging individualized treatment based on patient

characteristics and clinical context[17,63]. The more gradual progression of weak opioids in both languages may be partly explained by their more stable clinical role and lower variability in prescribing policies compared with strong opioids[64]. For example, weak opioids such as tramadol and codeine are primarily used for mild-to-moderate acute or chronic pain, and their safety profile and risk of misuse are generally considered lower than those of strong opioids, resulting in more consistent and less restrictive regulatory frameworks over time [65–67]. Nevertheless, increasing evidence points to misuse in certain geographical contexts[68,69].

In Spanish-language tweets, the upward trend observed between 2018 and 2023 may reflect a temporal lag compared with the Anglophone pattern, consistent with studies indicating a later emergence of concern regarding opioids in these contexts[12,28,70]. The greater presence of mentions of non-opioid analgesics during the same period may reflect increased discussion of therapeutic alternatives and self-medication practices, a phenomenon described in settings with lower prevalence of opioid misuse but growing concern regarding chronic pain management[26,28,71]. Conversely, the temporal stability of opioid antagonists in both languages is consistent with research indicating a limited presence of harm-reduction content on social media despite its expansion in public policy[12,53], suggesting a gap between policy implementation and social visibility.

Overall, these temporal patterns highlight how digital discourse responds dynamically to epidemiological, regulatory, and media changes, reproducing cycles of attention that intensify during crisis periods and attenuate during phases of stabilization. This behavior is consistent with recent studies showing that digital narratives and emotional expression on social media fluctuate according to epidemiological and media contexts, acting as sensitive indicators of social fatigue, public alarm, and shifts in collective attention[72].

Topic modeling further revealed substantial differences in how communities discuss analgesics, suggesting that digital discourse reflects region-specific epidemiological, media, political, and cultural dynamics. In English-language tweets, the predominance of content centered on personal perceptions and individual experiences of opioid use suggests that personal narratives play a central role in public discourse on the opioid crisis. Users share experiences of pain, barriers to access, stigma-related concerns, and coping strategies, contributing to the formation of digital support communities and influencing both public perception and policy development[27,73,74].

Moreover, the strong presence of opioid crisis narratives and discussions related to the pharmaceutical industry on X is consistent with the influence of media events and legal proceedings that have shaped public debate in the United States over the past decade[22,73]. Studies indicate that cycles of intense media coverage and litigation against pharmaceutical companies mediate digital discourse, amplify public attention, and reinforce interpretative frameworks centered on corporate responsibility, thereby contributing to a climate of public outrage that is rapidly reflected on social media[73,75]. Investigative reporting and media narratives on overdoses, malpractice, or regulatory failures directly influence social perceptions and shape the debate toward criminalization or public health–oriented solutions[75,76]. This body of evidence underscores that social media platforms do not function solely as spaces for spontaneous expression, but rather as communicative environments strongly shaped by media and judicial events, which reproduce and amplify moments of heightened controversy. In contrast, topics such as analgesic efficacy, regulation, and public health response remain underrepresented despite their clinical relevance, suggesting that social media communication does not consistently prioritize clinical or preventive content. This pattern aligns with prior infodemiological studies demonstrating the spread of misleading or inaccurate health-related narratives[77].

In contrast, the thematic distribution observed in Spanish-language tweets reflects a different communicative structure, shaped by the historically lower presence of potent opioids in healthcare systems[59,78]. The predominance of themes related to therapeutic alternatives for chronic pain management, as well as therapeutic use and self-medication, suggests that digital discourse is more strongly oriented toward pain management and everyday analgesic use than toward epidemiological risks associated with opioid consumption. This pattern is associated with greater use of non-opioid analgesics and lower availability of strong opioids, which reduces perceived risk among the general population[12,28]. These findings are consistent with international literature describing substantial heterogeneity in opioid access and consumption across regions, with significantly higher levels in North America compared to Latin America, where regulatory, cultural, and economic barriers have historically limited availability[58–61]. In this context, several studies have reported increased use of weak opioids such as tramadol, along with rising non-medical use and dependence potential, highlighting that risk patterns vary considerably depending on the epidemiological context[58,68,69].

This helps explain the lower presence, in Spanish-language digital conversations, of content related to the lethality of potent opioids or illicit trafficking, likely reflecting both a lower epidemiological burden and more limited exposure resulting from the historical underuse of these drugs and the still emerging impact of illicit fentanyl in these settings[12,79–81]. Consequently, discourse on X appears aligned with these structural differences, showing greater emphasis on therapeutic use, self-medication, and personal experiences, consistent with findings from the infodemiological literature[22,82].

The temporal evolution of topics further demonstrates that digital discourse on analgesics is dynamic and highly sensitive to epidemiological, media, and social changes. While some topics remain stable, others exhibit marked fluctuations reflecting the influence of critical events and health policy transformations. For example, in English-language tweets, the stability of content related to personal perceptions aligns with studies indicating that autobiographical narratives remain consistently present regardless of media cycles, as they are rooted in lived experience and the day-to-day management of chronic pain[44]. In contrast, the progressive increase in attention to the opioid crisis and the pharmaceutical industry can be attributed to the influence of media and legal milestones, particularly between 2017 and 2023, when litigation and investigative reporting intensified[73,83,84]. Meanwhile, the decline in mentions of overdose and mortality after 2016 may reflect a shift in focus toward institutional accountability, including pharmaceutical industry practices, regulatory frameworks, and public policy responses[85,86].

In Spanish-language tweets, temporal patterns show a different trajectory, more closely aligned with regional epidemiological realities. The progressive increase in interest in therapeutic alternatives for chronic pain between 2016 and 2020 coincides with the expansion of non-opioid strategies recommended by clinical guidelines and their adoption in clinical practice, reflecting a shift toward safer, multimodal approaches to pain management[86]. Mentions of opioid trafficking and use showed notable fluctuations without a clear long-term trend, suggesting a more reactive discourse driven by isolated events rather than sustained epidemiological processes. The pronounced peak in 2019 in mentions related to opioid-related lethality is consistent with increasing Spanish-language media coverage of illicit fentanyl in the United States and Canada, which began to be widely disseminated in Hispanic media that year, generating a perception of emerging

risk even in low-prevalence settings[87,88]. The literature indicates that the international dissemination of overdose-related news or public health warnings can trigger abrupt increases in digital activity in countries not directly affected, as social media function as transnational channels amplifying health alerts[12].

The prominent attention received by fentanyl and oxycodone in Twitter discourse over the past decade can be explained by their central role in the opioid crisis, widely recognized as one of the most severe public health emergencies globally[87,89,90]. In this context, the temporal analysis focused specifically on these two drugs because they represent key phases in the epidemiological and social evolution of the crisis. Fentanyl has been identified as the main driver of the most recent phase, being implicated in the majority of overdose deaths associated with synthetic opioids in the United States and Canada, with mortality increasing by more than 1000% between 2013 and 2019[87,90]. Its high pharmacological potency—50 to 100 times greater than morphine—combined with rapid onset, low cost, and expansion in illicit markets, has contributed to its high lethality and central role in public and media discourse[89–93]. In contrast, oxycodone played a pivotal role in earlier phases of the epidemic through widespread prescribing driven by aggressive marketing strategies and a misleading perception of low addiction risk[45,89]. Following the introduction of OxyContin in 1996, retail sales increased by approximately 866% between 1997 and 2007, making it one of the most widely prescribed opioids for moderate-to-severe pain[89,94]. Multiple studies have demonstrated that its commercial expansion contributed substantially to increased overdose mortality in subsequent decades[89,95].

This evolution has been described in terms of "epidemic waves," with prescription opioids such as oxycodone driving early phases and synthetic opioids such as fentanyl driving later stages[49,62]. In this framework, the selection of these two drugs allows for a paradigmatic representation of the historical progression of the crisis and enables analysis of how this evolution is reflected in digital discourse. Both substances also exhibit high visibility in media and social platforms; previous infodemiological studies have shown that fentanyl accounts for approximately 27% of posts related to strong opioids on X, reinforcing its suitability as an indicator of digital discourse[22].

This structural relevance is directly reflected in digital conversations, where peaks in public attention tend to align with periods of epidemiological intensification, government

alerts, mortality report releases, or high-impact media events[96]. The findings show that, in both languages, mentions of fentanyl and oxycodone increased progressively over time, peaking in 2023. This sustained growth suggests that digital discourse not only mirrors epidemiological trends but also responds to increasing media visibility of these opioids as key indicators of crisis escalation[96,97]. The decline observed in 2024 may reflect shifting media attention following stabilization or reductions in opioid-related mortality, a pattern previously described in studies of media cycles and social media dynamics[98,99].

The higher volume of English-language tweets may be partly explained by the larger English-speaking user base on X/Twitter. However, this pattern is also consistent with the epidemiological context, which identifies the United States as the country most affected by the opioid crisis[48,87,100]. This has generated intense media, political, and social attention, likely amplifying digital discourse in English[22,96]. In contrast, the lower—although increasing—presence of Spanish-language tweets may reflect both a smaller user base and the gradual international expansion of concern, particularly with the emergence of fentanyl as a threat in several Spanish-speaking countries and increasing attention from health authorities, although prevalence and mortality remain comparatively lower[12,81].

Taken together, these findings suggest that digital discourse on analgesics—and particularly on fentanyl and oxycodone—may function as a sensitive infodemiological indicator of epidemiological and media dynamics associated with the opioid crisis. The predominance of narratives centered on potent opioids, combined with the limited visibility of preventive strategies and therapeutic alternatives, points to potential communication gaps that may influence public risk perception and pain management practices. Furthermore, the convergence of both languages toward a peak in 2023 suggests that, despite differences in epidemiological impact, the opioid crisis has acquired a global dimension within the information space. Accordingly, social media analysis may provide valuable complementary insights for public health surveillance, inform clinical communication strategies, and support prevention and digital monitoring initiatives[101].

4.1. Limitations:

This study presents several limitations that should be considered when interpreting the findings. First, although the API used provides comprehensive access to public tweets,

the analysis was restricted exclusively to posts containing generic drug names. This approach may have excluded relevant conversations that employed slang, abbreviations, misspellings, or indirect references to opioid and non-opioid analgesics, potentially reducing the sensitivity of the search strategy.

Second, users of X do not represent the general population; they tend to be younger, with higher levels of digital literacy and specific sociodemographic characteristics, which introduces an inherent bias in the interpretation of public discourse. In addition, the study relies exclusively on data from the X platform (formerly Twitter), and therefore the findings may not be representative of communication dynamics observed on other social media platforms with different user profiles and interaction patterns. Furthermore, the transition from Twitter to X may have introduced changes in the user base, participation dynamics, and content dissemination algorithms, which could have influenced the observed patterns. Nevertheless, the longitudinal design of the study allows these potential variations to be contextualized within broader temporal trends.

Third, although standardized text-processing procedures were applied, unsupervised modeling techniques are inherently sensitive to decisions made during data cleaning and may oversimplify complex discourse, particularly in contexts where irony, ambiguity, or figurative language are prevalent. This may limit the accuracy of topic identification and their subsequent interpretation.

In addition, the potential presence of bots or automated accounts—although not systematically detected—may have marginally influenced the temporal and thematic distribution of the corpus.

Finally, the observed peaks in activity may be influenced by external factors—such as media cycles, regulatory announcements, or viral events—that do not necessarily reflect underlying epidemiological changes. Nevertheless, the methodology employed is consistent with previous infodemiological studies and provides a useful tool for characterizing communication dynamics surrounding analgesics[22,26,28,35,71,102].

5. CONCLUSIONS:

This study provides a detailed characterization of how public discourse on opioid and non-opioid analgesics has evolved on X over the past decade. The findings show that strong opioids account for a substantial proportion of digital conversation and that temporal trends closely mirror epidemiological, media, and regulatory developments. In addition, the thematic differences observed between English- and Spanish-language content reveal distinct cultural patterns. The multilingual approach adopted constitutes a key strength, as it enables the comparison of narratives across diverse linguistic and epidemiological contexts and facilitates the identification of cultural variations in the perception and use of analgesics. Furthermore, the temporal patterns observed for fentanyl and oxycodone point to increasing public sensitivity toward these potent opioids and their central role in shaping the evolution of the crisis.

Social media platforms function as infodemiological indicators capable of capturing rapid fluctuations in public attention and societal concern. Continuous monitoring of data from X could provide a valuable means of identifying emerging trends related to opioids. In this regard, the analysis of digital discourse allows for the early detection of shifts in public narratives that may anticipate changes in risk perception, patterns of use, or acceptance of regulatory policies, as well as the identification of potential communication gaps relevant to clinical practice and public health.

Taken together, this study suggests that social media platforms constitute a valuable and complementary source for understanding the social dimension of the opioid crisis and for informing decision-making processes. Beyond the mere description of trends, these findings may contribute to guiding clinical communication strategies that are better aligned with public concerns, adapting interventions to specific cultural contexts, and strengthening prevention and harm-reduction initiatives in pain management.

6. LIST OF ABBREVIATIONS:

AEMPS: Spanish Agency of Medicines and Medical Devices

API: Application Programming Interface

CVI: Cluster Validity Indices

FDA: Food and Drug Administration

HDP: Hierarchical Dirichlet Process

INN: International Nonproprietary Name

LDA: Latent Dirichlet Allocation

NMF: Non-negative Matrix Factorization,

7. DECLARATIONS:

Ethics approval and consent to participate:

This study received approval from the Research Ethics Committee of the University of Alcalá (Ethics Code: CEID/2024/1/005) and was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki. Informed consent was not required, as the study did not involve direct participation of human subjects nor any intervention involving individuals, relying exclusively on the analysis of publicly available tweets. Furthermore, specific measures were implemented to protect user privacy, including the avoidance of disclosing account names or any information that could enable the identification of individuals in this report.

Consent for publication:

Not aplicable.

Availability of data and materials:

The datasets generated and/or analyzed during the current study are available upon reasonable request. In addition, the raw de-identified data may be made available upon reasonable request from the corresponding authors.

Competing interests:

The authors declare that they have no competing interests

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Authors' contributions:

TV, AR-I, MAA-M and MA-M were the main contributors to the research design, coordination of data analysis, and manuscript preparation. MAA-M and JQ specifically coordinated data acquisition. TV and AR-I conducted data processing. MAO contributed to the manuscript as a reviewer. The interpretation and analysis of the results, as well as the writing of the manuscript, were tasks performed by all authors with special dedication from the first and last authors. All authors have read and approved the final version of the manuscript.

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