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# Editorial Comments: JCMM Volume 2 Issue 2

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In the second issue of JCMM for 2023, we bring to you an assortment of research that transcends geographical boundaries, reflecting contributions from authors based in India, Sri Lanka, the UK, the US, Kazakhstan, Iran, and Saudi Arabia. These studies span various disciplines – from digital marketing and healthcare to artificial intelligence and sustainable materials – creating a comprehensive discourse that continues to unpack the multifaceted impacts of the COVID-19 pandemic. Vishesh Rai and Vikas Chauhan [1] delve into the necessity of digital marketing strategies during uncertain times, while Hameed et al. [2] shed light on the mental and physical health challenges faced by healthcare professionals during the pandemic. Gayathri et al.'s [3] exploration of the VGG-16 architecture for accurate brain tumor detection showcases the potential of AI in the medical field. Our two mini-reviews further enrich this global discourse. Eraghi et al.'s [4] review critically discusses the psychological impacts of quarantine during pandemics and provides strategies to manage mental health in such crises. Meanwhile, Naik et al.'s [5] review explores the potential of natural cellulosic fibers as sustainable alternatives in various industries, highlighting advancements in their extraction, treatment, and characterization methods. In addition to this, we are delighted to announce an upgrade to the PDF format of our published articles. This revision is aimed at improving readability, facilitating efficient navigation, and harmonizing with various online viewing platforms. We trust that these changes will significantly enhance the reading experience for our esteemed readers. The breadth of geographical representation in this issue demonstrates the global scope of the challenges we face and the solutions we seek. This diverse body of research embodies our commitment to fostering a comprehensive understanding of the post-pandemic world – one that incorporates perspectives from across the globe. As we navigate the remainder of 2023, we anticipate discovering more valuable insights from these and future contributions, fostering a rich, global discourse on resilience, adaptation, and growth in these extraordinary times. Together, we look forward to applying the lessons learned to shape a healthier, balanced, and more sustainable world.

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# Market Penetration through Digital Marketing: A Case Study of a Tractor Dealership During Covid-19 Pandemic

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**Abstract**

The present study investigates the efficacy of digital marketing strategies in enhancing customer reach and sales for a tractor dealership, "Shyam Tractors of Sonalika International Tractors Limited," located in Seoni, Madhya Pradesh, during the COVID-19 pandemic. The dealership adopted digital marketing to stimulate additional inquiries, leading to increased customer reach and sales. Of the total inquiries received over four months, 32% were sourced from digital marketing initiatives. These strategies encompassed the use of automation tools for continuous customer interaction, resulting in amplified brand visibility and customer trust, and fostering positive word-of-mouth. The findings suggest that the success of digital marketing strategies is contingent upon location, demographics, and target audience, emphasizing the necessity of customizing strategies to local market conditions. While digital marketing showed promising results, the continued relevance of traditional marketing underscores the need for a balanced marketing approach for optimal customer engagement. In summary, this study concludes that digital marketing strategies can effectively augment customer reach, sales, and engagement in the tractor industry, particularly during periods of economic uncertainty and market disruption. This implies that tractor dealerships could benefit significantly from integrating digital marketing strategies into their business models.

***Keywords:*** Digital Marketing; Tractor Dealership; Customer Engagement; Sales Enhancement; Automation Tools

## 1 Introduction

Agriculture, a vital industry necessitating long work hours, has seen significant improvements in productivity and efficiency with the advent of tractors [1–3]. This essential farming tool has witnessed substantial sales growth, especially in India, prior to the COVID-19 pandemic [4–6]. The pandemic's impact has notably altered customer behavior within the tractor industry, necessitating novel marketing strategies [7]. Traditional marketing strategies, including print advertisements and direct mail, had been primary modes of customer interaction in this industry [8, 9]. With technological advancements and the influence of the pandemic, however, businesses are increasingly incorporating digital marketing strategies to broaden customer reach and enhance sales [10–12]. Research indicates that digital marketing substantially improves customer reach, engagement, and sales across various industries [13]. A study by the Global Web Index showed that a significant portion of consumers research products online before purchasing, indicating the importance of a robust online presence [14]. Yasmin et al. [15] discussed the concept of digital marketing, explaining its integral role in modern marketing, service quality improvement, and cost-effective reach. They underscored the role of technology in driving e-marketing, suggesting a shift in focus from technology to the business model. Further, Khan and Islam [16] highlighted digital marketing's impact on customer loyalty, emphasizing its importance in competitive business markets.

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Keke [17] and Hamdani et al. [18] explored the relationship between digital marketing and consumer behavior, highlighting the relevance of social media channels and the influence of digital marketing on consumer decision-making. Notably, studies show that content marketing generates three times as many leads as traditional outbound marketing, but at 62% less cost [16]. The present study aims to investigate the impact of digital marketing on a tractor dealership, specifically "Shyam Tractors of Sonalika International Tractors Limited in Madhya Pradesh, Seoni," which was affected by COVID-19 restrictions. It seeks to contribute to the existing literature on digital marketing within the tractor industry and provide insights into the effectiveness of digital marketing strategies in augmenting customer reach and sales.

# 2 Materials and Method

## 2.1 Data collection

To achieve this study's objectives, primary and secondary data was collected. The primary data collection involved a questionnaire survey distributed to identified target respondents, including existing customers, farmers owning tractors, potential buyers, and tractor operators within the selected district. The questionnaire, designed in four stages, was tested and refined through a pilot survey with a small group of people from the target respondents before full-scale distribution. The dealership used both paper-based and digital distribution methods for comprehensive coverage. Face-to-face interaction and immediate feedback were facilitated through hard copy distribution during village visits by the marketing team. In contrast, digital platforms provided wide-reaching and convenient data collection methods. Using their WhatsApp customer database, the dealership shared the questionnaire electronically via Google Forms. The combined approach ensured a broader range of responses and wider audience reach. The responses from both methods were then compiled for analysis. Secondary data was collected from dealership records, including RTO data, past customer contact information, post-sales service details, and ongoing inquiry details. The integration of primary and secondary data sources provided a comprehensive understanding of the market landscape and the dealership's performance.

## 2.2 Data analysis

The primary and secondary data were subjected to thorough analysis. The primary data from the questionnaires were analyzed using Microsoft Excel, which provided insights into customer preferences, social media consumption patterns, and the demand for different tractor models. RTO data and other secondary data provided insight into the tractor industry's overall landscape in the district. Additionally, the dealership used built-in analytics tools from digital marketing platforms like WhatsApp and Facebook. These tools provided crucial metrics such as impression tracking, click-through rates, conversion tracking, and demographic analysis. The social media consumption survey helped to identify active customer platforms, while the RTO data helped analyze the demand for different tractors. By utilizing these built-in analytics tools and comprehensive data analysis, data-driven decisions were made for the dealership's digital marketing strategies. It should be noted that while statistical tests can be used for data analysis, this study leveraged the analytical tools inherent in digital marketing platforms to assess the performance and effectiveness of the campaigns, thus eliminating the need for additional statistical tests.

## 2.3 Advertising approach

The dealership tailored its Facebook and WhatsApp marketing efforts to reach a specific target audience, identified through primary and secondary data analysis. The target audience, comprising individuals interested in buying tractors, seeking product information, and requiring post-sales service, varied based on the objective of each marketing effort. An illustrative example can be seen in our response to data revealing higher demand for 60 HP tractors in a specific village, resulting in a focused marketing effort promoting this model in the area. This is just one of several data-driven strategies tailored to specific audiences. To enhance digital marketing efforts, the dealership:

- Established an online presence through a Facebook business page and WhatsApp business accounts.
- Created and ran targeted ads using Facebook's business tools. A suitable product was selected based on analyzed data, and ads were targeted at the most relevant potential customers.
- Utilized WhatsApp for customer engagement by linking it with the Facebook page. The WhatsApp business account provided customers with automated messages about the dealership's offerings and a catalog to browse through different tractor models.
- Implemented a market automation strategy to increase customer engagement. Using the "Textlocal" software, bulk personalized SMS campaigns were conducted to inform customers about service reminders, latest updates, and offers.

Effectiveness of the strategies was gauged by tracking several metrics such as lead generation, engagement rates, click-through rates, and conversion rates. These metrics were analyzed, and based on the results, necessary adjustments were made to the marketing approach. The dealership faced challenges like a language barrier, limited internet connectivity, and digital literacy among potential customers. Solutions included translation of marketing content into local languages, optimization of content for low-bandwidth connections, creating offline versions of promotional materials, and simplification of steps for customers to contact the dealership.

Customer feedback and engagement were instrumental in shaping the dealership's digital marketing strategies. Active feedback collection and personalization of marketing efforts based on customer preferences were significant components of the approach.

## 3 Results and Discussion

Table 1 and Figure 1 reveal key insights into the tractor sales and social media usage, respectively, in different tehsils serviced by the dealership.

Table 1: RTO data concerning tractor sales by tehsil and horsepower range.

| **Tehesil** | **>30 HP** | **31-40 HP** | **41-50 HP** | **52-60 HP** | **>60 HP** |
|---|---|---|---|---|---|
| Tehesil A | 1 | 43 | 194 | 16 | 6 |
| Tehesil B | 0 | 10 | 76 | 7 | 0 |
| Tehesil C | 0 | 14 | 51 | 10 | 0 |
| Tehesil D | 0 | 84 | 166 | 14 | 10 |
| Tehesil E | 1 | 41 | 204 | 26 | 5 |
| Tehesil F | 0 | 32 | 128 | 10 | 4 |
| Tehesil G | 0 | 97 | 240 | 21 | 1 |
| Tehesil H | 0 | 74 | 428 | 69 | 6 |
| **Total** | **2** | **395** | **1487** | **173** | **32** |

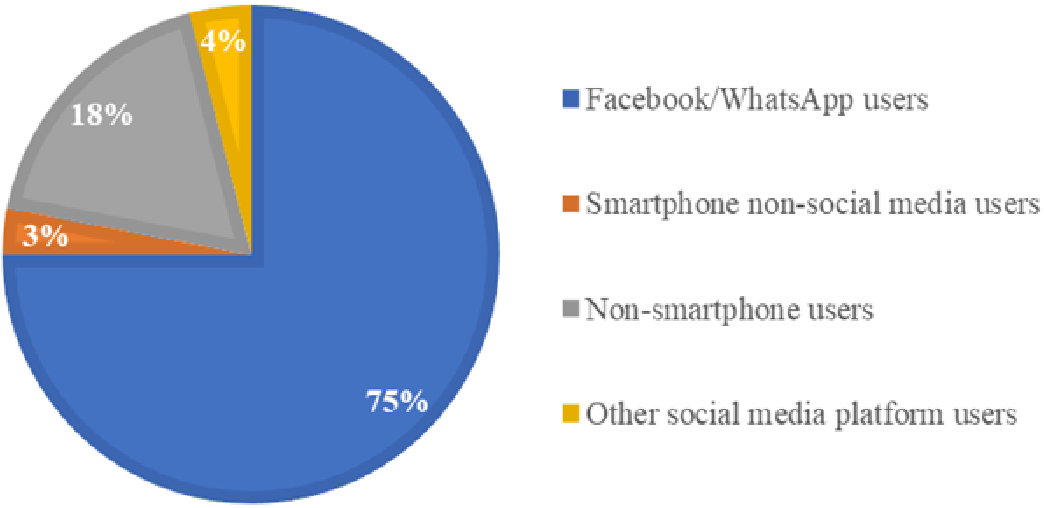


Figure 1: Social media usage in rural areas dealt by tractor dealership

### 3.1 Tractor sales

The dealership sold a total of 2089 tractors, with Tehsil H and G leading sales at 577 and 359 units, respectively, while Tehsil B recorded the lowest with 93 tractors. In terms of horsepower, tractors within the 41-50 range were the most popular, accounting for 1487 sales, followed by those in the 31-40 range at 395 units. Tractors exceeding 60 horsepower experienced the least demand with 32 units sold. Based on these findings, marketing efforts were focused on promoting tractors within the 41-50 and 31-40 horsepower ranges, primarily in Tehsils H and G.

### 3.2 Social media usage

A survey involving 500 participants from the rural areas serviced by the dealership revealed that 75% of respondents actively used Facebook or WhatsApp. However, a substantial 18% did not possess smartphones, while 3% owned smartphones but did not engage with any social media platforms. A mere 4% used other social media platforms. Given the high Facebook and WhatsApp usage, these platforms were leveraged for digital marketing, including providing tractor model information, pricing, and special offers. However, considering the significant portion of the target audience not using smartphones or social media, a multi-channel marketing approach was adopted. This approach involved traditional methods such as print advertising and radio ads, coupled with a bulk SMS technique through "Textlocal" software for those not using social media or without smartphones. Moreover, a referral incentive program was introduced, offering discounts for new customers and incentives for those who referred others, boosting the reach of the dealership's offerings. This holistic marketing approach allowed the dealership to maximize its reach and engage with potential customers through multiple channels.

### 3.3 Inquiry trends and impact of marketing strategies

Table 2 provides insights into the effects of digital marketing on prospective customer engagement, as reflected by the number of inquiries recorded over two different four-month periods.

Table 2: Number of inquiries recorded over two different four-month periods.

| **Tehesil** | **Feb-March 2022** | | **Apr-May 2022** | |
|---|---|---|---|---|
| | **Digital** | **Traditional** | **Digital** | **Traditional** |
| Tehesil A | 2 | 12 | 1 | 6 |
| Tehesil B | 8 | 11 | 6 | 8 |
| Tehesil C | 3 | 1 | 1 | 4 |
| Tehesil D | 2 | 1 | 4 | 7 |
| Tehesil E | 3 | 10 | 2 | 11 |
| Tehesil F | 1 | 5 | 4 | 7 |
| Tehesil G | 3 | 7 | 8 | 8 |
| Tehesil H | 16 | 38 | 17 | 35 |
| **Total** | **38** | **85** | **43** | **86** |

Though traditional marketing methods yielded more inquiries than digital marketing in both periods, an interesting trend emerges on closer observation: digital marketing inquiries increased from the first to the second period while traditional marketing inquiries remained static. Around 31% of inquiries in the first period and 33% in the second resulted from digital marketing, suggesting growing effectiveness of these strategies over time. However, the results differed across tehsils. In Tehsil H, digital marketing consistently outperformed traditional marketing, while the opposite held true in Tehsil F. Thus, factors such as location, demographics, and audience preferences significantly influence the success of digital marketing. Therefore, while digital marketing holds promising potential, a balanced blend of both traditional and digital strategies seems optimal for maximum reach and impact.

### 3.4 Sales trends and marketing impact

The impact of digital marketing was evident not only on engagement levels but also on actual sales. In February and March, digital marketing accounted for approximately 13% of 48 tractors delivered. In April and May, digital marketing contributed to roughly 17% of the 71 tractors sold. The growing percentage of sales via digital marketing indicates that these efforts are becoming more effective and critical over time.

### 3.5 Limitations of the study

While this study offers valuable insights into tractor sales trends, social media usage, and the impact of various marketing strategies in the rural Indian context, it is important to recognize the limitations that could have influenced the findings which are listed as follows:

- Sample Size: The sample size of the study, consisting of farmers, old customers, and tractor operators in the Seoni district, was relatively limited. This limitation may affect the generalizability of the findings to other regions or demographics within rural India.
- Response Bias: The data collection process relied on respondents voluntarily completing the questionnaires. This may have introduced a response bias, affecting the representativeness of the findings.
- Self-Reported Data: The primary data collected through questionnaires relied on self-reported information from the respondents. There is a possibility of inaccuracies due to memory recall, social desirability bias, or misinterpretation of the questions.
- Availability of Secondary Data: The secondary data collected from dealership records had its limitations as well. The accuracy of the data depended on the dealership's data management practices, which could introduce errors or biases in the analysis.
- External Factors: The study might have been impacted by external factors such as market conditions, seasonal variations, or unforeseen events that could influence customer behaviors and preferences.

### 3.6 Future opportunities

Despite its progress, the dealership has opportunities for further refinement in its digital marketing strategy. Improving the user-friendliness of the website, better utilization of social media for wider reach, conducting regular customer surveys for tailored marketing strategies, and harnessing emerging technologies like AI, machine learning, and chatbots can significantly enhance customer engagement and sales efficiency. By continually adapting and innovating, the dealership can stay competitive and optimize customer experience.

## 4 Conclusion

This research project set out to explore the potential of digital marketing in expanding customer reach and its effectiveness was convincingly demonstrated. It is noteworthy that digital marketing accounted for approximately 31% and 33% of customer inquiries in the first and second periods respectively. This significant contribution affirms that digital marketing is a potent strategy for broadening customer reach and generating more leads. Furthermore, the role of digital marketing in augmenting sales figures was also substantiated. Specifically, digital marketing was responsible for the sale of 13% of all tractors sold in February and March, and this figure rose to 17% in April and May. This escalation underscores the value of digital marketing in driving sales growth. A significant finding from the study was the efficacy of automation tools in enhancing customer engagement. Regular updates regarding latest schemes, reminders for service camps and events, and information about discount offers were circulated using these tools. This approach fostered better customer interaction, leading to positive word-of-mouth about the dealership in the market, as evidenced by feedback from customers and selected dealerships. In light of these findings, it can be concluded that digital marketing is not only a powerful mechanism for widening customer reach and boosting sales but also an invaluable tool for enhancing customer engagement. The successful implementation of automation tools within digital marketing strategies can facilitate constant customer connection, imparting crucial information to customers, thus bolstering brand visibility and fostering customer trust.

## Ethical Consideration

Ethical considerations were given priority throughout the research project. Informed consent was obtained from all participants prior to data collection. They were provided with detailed information about the study's purpose, data collection methods, and how the data would be used. Strict measures were put in place to ensure data privacy and confidentiality. All personal and sensitive information was anonymized and stored securely. Transparency and open communication were maintained throughout the research process. Participants were encouraged to ask questions and any concerns they may have had regarding data privacy or ethical considerations were addressed.

## Declaration of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Funding Declaration

This research did not receive any grants from governmental, private, or nonprofit funding bodies.

## Author Contribution

**Vishesh Rai**: Conceptualization, Investigation, Methodology, Writing - original draft, Data curation, Formal analysis, Validation, Writing - review and editing; **Vikas Chauhan**: Data curation, Formal analysis, Supervision, Investigation, Methodology, Writing - review and editing.

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# The Impact of the COVID-19 Pandemic and Associated Lockdowns on the Mental and Physical Health of Urologists

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**Abstract**

The COVID-19 pandemic and subsequent lockdowns have posed unprecedented challenges to healthcare professionals worldwide, including urologists. This study sought to evaluate the mental and physical health outcomes among urologists during this period. The study encompassed a sample of 150 urologists of varying ages and genders, using standardized scales to measure mental and physical health, activity levels, relationships, work-related stress, and preventive measures. Our findings underscored that urologists of both genders experienced significant psychological distress, with younger urologists (25-45 years) reporting higher levels of depression and anxiety. Doctors with higher hospital visit frequency exhibited more psychiatric morbidity, likely due to the heightened fear of virus exposure and subsequent risk to family members. The lockdown period was also marked by a decline in structured exercise and increased consumption of ultra-processed foods, leading to weight gain among participants. In light of these findings, we advocate for mental health outreach within the urology community, with a focus on younger professionals. Furthermore, we emphasize the importance of adequate protective measures in hospitals, promoting healthier lifestyles, and social support systems to bolster mental and physical health in such crises. Future research is recommended to explore the long-term consequences of the pandemic on urologists' health and to devise effective strategies to mitigate adverse effects.

***Keywords:*** COVID-19; Mental Health; Physical Health; Lockdown; Urologists

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# 1 Introduction

The COVID-19 pandemic has presented a global challenge due to its contagiousness and potential lethality [1]. As a control measure, many countries instituted lockdowns, imposing rigorous social and travel restrictions. These measures led to remote work, closure of businesses, and limited activities to essential services, thereby minimizing physical contact [2–4]. The SARS-CoV-2 pandemic's effects extend beyond physical and financial difficulties, such as illness, hospitalization, unemployment, and financial insecurity, to encompass significant psychological impact, including anxiety, loneliness, and fear [5]. Factors such as social isolation, home-schooling, temporary unemployment, and financial insecurity, all resulting from the pandemic experience, can profoundly affect an individual's mental and physical well-being [6, 7]. The impact differs across social groups, population densities, and those with predispositions to the virus [8]. Previous studies on community-wide disasters, such as natural disasters, war, fires, and terrorist attacks, have indicated immediate risks to mental and physical health, as well as social relationships. High levels of anxiety and depression, particularly among those perceiving themselves in poor health pre-pandemic, have been linked to the COVID-19 pandemic [9–11].

Further, moderate-vigorous physical activities have been found to positively affect resilience, mood, depressive symptoms, stress, anxiety, insomnia, and emotional disturbances due to the virus. Given the urgent need for research on the pandemic's effects [12–16], this study aims to conduct a comprehensive analysis of data gathered from urologists worldwide before and one month after their respective national lockdowns. The analysis will focus on institutional trust, attitudes towards the nation and government, physical and psychological health, and subjective well-being. In India, a nationwide lockdown was implemented in four phases. The survey was carried out during two periods: April 7 - April 12 (Period I) and May 21 - May 28 (Period II), when the COVID-19 confirmed cases were approximately 600 [17, 18]. The first lockdown saw a surge to over 10,000 cases, prompting the immediate enactment of a second lockdown [19–21]. In response, the Indian government categorized districts into green, red, and orange zones according to the severity of COVID-19 spread during the second lockdown. This period saw the cases rise to 42,505, nearly tripling the count from the first lockdown [22]. This study conducts statistical comparisons of participants' responses between Period I and Period II, in addition to examining their intra-individual responses. The primary objective is to offer practical information and theoretical insights into the immediate impact of the COVID-19 pandemic on the well-being, emotions, and social environment of practicing urologists.

# 2 Methodology

## 2.1 Participants and sampling

This comprehensive study aimed to investigate the experiences and challenges confronted by practicing urologists from various regions worldwide during the COVID-19 pandemic. The recruitment period for the study extended from January 29, 2020, to February 4, 2020. Before commencing the research, the Institutional Ethics Committee of Kasturba Medical College, Manipal, provided ethical clearance under the reference number ABCD2020, following a thorough review and approval of the study. Data collection involved the use of an anonymous, self-rated questionnaire distributed to the participants' workstations via Google Forms. This digital approach facilitated efficient and secure data gathering from a diverse pool of urologists globally. To uphold ethical standards and voluntary participation, all participants were required to provide electronic informed consent before enrolling in the study. Access to the questionnaire was granted solely to those who affirmed their consent, ensuring that only willing participants contributed to the research.

## 2.2 Measures

The questionnaire used in this study was meticulously constructed to gather a wide range of data from practicing urologists during the COVID-19 lockdown. It included basic demographic details and covered various dimensions related to activities, relationships, physical health, work-related concerns, and mental health. The questionnaire was divided into the following sections:

- Basic Demographic Data: This section collected fundamental demographic details such as age, gender, marital status, educational level, and professional specifics.
- Activities during Lockdown: This section probed into participants' primary activities during the lockdown, which could include spending time with family, reading, watching television, browsing social networks, playing video or indoor games, and engaging in academic work. Questions also touched on the development of new hobbies or habits, daily screen time, and preferred social media platforms for news updates during the lockdown.
- **Relationships**: This part investigated the impact of the lockdown on participants' relationships with family, friends, and colleagues. It asked about communication with relatives, friends, or colleagues, and the reasons behind these interactions.
- **Physical health**: In this section, participants reported their current weight in kilograms and their physical activity levels during the lockdown, including exercise, walking, jogging, playing sports, and other activities.
- **Preventive measures**: Participants were asked about their efforts to spread awareness of COVID-19, their use of sanitizers, face masks, gloves, and the availability of PPE in their respective hospitals.

- **Work-related**: This section contained queries about resuming work, the practice of telemedicine, participation in or conducting of webinars, and views on suspending elective outpatient department (OPD) and operative cases during the pandemic.
- **Mental health**: This section included questions about mood, coping strategies, concerns, energy levels, sleep patterns, libido, and overall mental and physical health status during the lockdown. Changes in smoking or alcohol consumption during this period were also addressed.

By employing an exhaustive and comprehensive data collection approach, the study aimed to offer valuable insights into the experiences of urologists during the COVID-19 pandemic and pinpoint potential areas for support and intervention to improve their well-being.

### 2.3 Data analysis

The data analysis process for this study comprised a series of steps to assure the correct interpretation of the collected data. Descriptive statistics were calculated for all variables in the study, thereby providing an exhaustive summary of the dataset. This facilitated the identification of patterns and trends, and enhanced understanding of the overall sample characteristics. To evaluate the questionnaire data, various statistical measures, including frequencies, percentages, means, and standard deviations, were employed. Frequencies and percentages were used to delineate the distribution of categorical variables such as gender, occupation, and department. Means and standard deviations were utilized to summarize the distribution of continuous variables, like age. Comparisons between different groups within the data were performed using suitable statistical tests. The chi-square test was used to compare categorical data, involving the analysis of the association between two or more categorical variables. This test determined if there was a significant relationship between the variables by comparing observed frequencies with expected frequencies assuming no association. For continuous data, the independent samples t-test was used to compare the means of two groups. This test determined if there was a significant difference between the means of the groups, taking into account any possible variation within the samples. It assessed whether observed differences were likely due to chance or a genuine difference between the groups. Logistic regression analysis was conducted to identify factors independently associated with access to mental healthcare services and self-perceived health status. This statistical method examined the relationship between a binary dependent variable (e.g., accessing mental healthcare services or not) and one or more independent variables (e.g., age, gender, department, etc.). The analysis yielded odds ratios, indicating the probability of a particular outcome occurring under specific variable conditions. All statistical analyses were performed using SPSS version 26.0 software, a widely accepted and powerful statistical tool for social sciences. This software facilitated efficient management, organization, and interpretation of the collected data, ensuring that the findings were both accurate and reliable.

## 3 Results and Discussion

The aim of this study was to explore the changes in various facets of individuals' lives during two separate lockdown periods. We examined the demographic characteristics, activities, and score scales of 150 participants in areas such as physical health, mental health, activity, relationships, work-related, and preventive measures. The findings revealed substantial changes between Lockdown Period I and Lockdown Period II in several aspects, while some remained constant. The subsequent sections present detailed data on the participants' demographics and engagement activities (Table 1), and compare scale scores for each aspect between the two lockdown periods (Table 2).

Our sample consisted of 150 participants, 58.66% (n=88) of whom were male and 41.33% (n=62) female. The majority of participants were aged between 25-35 (32.00%, n=48), followed by the age groups of 35-40 (26.66%, n=40), 40-50 (17.33%, n=26), less than 25 (11.33%, n=17), and more than 50 (12.66%, n=19). During the lockdown, 32.66% (n=49) of participants visited the hospital daily for work, while 34.00% (n=51) did so every 2-7 days, 24.66% (n=37) every 8-15 days, and 8.66% (n=13) visited more than 15 days. Regarding weight, 21.33% (n=32) of participants weighed less than 70 kg, 39.33% (n=59) weighed between 70-80 kg, 30.66% (n=46) weighed between 80-90 kg, and 8.66% (n=13) weighed more than 90 kg.

Most participants spent their lockdown time browsing social networks (44.00%, n=66), followed by spending time with family (30.66%, n=46), reading books (19.33%, n=29), and watching TV (4.00%, n=6). The results demonstrated significant changes between Lockdown Period I and Lockdown Period II in several areas. Physical health saw an increase from an average score of 6.12 (SD=1.21) to 6.26 (SD=1.10), t(149)=2.81, p=.013, d=0.19. Mental health also improved, moving from 4.13 (SD=1.58) to 4.43 (SD=1.57), t(149)=4.14, p¡.001, d=0.17. Work-related scores escalated from 5.82 (SD=1.02) to 6.20 (SD=0.98), t(149)=3.91, p¡.001, d=0.19. Further, relationships saw a significant increase from 0.75 (SD=0.56) to 0.83 (SD=0.52), t(149)=2.60, p=.002, d=0.07. Conversely, no significant changes were observed in activity levels between Lockdown Period I (M=6.60, SD=2.24) and Lockdown Period II (M=6.47, SD=2.34), t(149)=1.14, p=.230, d=0.00. Similarly, no significant differences were identified in preventive measures between the two periods, with scores of 5.42 (SD=2.17) in Lockdown Period I and 5.39 (SD=2.25) in Lockdown Period II, t(149)=0.24, p=.814, d=0.02. Our study was primarily focused on examining the transformation in various facets of individuals' lives during two distinct lockdown periods. The results revealed significant alterations in some areas, while others remained stable. This discussion will interpret the findings, compare them with existing literature, speculate on potential implications and recommendations for future research and practice, and address the challenges faced during the study and the opportunities for future work.

Table 1: Demographic Characteristics and Engagement Activities of Participants (N=150)

| **Category / Variable** | **Frequency (Percentage)** |
|---|---|
| Gender - Male | 88 (58.66%) |
| Gender - Female | 62 (41.33%) |
| Age - Less than 25 | 17 (11.33%) |
| Age - 25-35 | 48 (32.00%) |
| Age - 35-40 | 40 (26.66%) |
| Age - 40-50 | 26 (17.33%) |
| Age - More than 50 | 19 (12.66%) |
| Visit to hospital for work (lockdown) - Daily | 49 (32.66%) |
| Visit to hospital for work (lockdown) - 2-7 days | 51 (34.00%) |
| Visit to hospital for work (lockdown) - 8-15 days | 37 (24.66%) |
| Visit to hospital for work (lockdown) - More than 15 days | 13 (8.66%) |
| Present weight (Kg) - Less than 70 Kg | 32 (21.33%) |
| Present weight (Kg) - 70-80 Kg | 59 (39.33%) |
| Present weight (Kg) - 80-90 Kg | 46 (30.66%) |
| Present weight (Kg) - More than 90 Kg | 13 (8.66%) |
| Max engagement during lockdown - Reading books | 29 (19.33%) |
| Max engagement during lockdown - Spending time w/ family | 46 (30.66%) |
| Max engagement during lockdown - Watching TV | 6 (4.00%) |
| Max engagement during lockdown - Social network browsing | 66 (44.00%) |

Table 2: Comparisons of Scale Scores between Lockdown Period I and Lockdown Period II

| **Scale/Item** | **Period I** | **Period II** | **Mean Difference** | **p-value** | **Cohen's d** |
|---|---|---|---|---|---|
| Physical Health | 6.12 (1.21) | 6.26 (1.10) | 0.14 | 0.013 | 0.19 |
| Activity | 6.60 (2.24) | 6.47 (2.34) | -0.13 | 0.230 | 0.00 |
| Mental Health | 4.13 (1.58) | 4.43 (1.57) | 0.30 | 0.00 | 0.17 |
| Relationships | 0.75 (0.56) | 0.83 (0.52) | 0.08 | 0.002 | 0.07 |
| Work-related | 5.82 (1.02) | 6.20 (0.98) | 0.38 | 0.00 | 0.19 |
| Preventive Measures | 5.42 (2.17) | 5.39 (2.25) | -0.02 | 0.814 | 0.02 |

One of the primary findings was the improvement in both physical and mental health between the two lockdown periods. This may be attributed to the participants adapting to the lockdown situation over time, finding ways to cope with stressors, and engaging in healthier behaviors. This finding aligns with previous research, which suggests that individuals can develop resilience and enhance their coping mechanisms during challenging situations [23].The enhancement in work-related scores could be due to the participants adapting to remote working or the healthcare sector's response to the pandemic. This echoes research suggesting that organizations have invested in technology and infrastructure, thereby enabling better remote work experiences and supporting employees' well-being during the pandemic [24]. The improvement in relationship scores between the two lockdown periods might indicate that individuals utilized the time at home to strengthen bonds with their family and friends. This supports the theory that social connections can act as a buffer during crises and contribute to increased resilience and mental health [25]. Interestingly, no significant changes were observed in activity levels or preventive measures between the two lockdown periods. This could suggest that the participants had already adopted a consistent pattern of activities and preventive behaviors during the first lockdown period, which continued into the second lockdown period. Maintaining such behaviors may be crucial in mitigating the adverse effects of the pandemic on mental and physical health [26]. The demographic characteristics and engagement activities of the participants provide additional context for the findings. Social network browsing was the most common activity during the lockdown, followed by spending time with family and reading books. This emphasizes the importance of staying connected and engaging in meaningful activities to cope with the challenges posed by the pandemic. In summary, our study's results suggest that individuals may adapt and show resilience in the face of prolonged lockdown periods. The improvements in physical and mental health, relationships, and work-related scores between the two lockdown periods can be viewed as indicators of this adaptation. Nevertheless, further research is required to explore the long-term effects of the pandemic on individuals' well-being and the factors contributing to resilience and coping. Challenges faced during the study include the limited sample size and the cross-sectional nature of the data, which may not fully capture the dynamic changes experienced by individuals during the pandemic. Moreover, the sample may not be representative of the broader population, limiting the generalizability of the findings. Future work could address these limitations by employing a longitudinal design to track changes over time and by recruiting more diverse samples.

Additionally, future research could explore the role of individual differences, such as personality traits, coping styles, and social support, in shaping the adaptation process during lockdown periods. Investigating the effectiveness of interventions designed to enhance resilience and well-being during pandemics and other public health crises is another promising avenue for future research. It is vital for public health agencies, organizations, and communities to develop and implement strategies that support individuals' well-being and foster resilience during the ongoing pandemic and future public health crises.

# 4 Conclusion

This study provides significant insight into the impact of the COVID-19 pandemic and related lockdown measures on the physical and mental health of urologists. It reveals that urologists of both genders have endured comparable levels of psychological distress, including stress, anxiety, frustration, uncertainty, and depressive symptoms. Significantly, our younger participants aged 25-45 demonstrated notably higher levels of anxiety and depression compared to their older colleagues. The study also found that the frequency of hospital visits directly correlated with increased psychiatric morbidity, likely due to the increased fear of potential COVID-19 exposure and the consequent risk posed to their families.

The lockdown period precipitated a reduction in structured exercise, due to gym closures and event cancellations, and a concurrent increase in consumption of ultra-processed food, which collectively contributed to weight gain among urologists. Furthermore, digital screen time and online gaming saw a marked increase during the lockdown. The findings suggest the necessity of implementing mental health outreach programs specifically tailored to the needs of the urology community, focusing particularly on supporting younger urologists who reported higher levels of anxiety and depression. It also calls upon hospital administrators to prioritize the safety of doctors by providing adequate personal protective equipment, thus alleviating fears of COVID-19 infection. In addition, the promotion of healthy eating habits, regular physical exercise, and outdoor activities could significantly improve the physical and mental well-being of urologists. The value of social support was underscored by the comfort urologists found in spending quality time with their families during the lockdown. In conclusion, this study provides critical insights into the mental and physical health implications of the COVID-19 pandemic on urologists, thereby highlighting the need for interventions designed to bolster the well-being of healthcare workers, particularly during crisis periods. Future research should delve into the long-term effects of the pandemic on the mental and physical health of urologists, with a focus on identifying effective strategies to mitigate the adverse impacts of such crises on healthcare professionals.

# Declaration of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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# Author Contribution

**BM Zeeshan Hameed**: Conceptualization, Methodology, Writing - original draft, Writing - review and editing, Supervision. **Ali Talyshinskii**: Data curation, Formal analysis, Investigation, Writing - review and editing. **Nithesh Naik**: Methodology, Project administration, Writing - review and editing. **Sufyan Ibrahim**: Data curation, Formal analysis, Investigation, Writing - review and editing. **Milap Shah**: Conceptualization, Methodology, Validation, Writing - review and editing. **Anshuman Singh**: Investigation, Methodology, Validation, Writing - review and editing. **Mohammad Mirahmadi Eraghi**: Conceptualization, Methodology, Validation, Writing - review and editing. **Dharini Prasad**: Data curation, Formal analysis, Writing - review and editing. **Mohammed Kamal Filli**: Investigation, Methodology, Validation, Writing - review and editing. **Nisha S Tatkar**: Data curation, Formal analysis, Writing - review and editing. **Piotr Chlosta**: Investigation, Methodology, Writing - review and editing. **Bhavan Prasad Rai**: Conceptualization, Methodology, Validation, Writing - review and editing.

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# Exploring the Potential of VGG-16 Architecture for Accurate Brain Tumor Detection Using Deep Learning

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**Abstract**

This study explores the potential of the VGG-16 architecture, a Convolutional Neural Network (CNN) model, for accurate brain tumor detection through deep learning. Utilizing a dataset consisting of 1655 brain MRI images with tumors and 1598 images without tumors, the VGG-16 model was fine-tuned and trained on this data. Initial training achieved an accuracy of 91%, which was improved to 94% after hyperparameter optimization. The model's sensitivity, specificity, precision, recall, and F1 scores were strong, indicating its potential in accurately detecting brain tumors. The performance of the VGG-16 model was compared to several other techniques for brain tumor detection, including EasyDL, GoogLeNet, GrayNet, ImageNet, CNN, and a Multivariable Regression and Neural Network model. Although it did not achieve the highest accuracy, it outperformed GoogLeNet and ImageNet and demonstrated comparable accuracy to GrayNet and the Multivariable Regression and Neural Network. Its sensitivity and specificity suggest its potential in identifying tumors that other methods might miss, reinforcing its potential usefulness in medical applications. Nevertheless, there is room for improvement. Future studies could collect and annotate larger datasets to improve model generalizability. Exploring other deep learning architectures and enhancing model interpretability could further boost its clinical relevance. Despite these challenges, this study demonstrates the untapped potential of the VGG-16 architecture in brain tumor detection and contributes to the growing body of research on applying deep learning in the medical field.

***Keywords:*** VGG-16 Architecture; Brain Tumor Detection; Deep Learning; Convolutional Neural Network (CNN); Accuracy

## 1 Introduction

Brain tumors, characterized by abnormal cell proliferation within the brain, pose a critical health challenge [1, 2]. As the brain is confined within the rigid skull, any undue expansion can lead to severe complications, making early and accurate detection vital for effective treatment [3–5].

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Traditionally, detection involved an expert examination of medical images, primarily magnetic resonance imaging (MRI) scans. However, this approach can be time-consuming and potentially lead to missed or incorrect diagnoses [6–8]. Deep Learning (DL), a subfield of machine learning, has emerged as a powerful tool showing significant promise in various domains, notably in image recognition and analysis. DL systems have the potential to reduce human effort significantly and have revolutionized many sectors, including healthcare. However, applying DL to MRI-based brain tumor detection presents challenges and limitations. These include issues related to image quality, high degrees of anatomical variations, and the need for domain-specific expert interpretation [9–13]. Overcoming these challenges is a significant factor that can dramatically influence the effectiveness and reliability of DL models and understanding these challenges is integral to the context of the current study. Figure 1 outlines the general architecture of a deep neural network.

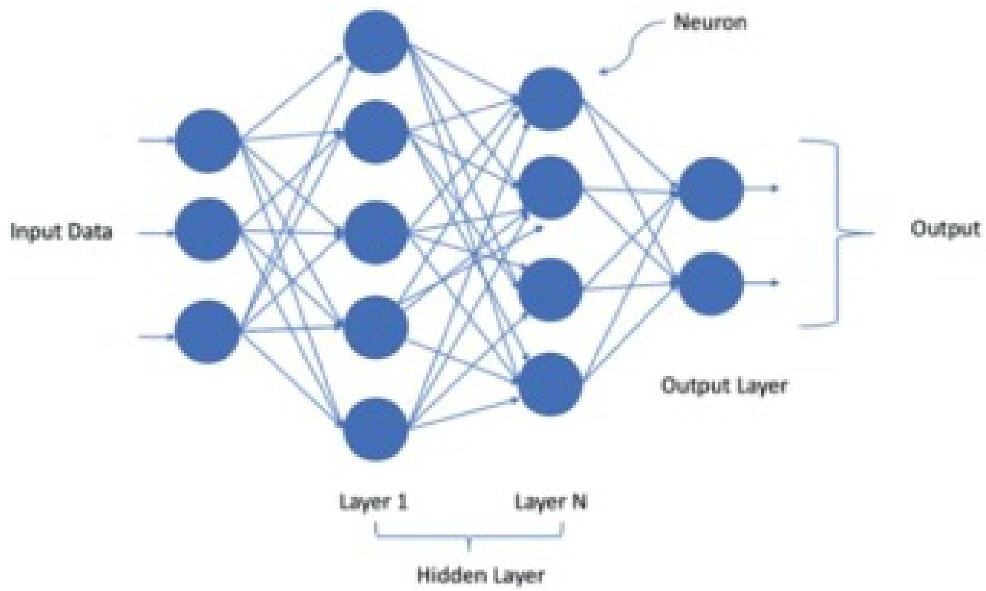



Figure 1: Deep neural network architecture [14].

While the potential advantages of the VGG-16 architecture in brain tumor detection are briefly mentioned in few of the earlier studies [15, 16], a more detailed context about the state-of-the-art models in this field is required. A comprehensive comparison of the VGG-16 architecture with these models will provide readers with a clearer perspective on our study's novelty and unique contributions. It would also explain why VGG-16 warrants exploration for brain tumor detection, considering its successful application in other image analysis tasks. In other words, the present study explores the untapped potential of the VGG-16 architecture, a Convolutional Neural Network (CNN) model, for accurate brain tumor detection through deep learning. By developing a model for diagnosing and detecting brain tumors using MRI images, the work aims to significantly reduce diagnosis time compared to conventional methods while ensuring high accuracy and efficiency.

## 2 Related Work

Deep learning techniques have been extensively employed in cancer/tumor detection, with numerous studies aiming to enhance their accuracy and efficiency. Each study, however, has unique aspects related to the type of cancer or tumor investigated, the deep learning techniques employed, the performance metrics used, and the datasets utilized. These variables might influence the generalizability of the models to other datasets. By grouping the studies based on specific cancer or tumor types and the deep learning technique used, we can discern commonalities and differences and understand their implications for our current study. Numerous studies have leveraged convolutional neural networks (CNN) for cancer/tumor detection and segmentation. For instance, Yang et al. [17] used EasyDL and GoogLeNet, achieving impressive detection efficiencies of 96.9% and 92.54% respectively. Similarly, Cha et al. [18] developed a deep learning CNN (DLCNN) to distinguish the interior and exterior of the bladder. However, these studies are limited by the size and type of datasets used, which might restrict the applicability of the models to more diverse datasets. Some studies employed other deep learning techniques. Lorencin et al. [19] used a Multi-Layer Perceptron (MLP) with a Laplacian edge detector, while Harmon et al. [20] employed a multivariable logistic regression and neural network model for prediction, achieving an accuracy of 95%. Despite these promising results, the potential generalizability of these models to other datasets requires further investigation. In terms of segmentation, Ma et al. [21] utilized deep learning frameworks, specifically, fully convolutional residual networks (FCRN) and U-Net based deep learning techniques (U-DL), respectively. They improved the segmentation of cancerous regions in medical images, illustrating the potential of deep learning for precise tumor localization. Deep learning techniques have also been used for classifying various types of cancer. Coudray et al. [22] used CNN to categorize whole-slide images of lung tissue with remarkable results. Similarly, Cruz-Roa et al. [23] and Bar et al. [24] employed deep learning algorithms for pathology identification, showcasing their potential in this domain. However, limitations in these studies, such as the size and specificity of the datasets used, may affect the generalizability of their models.

While previous studies demonstrate the potential of deep learning techniques in cancer/tumor detection, limitations regarding dataset size and diversity, and the specificity of the models developed, suggest a need for additional research. Understanding these limitations can help inform and refine the development of our VGG-16 architecture-based model for brain tumor detection using MRI images.

# 3 VGG-16 Architecture

## 3.1 Description of VGG-16 architecture

The VGG-16 architecture, also known as the Visual Geometry Group-16, is a deep learning model created by researchers at the University of Oxford [25]. This Convolutional Neural Network (CNN) is specifically designed for image recognition and classification tasks [26–28]. VGG-16 is renowned for its simplicity and relatively lower computational complexity compared to other deep learning architectures like ResNet and Inception [29]. The architecture consists of a total of 16 weight layers, including 13 convolutional layers, 3 fully connected layers, and 5 max-pooling layers [30].

## 3.2 The 16-layer structure

The VGG-16's 16-layer structure is organized hierarchically, with each layer building upon the features extracted from the preceding layer [31]. The input layer, which receives the input image data. This data is typically resized to a fixed dimension (e.g., $224 \times 224$ pixels) before being introduced to the network [32]. There are 13 convolutional layers, each responsible for extracting features from the input image using a series of filters or kernels. Each filter slides over the input data, performing element-wise multiplication and summation to generate a feature map. Notably, the convolutional layers in VGG-16 employ small 3×3 filters, enabling the network to learn more complex patterns with fewer parameters. Following each convolutional layer, an activation layer applies a Rectified Linear Unit (ReLU) activation function. This step introduces non-linearity into the model, allowing it to learn more intricate patterns. The architecture includes five pooling layers, which reduce the spatial dimensions of the feature maps, helping decrease computational complexity and control overfitting. VGG-16 uses max-pooling, which retains the maximum value within each pooling window. Lastly, there are three fully connected layers, which combine the features extracted from the previous layers and make the final predictions. The last of these fully connected layers utilizes a softmax activation function to output probabilities for each class [30, 33–36].

## 3.3 Convolution and pooling layers

The convolution and pooling layers are the foundational components of the VGG-16 architecture. They enable the network to learn hierarchical feature representations from the input image data [37, 38]. The convolution layers perform a pivotal role in the VGG-16 architecture by extracting features from the input images using a series of filters or kernels. These filters are small matrices with specific dimensions (e.g., 3×3), which slide across the input data, executing element-wise multiplication and summation with the underlying input data. The result is a feature map that provides a higher-level abstraction of the input image. Throughout the VGG-16 architecture, the convolution layers utilize small 3x3 filters. These filters allow the model to learn more complex patterns and hierarchical representations with fewer parameters than larger filter sizes would require. As the network progresses through multiple convolution layers, the filters learn to capture increasingly complex and abstract features. This hierarchical feature extraction process enables the model to discern intricate patterns within the images, contributing to its effectiveness in image recognition and classification tasks. The pooling layers have an essential role in reducing the spatial dimensions of the feature maps produced by the convolution layers. By down sampling the feature maps, the pooling layers decrease computational complexity and aid in controlling overfitting, thereby ensuring that the model generalizes well to unseen data. In the VGG-16 architecture, max-pooling is used in the pooling layers. Max-pooling operates by selecting the maximum value within each pooling window (e.g., 2x2) and discarding the remaining values. This operation effectively retains the most prominent features while reducing the size of the feature maps. Max-pooling is applied after specific convolution layers, resulting in a total of five pooling layers throughout the network [30, 33–36].

## 3.4 Advantages of Using VGG-16 architecture

The VGG-16 architecture offers numerous advantages when applied to image recognition and classification tasks.The simplicity of the VGG-16 architecture, facilitated by the use of small 3x3 filters and an uncomplicated architecture, makes it easy to understand and implement. Compared to other deep learning architectures, VGG-16 requires fewer parameters, which reduces the computational resources needed for training and inference, hence offering lower computational complexity. The pre-trained VGG-16 model can be fine-tuned for various tasks, allowing researchers to leverage the knowledge obtained from large-scale datasets like ImageNet and adapt it to specific applications with relatively smaller datasets. This is known as transfer learning. Finally, the hierarchical structure of the VGG-16 architecture allows the model to learn robust and discriminative feature representations, making it suitable for various image recognition and classification tasks, including medical image analysis [29, 30, 39].

# 4 Methodology

A comprehensive methodology is crucial for the successful implementation of the VGG-16 architecture for accurate brain tumor detection. The following sections detail the various steps involved in the process.

## 4.1 Dataset

The dataset used in this study consisted of Magnetic Resonance Imaging (MRI) scans of the brain, comprising 1655 images with tumors and 1598 images without tumors. It was diverse and represented various tumor types, sizes, and stages. The data was sourced from two publicly available online repositories, namely the Brain Tumor Dataset from the Cancer Imaging Archive (TCIA) and the Brain MRI Images for Brain Tumor Detection from Kaggle. The Cancer Imaging Archive (TCIA) is an open-access database that provides a large collection of medical images for research purposes. The specific dataset used from TCIA can be accessed at www.cancerimagingarchive.net. In addition, the Brain MRI Images for Brain Tumor Detection dataset from Kaggle, an open-source platform for predictive modelling and analytics competitions, was also used. The dataset can be accessed at www.kaggle.com. These databases offer curated datasets for research purposes, contributing to the robustness and diversity of our dataset.

Once obtained, the dataset was split into three subsets for training, validation, and testing, maintaining a ratio of 80:10:10, respectively. This separation ensured that the model could be trained and fine-tuned on a significant portion of the data, while also being evaluated fairly and independently on unseen data for validation and testing.

## 4.2 Implementation of VGG-16 architecture for brain tumor detection

### 4.2.1 Preprocessing

Preprocessing of MRI images is pivotal to ensure the effective learning capability of the VGG-16 model from the input data. The initial step in preprocessing medical image data involves cropping the extra regions from the MRI scans. To accomplish this, images were first blurred to soften well-defined boundaries. Subsequently, contours were identified using an inbuilt function such as cv2.findContours. Given that pixels are stored in array form, the extreme points of the region of interest were found using max and min functions. Any pixels falling outside this boundary were then eliminated. The subsequent step entails visualizing the data to evaluate the quality of the images and determine any further modifications required. A function was developed to display images from a specific folder, enabling the user to view random samples from the dataset. For instance, by invoking this function with the training set as a parameter and specifying the number of images 'n' as 30, the function would display 30 random images from the 'yes' and 'no' folders within the training dataset. Images were displayed in a grid format, also known as subplots. In this instance, a 10x3 subplot was created, but other configurations, such as 5x6, can also be employed. To acquire an approximate understanding of the dimensions of the cropped images, a histogram was generated. This visualization aided in determining whether or not the images required resizing. In most instances, images were not uniform in size and hence required resizing for computational purposes. Based on the histogram analysis, it was determined that the images required resizing. As a result, MRI scans were resized to dimensions of 224 x 224 pixels, compatible with the input requirements of the VGG-16 model. The resized images were then normalized to ensure a consistent range of pixel values. Finally, data augmentation techniques were employed to enhance the diversity of the training dataset and improve the model's generalization capabilities.

### 4.2.2 Transfer Learning

The VGG-16 model pretrained on a large-scale dataset, such as ImageNet, can be fine-tuned to adapt to the specific task of brain tumor detection. The final fully connected layer of the pretrained model should be replaced with a new layer that outputs the appropriate number of classes (e.g., tumor or no tumor). The model can then be trained on the labeled MRI scans using backpropagation and optimization algorithms, such as stochastic gradient descent or Adam. In this case, the model was trained on approximately 2500 images. Initially, the model was trained with 10 epochs and a batch size of 150, which took 17 cycles per epoch and 2 hours to train, achieving an accuracy of 91% on the training set. After tweaking the values, the number of epochs was increased to 11, and the batch size was adjusted to 250. This configuration took 10 cycles per epoch and 2 hours to train, resulting in an improved accuracy of 94% on the training set. A graph of the model's loss and accuracy versus the number of epochs was plotted, showing that the loss decreased and accuracy increased as the number of epochs increased, indicating that the model had learned effectively.

### 4.2.3 Fine tuning

The learning rate, batch size, and other hyperparameters should be tuned to optimize the model's performance. Regularization techniques, such as dropout or weight decay, can be employed to prevent overfitting. In this project, the batch size was fine-tuned to achieve better performance. When tested, the final model achieved an accuracy of 93

## 5 Evaluation of Model Performance

To evaluate the performance of a model, several metrics can be used. These metrics help to assess the model's effectiveness in predicting the correct outcomes and handling false positives and false negatives. A confusion matrix is a common tool for visualizing the performance of a model, as shown in Table 1.

Table 1: Confusion matrix

| | **Predicted Negative** | **Predicted Positive** |
|---|---|---|
| **Actual Negtive** | True Negative | False Positive |
| **Actual Positive** | False Negative | True Positive |

The confusion matrix consists of four components:

- **True Positives (TP)**: These represent the cases where both the actual and predicted class values are positive. For example, if the actual class value indicates that a passenger survived and the predicted class also indicates that the passenger survived.
- **True Negatives (TN)**: These represent the cases where both the actual and predicted class values are negative. For example, if the actual class value indicates that a passenger did not survive, and the predicted class also indicates that the passenger did not survive.
- **False Positives (FP)**: These occur when the actual class value is negative, and the predicted class value is positive. For example, if the actual class value indicates that a passenger did not survive, but the predicted class value indicates that the passenger survived.
- **False Negatives (FN)**: These occur when the actual class value is positive, and the predicted class value is negative. For example, if the actual class value indicates that a passenger survived, but the predicted class value indicates that the passenger did not survive.

Several performance metrics can be derived from the confusion matrix:

- **Accuracy**: The ratio of correctly predicted observations to all observations. It is a useful metric when the datasets have symmetric false positives and false negatives. The same is mathematically represented by Eq.1.

$$Accuracy = (TP + TN)/(TP + FP + FN + TN) \tag{1}$$

- **Precision**: The ratio of correctly predicted positive observations to total predicted positive observations. It is related to the false positive rate and mathematically represented by Eq.2.

$$Precision = TP/(TP + FP) \tag{2}$$

- **Recall (Sensitivity)**: The ratio of correctly predicted positive observations to the total observations in the actual class, which is mathematically represented by Eq.3.

$$Recall = TP/(TP + FN) \tag{3}$$

- **F1 Score** - The weighted average of Precision and Recall. It is more useful than accuracy when the class distribution is unequal, or when false positives and false negatives have different costs and is mathematically represented by Eq.4.

$$F1Score = 2(Recall \times Precision)/(Recall + Precision) \tag{4}$$

By analyzing these metrics, a better understanding of the model's performance and identify areas for improvement were gained in the present work.

## 6 Results and Discussion

### 6.1 Presentation of intermediate results

Figure 2 represents the obtained confusion matrix.The matrix was used to evaluate the VGG-16 model's performance in brain tumor detection using various metrics (discussed in the earlier sections) to assess its effectiveness. The intermediate results obtained for each metric is represented in Table 2. The performance of the VGG-16 model for brain tumor detection was thoroughly evaluated using a comprehensive set of metrics derived from a confusion matrix, including sensitivity, specificity, precision, recall, and the F1 score. The model exhibited a high sensitivity of 93.97%, indicating its robust ability to correctly identify cases with brain tumors. This implies that our model successfully detected approximately 94% of the positive cases from the total actual positive cases. This high level of sensitivity is particularly crucial in medical diagnostics, where failing to detect a condition, such as a tumor, could lead to severe consequences.

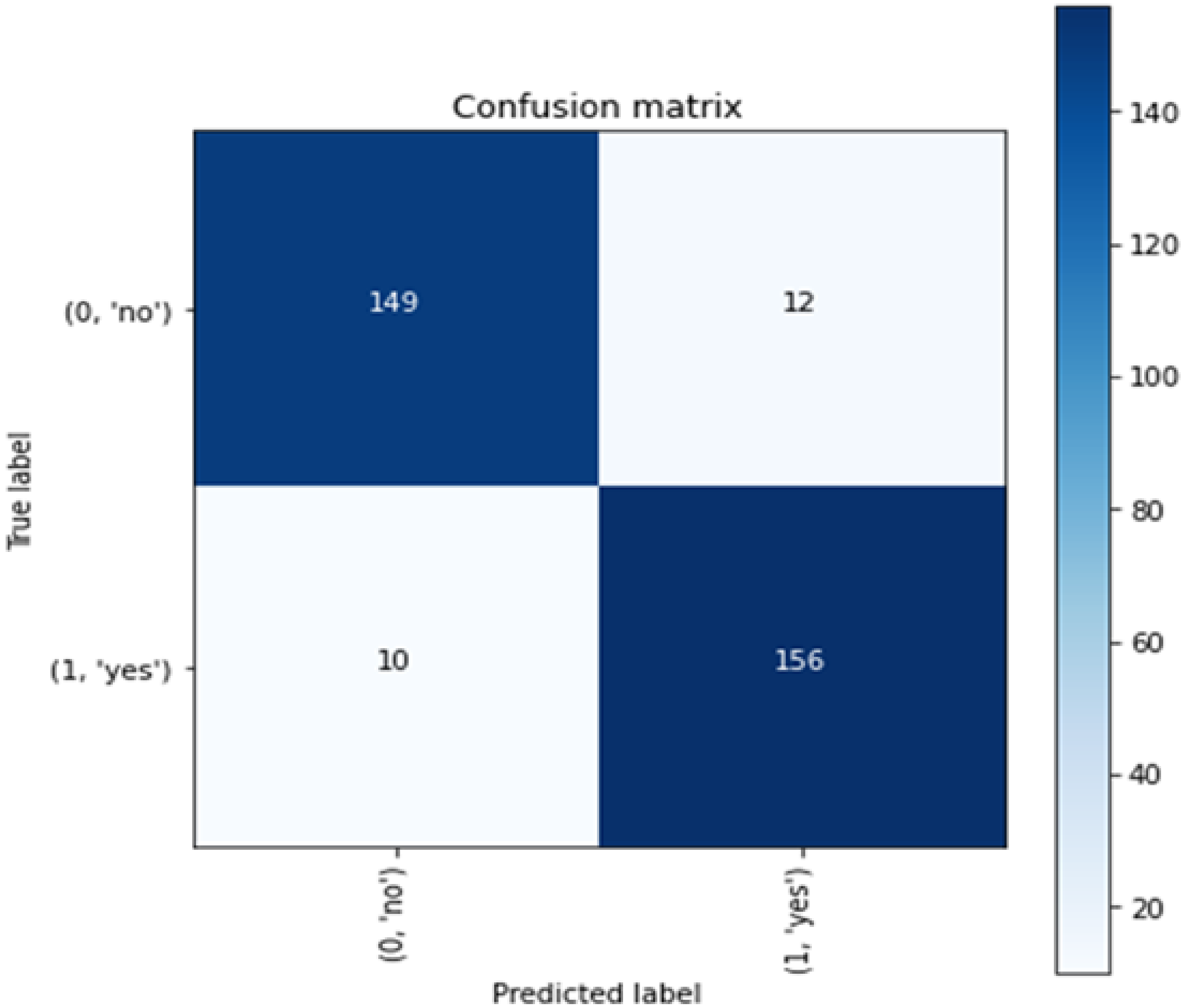
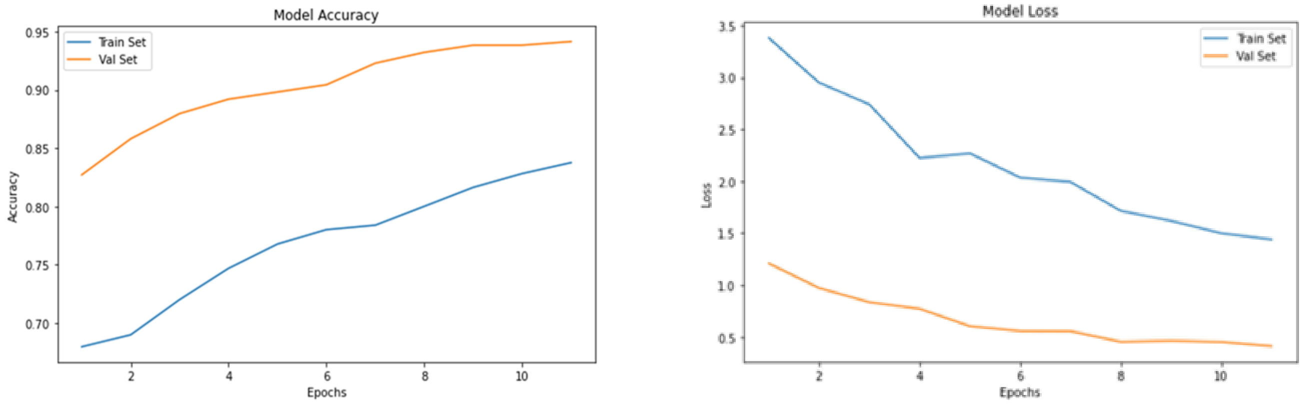



Figure 2: Confusion matrix obtained for the dataset

Furthermore, the model's specificity was recorded at 92.54%, reflecting its proficiency in accurately identifying negative cases, i.e., scans without tumors. This suggests that the model correctly classified about 93% of the actual negative cases, thus demonstrating its effectiveness in avoiding false positives. The precision score was another important metric used to evaluate the performance of our model. The precision score was found to be 93.28%, indicating that when our model predicted a positive case (presence of a tumor), it was correct approximately 93% of the time. This level of precision can greatly assist clinicians by providing reliable predictions, thus reducing the risk of false-positive diagnosis. The recall score, which is identical to sensitivity in binary classification problems, was found to be 93.27%, reiterating the model's strong ability to identify all actual positive cases accurately. Lastly, the F1 score, which represents the harmonic mean of precision and recall, was computed to be 93.27%. A high F1 score signifies a well-balanced model in terms of recall and precision, indicating that our model is neither excessively biased towards false positives nor false negatives. This balance is vital in ensuring a robust and reliable diagnostic model. From the obtained results, it could be inferred that the strong performance metrics demonstrated by our VGG-16 model suggest its significant potential for effective and reliable brain tumor detection from MRI scans. This success opens up avenues for further research into the application of deep learning architectures for medical diagnostic tasks. Future work could involve refining the model and validating its effectiveness on a larger, more diverse dataset, thus paving the way for a reliable, AI-assisted diagnostic tool in neurology.

Table 2: Model performance metrics

| **Metric** | **Value** |
|---|---|
| Sensitivity | 0.9397 |
| Specificity | 0.9254 |
| Precision score | 0.9328 |
| Recall score | 0.9327 |
| F1 Score | 0.9327 |




(a) (b)

Figure 3: Relationship between model performance (**a**) accuracy versus number of epochs; (**b**) model loss versus number of epochs.

Figure 3 delineate the relationship between model performance and the number of training epochs, offering essential insights into the learning dynamics of the machine learning model throughout the training phase. Figure 3 demonstrates that both the training and validation accuracy show a predominantly increasing trend with a growing number of epochs, a promising indication of the model's learning capability and its proficiency in generalizing unseen data. While there exist sporadic minor dips in the accuracy, they are negligible in the grand scheme of the training process due to the overarching upward trajectory. This progressive increase in accuracy suggests that the model strikes a healthy balance between learning and generalizing - it neither overfits to the training data nor underfits by failing to capture the necessary patterns. Nonetheless, continued observation is warranted until the accuracy for both training and validation sets attains a plateau or reaches a satisfactory threshold, which signifies the model's convergence. Figure 4 presents a mirror image of the preceding scenario - the model loss for both training and validation sets exhibits a steady decrease as the number of epochs progresses. This downward trajectory in loss underpins the efficacy of the model's learning strategy, signifying the minimization of discrepancies between the model's predictions and the actual targets. The dwindling model loss attests to the fact that, as the training unfolds across epochs, the model hones its prediction-making skills, leading to more precise outputs. In a nutshell, the overall performance of the model appears to be promising, shedding light on the potential of deep learning architectures in the domain of medical image analysis.

## 6.2 Comparison of VGG-16 model performance to existing techniques

To furnish a comprehensive understanding of the VGG-16 model's competitive standing in the realm of brain tumor detection, its accuracy was juxtaposed with several other established models. Table 3 elucidates this comparison with the respective accuracies of the models.

Table 3: Comparison of Model Accuracies

| Model | Accuracy |
|---|---|
| VGG-16 (my model) | 93% |
| EasyDL | 96.6% |
| GoogLeNet | 92.54% |
| GrayNet | 95% |
| ImageNet | 91% |
| CNN | 96% |
| Multivariable Regression and Neural Network | 95% |

Albeit not claiming the accolade of the most accurate model, the VGG-16 model's performance puts forth a strong competition. The model boasts superior accuracy than GoogLeNet and ImageNet, while demonstrating a performance on par with the likes of GrayNet and the Multivariable Regression and Neural Network model. This comparative examination underlines the considerable potential that the VGG-16 model embodies for the task of brain tumor detection. However, the pursuit of further enhancements remains imperative to either match or exceed the prowess of the top-tier models in the field.

# 7 Conclusion

The rising prominence of Convolutional Neural Networks (CNNs) has revolutionized image classification and segmentation across various fields. While designing a custom CNN is intricate due to decisions regarding layers, filter sizes, padding types, and more, pre-trained models like VGG-16 offer a powerful alternative. Despite its extensive use in other domains, its applicability in brain tumor detection remained unexplored, prompting this investigation. The VGG-16 model used in the present work demonstrated promising results, achieving a 93% accuracy rate in detecting brain tumors. Performance metrics including sensitivity, specificity, precision, recall, and F1 score further validated the model's efficacy. Compared to established techniques, the VGG-16 model showcased competitive performance—exceeding GoogLeNet, GrayNet, and ImageNet, albeit falling short of EasyDL and CNN. This underscores the potential of the VGG-16 architecture in brain tumor detection, necessitating further exploration. Looking ahead, the integration of CNNs in medical imaging signifies a significant stride in healthcare. As the field matures, more refined CNN models may facilitate superior diagnosis accuracy for brain tumors and other medical conditions. Delving into alternate imaging modalities, such as MRI and PET, might augment the detection precision further. There is also an exciting prospect in developing automated diagnostic and treatment systems using CNN models, which could profoundly transform the healthcare industry. In conclusion, this study substantiates the pivotal role of CNNs and pre-trained models like VGG-16 in medical image analysis. As research advances and these models are further refined, they hold the potential to revolutionize diagnosis and treatment accuracy in healthcare.

# Declaration of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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# Author Contribution

**Prerepa Gayathri**: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation; **Aiswarya Dhavileswarapu**: Data curation, Formal analysis, Investigation, Methodology, Software; **Sufyan Ibrahim**: Data curation, Formal analysis, Investigation, Methodology, writing: review and editing; **Rahul Paul**: Conceptualization, Methodology, Project administration, Supervision, Roles/writing: original draft, writing: review and editing; **Reena Gupta**: Conceptualization, Investigation, Resources, Supervision, writing: review and editing.

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# Mitigating Psychological Impacts of Quarantine During Pandemics: A Mini Review

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**Abstract**

The novel Coronavirus (COVID-19), originating in Wuhan, China in December 2019, quickly escalated into a global health crisis, infecting individuals across all strata of society. Declared a pandemic by the World Health Organization, this unprecedented emergency prompted governments worldwide to implement strict lockdowns and quarantine measures. The sudden onset of these procedures has had significant psychological effects on individuals and communities. This paper reviews the psychological impacts of prolonged quarantine and discusses adaptive stress-coping strategies to mitigate these effects. Our goal is to highlight effective approaches to manage mental health amidst such crises, aiming to provide guidance for future public health emergencies.

***Keywords:*** Pandemic; Psychological crisis intervention; Public mental health crisis; Quarantine; Emergency strategies

## 1 Introduction

The SARS-CoV-2 infection, commonly referred to as COVID-19, has emerged as a significant global health crisis. Though the pandemic's impact on physical health is well-documented, with over 23 million infections and approximately 900,000 fatalities across 213 countries and territories within ten months of its outbreak, its influence on mental health is also considerable [1, 2]. This mental health impact extends beyond infected individuals to include carriers and the uninfected population [3–5]. Strategies such as quarantine and isolation have long been employed to combat communicable diseases. Quarantine involves the restriction of individuals or groups exposed to infectious diseases from others who have not been exposed. In contrast, isolation entails separating those who have contracted a communicable disease for public health purposes, either voluntarily or by state order (Figure 1) [6, 7]. These terms are often used interchangeably [8].

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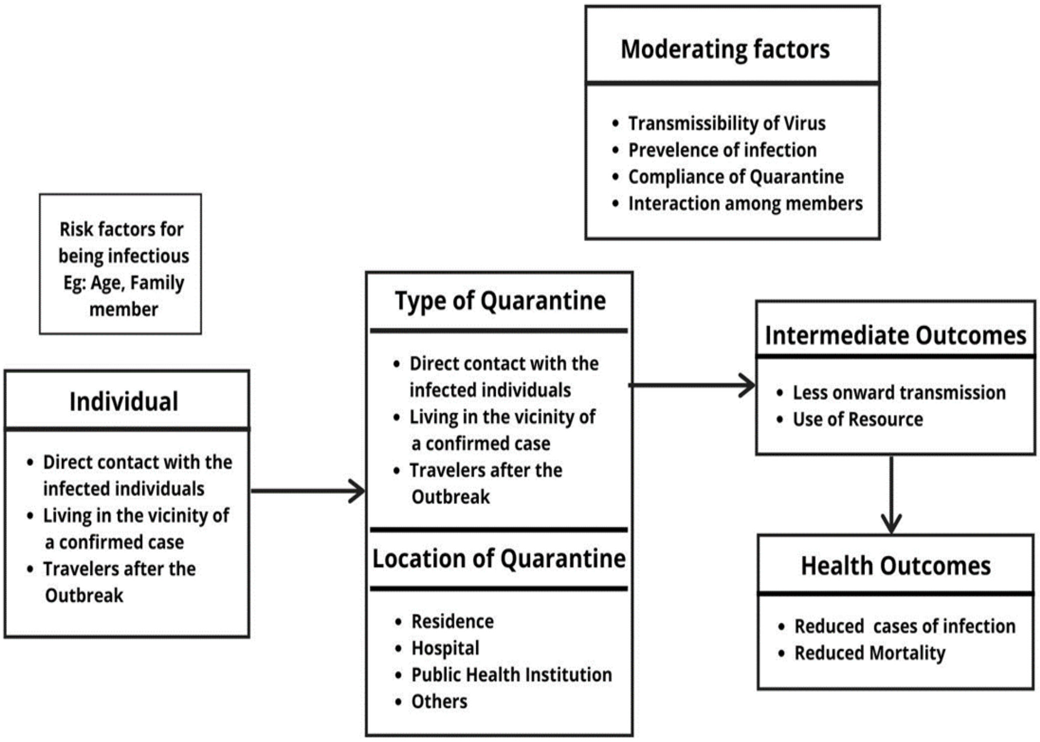


Figure 1: Isolation measures for communicable diseases.

Historically, 'quarantine' was first used in 1127 for leprosy cases in Italy and later in relation to the Black Death [9]. The COVID-19 outbreak has popularized a new term, 'social distancing,' which encourages maintaining physical distance and avoiding touching surfaces in public spaces to reduce virus exposure [10]. The highly infectious nature of COVID-19 led to an upsurge of acute infectious pneumonia cases across approximately 200 countries. The virus, originating from China, spread globally within a few months from December 2019. As of October 10, 2020, the pandemic has infected 37,135,041 individuals and caused 1,073,055 deaths across 217 countries, with these numbers still rapidly increasing [11]. To date, 27,910,257 individuals have recovered from COVID-19, and 8,151,729 active cases are undergoing treatment. The pandemic has induced substantial fear and widespread panic worldwide. The World Health Organization (WHO) has issued guidelines on preparedness, rapid case detection, and prevention of community transmission. These measures encompass providing supplies, technical expertise, and training. Worldwide lockdown policies advocating "work-from-home," "stay-at-home," and "social distancing" have been implemented. Many countries have suspended business activities, established individual quarantine facilities, equipped chronic ventilators, and halted all travel channels. They have also established local, provincial, and national health surveillance and response systems (Figure 2). While these measures are crucial in reducing COVID-19 infection rates, they present considerable challenges and contribute to increased psychological stress on individuals and communities. The ongoing pandemic, threatening countless lives and livelihoods, has created immense psychological pressure. Its incessant spread has resulted in prolonged closure of educational institutions, affecting the mental health of students [12]. Additional stressors, such as job insecurity, uncertainty over health status, separation from loved ones, and reduced social interactions, significantly impact mental health. COVID-19 has engendered a stigma, fostering suspicion and fear, even among close contacts. The spread of misinformation through social media exacerbates stress, leading to increased reports of depression, anxiety, and suicidal ideation. Therefore, it is crucial to conduct a cost-benefit analysis before implementing strict lockdown measures to minimize adverse effects [13].

## 2 Psychological Impact of Quarantine: Students and Healthcare Professionals

Quarantine and isolation are recognized as effective methods for restricting the spread of unknown diseases. However, authoritarian regulations isolating people from friends, family, and society can have detrimental effects [13]. With the alarming increase in Coronavirus cases, it is crucial that policymakers provide guidance to the public to mitigate panic [13, 14]. Several studies conducted during the Ebola, SARS, and swine flu outbreaks have extensively investigated the effects of quarantine on mental health, wellbeing, contributing factors, and the mitigation of psychological impacts. Most of these studies identified a pattern of increasing psychological disorders such as anxiety, depression, and confusion during pandemic outbreaks [15]. Strong evidence suggests that lack of contact with loved ones escalates anxiety levels within the population [16]. A study conducted in 194 different cities in China involving 1210 respondents indicated that 54% were experiencing mental health issues, with 29% exhibiting mild to severe anxiety symptoms and 17% demonstrating serious depressive symptoms, clearly illustrating that COVID-19 is causing specific mental health problems [17]. Therefore, attention should be given to community mental health to prevent fear, anxiety, and other concerning conditions [18]. All communities, including undergraduate students, working professionals, and healthcare workers, have reported negative responses like fear, anxiety, sadness, and guilt, according to previous studies' outcomes.

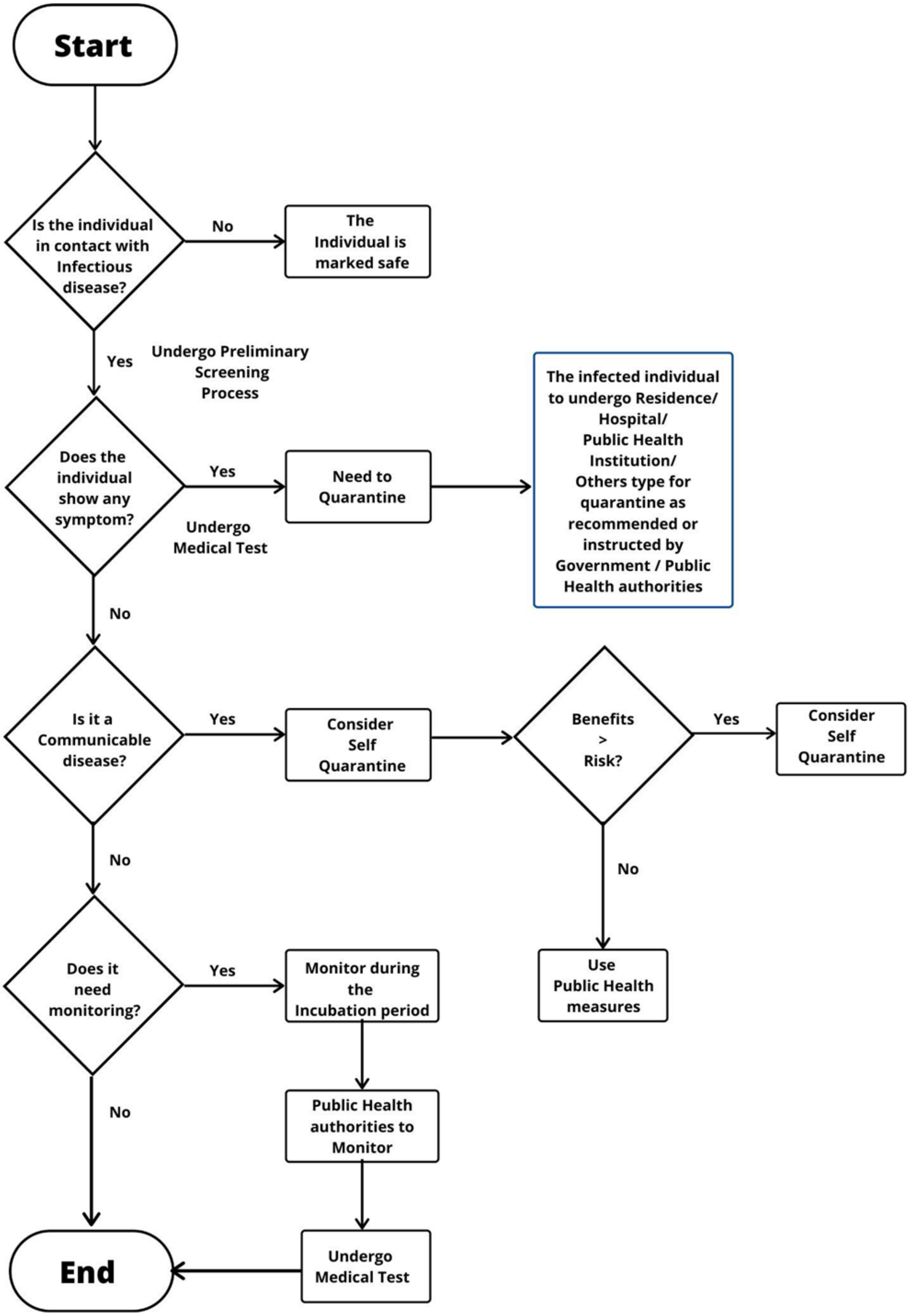


Figure 2: Flowchart for Managing Symptomatic Travelers During Pandemic: A Step-by-Step Guide to Preventing the Spread of Infectious Diseases.

Qualitative studies on quarantined students identified a range of psychological effects of quarantine, such as confusion, fear, anger, grief, numbness, and anxiety-induced insomnia [19–25]. If a person is already suffering from depression, emotional exhaustion, and lack of control, forced quarantine can exacerbate these conditions. With educational institutions closed for months, confinement to a small space is inducing anxiety among students. Students with suicidal ideation or tendencies can be particularly at risk under these circumstances. Research comparing anxiety symptoms in quarantined parents and students with non-quarantined individuals found that post-traumatic stress cases were significantly higher in quarantined students [25, 26]. Meanwhile, quarantined healthcare professionals reported fatigue, detachment, distress, irritability, sleeplessness, impaired concentration and indecisiveness, worsening work conditions, and reluctance to work or consideration of resignation. Symptoms of PTSD and acute depression, often triggered by close contact with infected individuals, were prevalent among healthcare professionals [27]. During the SARS outbreak, a survey conducted on hospital staff infected with the virus and quarantined for nine days found that prolonged quarantine exacerbated stress disorders [28].

# 3 Mitigation of Psychological Effects

During the pandemic, there are definitive strategies to enhance emotional wellbeing and to shield oneself and loved ones from psychological distress. Different individuals manage stress in diverse ways. Governments worldwide are actively running campaigns and counseling on nCOVID-19 to control community transmission. However, there has been insufficient reflection on the psychological impacts of quarantine, job stability, and reducing fear among quarantined individuals. Table 1 provides detailed characteristics of studies conducted during the SARS pandemic, focusing on stress associations. Social media can only partially alleviate the impact of quarantine; it can't replace the lack of physical interaction. Here are some methods to mitigate the psychological effects[29, 30]:

- Keep the quarantine period short and scientifically justified.
- Provide up-to-date information. This transparency ensures that those quarantined understand the severity of the situation and the purpose of quarantine.
- Ensure adequate supplies are provided, and additional resources are available for emergencies.
- Decrease boredom and improve communication through virtual engagement programs.
- Offer clear instructions on stress management and provide continuous assurance that better days are ahead. Public health officials should be clear about actions taken for symptomatic individuals.
- The elderly need to support their children during this traumatic period, reassuring them and encouraging calmness and composure.
- With schools closed, children may feel isolated, bored, and develop certain fears. Parents should engage them in activities and discussions about the virus and encourage reading or storytelling.

The COVID-19 pandemic is having a profound psychological impact on society's mental health as people grapple with isolated living, unprecedented uncertainty, and drastic lifestyle changes. Emotions such as sadness, frustration, disappointment, restlessness, indecisiveness, and lethargy can affect a range of psychological functions. Depression can result from prolonged isolation and the confined environment of lockdown, impacting self-esteem and confidence [31]. Various thoughts based on perceptions, perspectives, and beliefs can lead to mixed feelings. Preventative measures include enhancing self-esteem and confidence by highlighting the positive aspects of the situation and resources available to overcome current difficulties. Verbal assurance can provide hope to those feeling hopeless, practical help can combat feelings of helplessness, and self-worth can be nurtured to prevent feelings of worthlessness. Treatment options include counseling, antidepressant medication, psychotherapy, and electroconvulsive therapy (ECT). Early identification of psychological disorders, treatment by specialized doctors, follow-up care by trained health workers, and community support are essential. Motivational speakers can offer lectures on emotional skills involving self-awareness, self-regulation, motivation, empathy, happiness, and social skills. In cooperation with police and NGOs, it's crucial to establish well-publicized helplines offering a range of services from counseling to shelter and medical support. Access to transportation, specialized psychological support, and other essential services can help resolve psychosocial and mental health issues. The sudden unavailability of alcohol after the lockdown has led to severe withdrawal symptoms and an increase in domestic violence incidents and self-harm attempts globally. According to the International Labour Organization (ILO), the current crisis may result in the loss of over 200 million full-time jobs worldwide in various sectors within the next three months. The power of positive thinking techniques can cultivate better emotional health, happiness, and productivity. Concerns about future security, job retention, financial constraints, and strained interpersonal relationships exist. nCOVID-19 could change the world of work, allowing more remote work options in the future. A lasting solution to the unemployment epidemic must be sought by examining its various aspects. One must remain optimistic and hopeful while behaving responsibly. High-speed scientific research and large-scale studies on the long-term mental health consequences of the economic impact of the epidemic are essential and should be coordinated, comprehensive, and targeted to yield meaningful results.

Table 1: A Summary of studies investigating the psychological impacts and outcomes of quarantine.

| Author & Year | Country | Design | Participants | Quarantine Period | Measures & Outcomes |
|---|---|---|---|---|---|
| Bai et al. (2004) [16] | Taiwan | Cross-sectional | 338 Hospital staff | 9 days | Investigation into acute stress disorder and emotional changes during the SARS survey. Reports of stigma and workforce attrition. |
| Blendon et al. (2004) [18] | Canada | Cross-sectional | 501 Canadian residents | Unclear | Research indicates substantial psychological and economic effects of the SARS epidemic despite low population spread. Successful attempts to inform the public about SARS. |
| Cava et al. (2005) [19] | Canada | Qualitative | 21 Toronto residents | 5 to 10 days | Interviews reveal dual role of public health in compliance monitoring and care for quarantined patients. Implications for future public health crises planning. |
| DiGiovanni et al. (2004) [20] | Canada | Mixed methods | 1509 Toronto residents | Variable | Compliance tracking and reputation found to be impactful. Significance of clear policies and processes across jurisdictions noted. |
| Hawryluck et al. (2004) [26] | Canada | Cross-sectional | 129 Toronto residents | 10 days | High prevalence of psychological distress among quarantined individuals reported. |
| Lee et al. (2005) [32] | Hong Kong, China | Mixed methods | 903 individuals, 856 undiagnosed | Unclear | Stigmatization observed in various aspects of life such as labor, interpersonal relations, and services. |
| Liu et al. (2012) [33] | China | Cross-sectional | 549 hospital employees, 104 quarantined | Unclear | Risk increase of depressive symptoms observed after 3 years. Altruistic risk acceptance found to minimize post-outbreak depressive symptoms. |
| Marjanovic et al. (2007) [34] | Canada | Cross-sectional | 333 nurses | Unclear | Significant relationships found between psychosocial and working conditions and burnout/stress. Model for lower avoidance behaviors, emotional exhaustion developed. |
| Maunder et al. (2003) [35] | Canada | Observational | Health care professionals | 10 days | Effects of quarantine and contagion on families and friends reported. Anxiety, frustration, and insomnia prevalent. |
| Mihashi et al. (2009) [36] | China | Retrospective cross-sectional | 187 workers, faculty, students | Unclear | Predictive factors for onset of mental disorders observed. Mass isolation risk control variables showed a low association with manifestation of psychological illness. |
| Pan et al. (2005) [23] | Taiwan | Observational | 12 college students | Unclear | Alienation and isolation issues common among quarantined students. |
| Reynolds et al. (2008) [37] | Canada | Cross-sectional | 1057 cases | 2 to 30 days | Increased psychological distress, including PTSD symptoms among healthcare workers reported. |
| Sprang and Silman (2013) [27] | USA and Canada | Cross-sectional | 398 parents | Unclear | Trauma observed in children and parents due to interventions like quarantine and isolation. |
| Wu et al. (2009) [28] | China | Cross-sectional | 549 hospital employees | Unclear | About 10% exhibited elevated levels of post-traumatic stress symptoms (PTS) post-SARS outbreak. Public's views of such incidents can mediate the psychological effect of traumatic changes. |

# 4 Methods to Strengthen Mental Health During the Quarantine

## 4.1 Establishing routines

Cultivating the discipline harkening back to pre-quarantine days is essential. The laid-back, work-from-home lifestyle can trigger negative thinking due to a stagnant environment. Make a point to eat meals timely, ensure a balanced sleep routine without oversleeping, and create an exercise schedule. Approach it one day at a time. Implementing these strategies can facilitate adjustment to the outside world and acclimation to the new lifestyle.

## 4.2 Limit screen time

Undeniably, work, study, and remote learning have increased screen time, which isn't beneficial for the body as it can affect vision and memory. Hence, it's important to take regular breaks when using screens, and moderate overall screen time [38].

## 4.3 Self-care & limited media

Invest time in self-care activities: shift your perspective from "I am stuck inside" to "I can finally focus on my home and myself". Home workouts, meditation, and yoga can provide stress relief during quarantine. Cultivating a positive attitude through conscious engagement in productive activities is crucial for stress management. Utilize this period to tackle previously sidelined goals, create a quarantine routine, and indulge in hobbies [34]. Perceiving quarantine as a trap intensifies stress. Instead, try slowing down and focusing on personal needs. Stay informed but not overwhelmed: In times of uncertainty, it's essential to stay informed without succumbing to anxiety. Avoid overexposure to news, particularly negative reports, which can create a sense of panic. Always seek information from reliable sources to evade the panic triggered by fake news. Trustworthy sources include the Centers for Disease Control and Prevention (CDC), World Health Organization (WHO), state and local health departments, and your doctor [39].

## 4.4 Stock nonperishable supplies

Consider purchasing extra canned food and daily provisions to reduce store visits. The National Alliance on Mental Illness recommends asking doctors for extended prescriptions to cover long-term supplies, thereby minimizing the frequency of leaving home (https://www.nami.org/Blogs/NAMI-Blog/March-2020/Coronavirus-Mental-Health-Coping-Strategies).

## 4.5 Take it day-by-day

A sense of purpose stems from setting and achieving goals. Aiming for a few activities each day and checking them off the list can bolster confidence. Remember, you are not alone in this situation and you can still reach your full potential even amidst a pandemic. Life in quarantine can be particularly challenging for individuals with pre-existing conditions. Balancing restrictions and allowances should be an ongoing process, with strategies updated to consider the psychological effects of long-term quarantine. Stringent measures such as social distancing, controlled public movement, and regulating long-distance public transportation are vital public health strategies in controlling the COVID-19 outbreak and preventing community spread. The global economy is under significant strain, and efforts to restore it must be enacted swiftly as poverty rates soar. With over 37 million confirmed cases globally, the COVID-19 outbreak is reaching record numbers. Countries worldwide are united in their fight to find a cure or at least reduce community spread and contain the disease. Several damage control measures have been undertaken, but based on current knowledge about the virus, testing, contact tracing, quarantine, and isolation remain the most effective methods for reducing the virus's spread. As of now, most countries have lifted lockdowns and people have resumed their regular lives. To avoid quarantine and isolation, safety measures at workplaces must be implemented by authorities, and individuals should adhere to precautions such as wearing face masks and frequent hand washing [40].

# 5 Conclusion

The COVID-19 pandemic has induced an unprecedented level of anxiety and stress that is poorly recorded due to current limitations. It's imperative to sharply focus on the mental health issues arising from prolonged periods of isolation, lockdown, and quarantine. Implementing measures such as offering round-the-clock counseling services, destigmatizing mental health issues, and facilitating effective communication from political and scientific leaders can help mitigate the adverse effects of such societal seclusion. Early implementation of quarantine measures, alongside other recommendations from the World Health Organization, is critical to ensuring their effectiveness. However, quarantining, which essentially deprives people of their liberty for the greater public good, is often contentious and has its limitations. If quarantine is deemed necessary, our findings suggest that officials should make every effort to ensure this experience is as tolerable as possible for those who must endure extended periods of quarantine. This will mitigate the psychological toll and foster greater compliance with public health directives.

## Declaration of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Author Contribution

**BM Zeeshan Hameed**: Conceptualization, Investigation, Methodology, Writing - review and editing; **Mohammad Mirahmadi Eraghi**: Data curation, Formal analysis, Investigation, Methodology, Writing - original draft, Writing - review and editing; **Mohammed Kamal Filli**: Data curation, Formal analysis, Investigation, Methodology, Writing - review and editing; **Sambit Dash**: Investigation, Methodology, Validation, Writing - review and editing; **Sufyan Ibrahim**: Conceptualization, Investigation, Methodology, Writing - original draft, Writing - review and editing.; **Mrudula Chandrika**: Investigation, Methodology, Validation, Writing - review and editing; **Sharmila Jajodia**: Data curation, Formal analysis, Investigation, Methodology, Writing - review and editing.

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# A Mini Review of Natural Cellulosic Fibers: Extraction, Treatment and Characterization Methods

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**Abstract**

Natural cellulosic fibers have garnered significant attention in recent years due to their potential as eco-friendly and sustainable alternatives to synthetic materials in various industries, such as composite reinforcement, textiles, and packaging. The successful utilization of these fibers depends on understanding their properties, which can be achieved through comprehensive characterization methods. This mini-review discusses the extraction, treatment, and characterization of natural cellulosic fibers, focusing on the latest advancements in these areas. The extraction methods of natural cellulosic fibers, including chemical, physical, and biological processes, are discussed. The choice of extraction method impacts the fiber's morphology, crystallinity, and purity, which ultimately affects its performance in different applications. Surface modification methods, including chemical treatments like treatment, acetylation, silane treatment, grafting, bleaching, and physical treatments such as corona treatment, plasma treatment, and UV/ozone treatment, are also explored. These treatments can enhance the compatibility and performance of natural cellulosic fibers in various applications. Characterization techniques for natural cellulosic fibers are reviewed, including mechanical properties testing (tensile strength, flexural strength, and impact strength), morphological analysis (scanning electron microscopy (SEM) and transmission electron microscopy (TEM)), and advanced techniques such as atomic force microscopy (AFM), confocal Raman spectroscopy, and X-ray photoelectron spectroscopy (XPS). Furthermore, the application of the Weibull distribution for analyzing the tensile strength of natural cellulosic fibers is discussed, providing valuable information on the fiber's strength distribution and reliability. This review highlights the importance of comprehensive characterization methods in understanding the properties and potential applications of natural cellulosic fibers. The continued development of these techniques will be crucial for the advancement and commercialization of these sustainable materials as eco-friendly alternatives to traditional materials in a wide range of industries.

***Keywords:*** Natural Fibers; Extraction Methods; Surface Modification; Characterization Techniques; Sustainable Materials

## 1 Introduction

The demand for sustainable, environmentally friendly materials has driven the exploration of natural fibers as potential alternatives to synthetic fibers in composite materials. Due to their biodegradability, abundance, low density, recyclability, sustainability, non-toxicity, non-corrosiveness, eco-friendliness, and low carbon emissions, natural fibers are identified as viable replacements for petroleum-based fiber-reinforced composites [1–4]. Natural fibers are obtained from various parts of plants, such as stems, leaves, bark, roots, fruits, and seeds. Researchers have examined different plant fibers like banana, hemp, sisal, coir, and bamboo for reinforcement in polymer composites. Recent studies have explored the suitability of fibers such as Sansevieria cylindrica, Sansevieria ehrenbergii, Prosopis juliflora, Indian mallow, Saharan Aloe vera, Furcraea foetida, Thespesia populnea, aerial roots of banyan trees, red banana peduncle, Calotropis gigantea, and Leucas Aspera [5–19].

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The final properties of polymer composites depend on the resin's nature, fiber alignment, and bonding between the fiber and matrix [20]. Researchers have extracted fibers from various parts of the banana plant, including the stem, while banana peduncles are often discarded as waste. To utilize this waste more beneficially, recent studies have focused on extracting, treating, and characterizing natural fibers from the banana peduncle, particularly from the Nendran Banana Peduncle (NBP). The properties of natural fibers depend on their source, harvesting method, and processing techniques. Therefore, it is essential to characterize natural fibers and understand their properties to enhance their performance as a reinforcement in composite materials. Natural fibers have gained increasing interest as a reinforcement in composite materials due to their unique properties, such as biodegradability, low cost, low density, high strength, and renewability [1–3, 5]. Using natural fibers in composite materials can reduce the environmental impact by replacing synthetic fibers, which are derived from non-renewable resources and have a high carbon footprint. Various fibers, including those derived from plants like bamboo, hemp, sisal, coir, and jute, and those derived from animal sources such as wool and silk, have been investigated for potential use in composite materials. The mechanical properties of natural fibers vary depending on their source and processing methods [21, 8–10]. Despite the potential advantages of using natural fibers in composite materials, challenges exist. One main challenge is achieving good fiber-matrix adhesion, essential for transferring stresses between the fiber and matrix and ensuring the mechanical integrity of the composite material. Natural fibers also have inherent variability in their properties, which can make it difficult to achieve consistent properties in composite materials. Utilizing natural cellulosic fibers offers several advantages over synthetic fibers, including renewability, biodegradability, and low environmental impact, making them promising candidates for sustainable and eco-friendly composite materials. Recent advances in extraction, treatment, and characterization methods have enhanced the properties of natural fibers, leading to the production of eco-friendly composite materials. The appropriate utilization of natural cellulosic fibers can play a significant role in sustainable development by reducing the dependence on petroleum-based products and minimizing environmental pollution. THe various techniques employed in the extraction, treatment, and characterization methods for natural cellulosic fibers have led to the production of eco-friendly composite materials with improved properties. Researchers have explored various extraction methods, including enzymatic extraction, microwave-assisted extraction, and ultrasonic-assisted extraction. Similarly, recent advances in treatment methods, such as plasma treatment, nanocellulose modification, surface modification, and functionalization, have enhanced fiber-matrix adhesion and compatibility between fibers and the polymer matrix. Additionally, recent advances in characterization methods, including in-situ characterization, multi-scale characterization, and computational modeling, have improved our understanding of the physical, chemical, and mechanical properties of natural fibers [22, 23]. Physical properties such as density, moisture content, and fiber diameter affect the composite material's overall properties. Chemical properties, including chemical composition, functional groups, and degree of polymerization, determine fiber-matrix adhesion and compatibility between fibers and the polymer matrix. Furthermore, mechanical properties such as tensile strength, stiffness, and elongation at break affect the composite material's strength and durability [22–25]. Table 1 shows the physical and mechanical properties of different natural fibers [26].

Table 1: Physical and Mechanical properties of natural fibers [26] .

| Name of the fiber | Diameter ($\mu$m) | Length (mm) | Density (kg/mm$^3$) | Moisture gain (%) | Tensile strength (MPa) | Young's modulus (GPa) | Failure strain (%) |
|---|---|---|---|---|---|---|---|
| Abca | 18.2 | 4.9 | 1500 | 14 | 12 | 41 | 3.4 |
| Alfa | - | - | 890 | - | 350 | 22 | 5.8 |
| Bagasse | 20 | 1.7 | 900 | - | 290 | 17 | - |
| Banana | - | 2.9 | 1325 | - | 721.5 | 29 | 2 |
| Bamboo | 25 | 2 | 1500 | - | 575 | 27 | - |
| Coir | 17.5 | 1.25 | 1250 | 13 | 140.5 | 6 | 27.5 |
| Cotton | 14.5 | 42 | 1550 | 8.59 | 500 | 8 | 7 |
| Curaua | - | - | 1400 | - | 825 | 9 | 7.5 |
| Flax | 20 | 31.75 | 1450 | 12 | 700 | 60 | 2.3 |
| Hemp | 19.9 | 11.2 | 1200 | - | 530 | 45 | 3 |
| Isora | - | - | 1200 | 1.2 | 550 | - | 5.5 |
| Jute | 18.4 | 2.55 | 1400 | 17 | 325 | 37.5 | 2.5 |
| Kapok | 25 | 20 | 384 | 10.9 | 93.3 | 4 | 1.2 |
| Kenaf | 19.8 | 2.35 | 1300 | 17 | 743 | 41 | - |
| Piassava | - | - | 1400 | - | 138.5 | 2.83 | 5 |
| Pineapple | 50 | - | 1540 | - | 1020 | 71 | 0.8 |
| Ramie | 31.55 | 160 | 1550 | 8.5 | 925 | 23 | 3.7 |
| Sisal | 21 | 2.5 | 1400 | 14 | 460 | 15.5 | - |

Characterizing natural fibers is crucial for understanding their properties and potential as reinforcement in composite materials. Various techniques have been developed for the characterization of natural fibers, including microscopy, spectroscopy, thermal analysis, and mechanical testing. Microscopy techniques such as scanning electron microscopy (SEM) and optical microscopy are commonly used to analyze fibers' morphological features, including fiber diameter, shape, and surface morphology. Spectroscopy techniques, such as Fourier transform infrared spectroscopy (FTIR) and nuclear magnetic resonance (NMR) spectroscopy, are used to identify fibers' functional groups and determine their chemical composition.

Thermal analysis techniques, such as thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC), are employed to analyze fibers' thermal stability and degradation behavior. Mechanical testing techniques, including tensile testing and flexural testing, are used to determine fibers' mechanical properties [22, 24, 25, 27, 28]. Understanding natural fibers' properties and characteristics is essential for enhancing their performance as reinforcement in composite materials. Further research and development in this field will provide opportunities for creating sustainable and eco-friendly materials with improved properties. However, challenges associated with their use, such as achieving good fiber-matrix adhesion and dealing with inherent variability in fiber properties, must be addressed to fully realize their potential in composite materials. Thus, this mini-review article provides an overview of the techniques used in extraction, treatment, and characterization methods, while discussing the physical, chemical, and mechanical properties of various natural fibers.

# 2 Extraction Methods of Natural Cellulosic Fibers

The extraction of natural cellulosic fibers from plant material is an important process for their characterization and utilization in various applications. Recent research has explored different extraction processes for natural cellulosic fibers. The extraction process for natural cellulosic fibers depends on the plant source and the desired fiber properties [29]. Here are some commonly used methods:

## 2.1 Chemical extraction

Chemical extraction involves the use of chemicals such as alkalis or acids to break down the plant material and isolate the fibers. The fibers are then washed and treated with bleaching agents to remove impurities. Chemical extraction is a common method for isolating cellulose fibers from various plant sources, such as cotton, flax, and hemp [30, 31].

## 2.2 Physical extraction

Physical extraction involves the mechanical separation of cellulose fibers from other plant components. This can be achieved through various methods such as retting, decortication, and steam explosion. Retting is a process in which plant material is soaked in water to allow microbial degradation of non-cellulosic components, followed by mechanical separation of the cellulose fibers. Decortication involves the removal of the outer layer of the plant material to expose the cellulose fibers, which are then mechanically separated. Steam explosion involves the use of high-pressure steam to break down the lignin and hemicellulose components of the plant material, leaving behind the cellulose fibers [32–35].

## 2.3 Biological extraction

Biological extraction involves the use of microorganisms to break down the non-cellulosic components of the plant material. This process is known as bio-pulping and has the potential to be a more environmentally friendly alternative to chemical pulping [36–39]. The microorganisms used for bio-pulping include fungi and bacteria. Fungi such as Trichoderma reesei and Phanerochaete chrysosporium are commonly used for bio-pulping. These microorganisms produce enzymes that break down the lignin and hemicellulose components of the plant material, leaving behind the cellulose fibers [40, 41].

# 3 Chemical and Physical Property Determination

## 3.1 Chemical properties

Various chemical methods can be used to analyze the chemical composition of natural cellulosic fibers and determine the amounts of lignin, hemicellulose, and cellulose. These include:

- **Acid-base titration:** This method involves the use of acid and base solutions to determine the amount of hemicellulose, lignin, and cellulose in the fibers. The fibers are first treated with a strong acid to remove hemicellulose, followed by treatment with a strong base to remove lignin. The remaining residue is cellulose, which is weighed to determine its amount [42].
- **Spectrophotometry:** This method involves the use of a spectrophotometer to determine the amount of lignin in the fibers. The fibers are treated with a reagent that reacts with lignin to form a colored compound. The color intensity is then measured using a spectrophotometer, and the lignin content is calculated from a standard calibration curve [43, 44].
- **Gravimetric analysis:** This method involves the determination of the weight of the fibers and the weight of the ash remaining after burning the fibers at high temperatures. The weight of the ash represents the amount of non-cellulosic components in the fibers, such as hemicellulose, lignin, and minerals [45].
- **Elemental analysis:** This method involves the determination of the elemental composition of the fibers using techniques such as X-ray fluorescence (XRF) or inductively coupled plasma-optical emission spectroscopy (ICP-OES). Elemental analysis can provide information on the number of minerals and trace elements present in the fibers [46–48].

- **High-performance liquid chromatography (HPLC):** This powerful analytical technique has been used to study the chemical composition of natural cellulosic fibers. HPLC separates and identifies individual chemical components present in a sample based on their chemical and physical properties. One primary application of HPLC in natural cellulosic fibers is to analyze the monosaccharide composition of the fibers. HPLC can be used to analyze the individual glucose units in the fiber and to quantify the percentage of different monosaccharides present. This information can be used to understand the chemical composition and properties of the fibers [49–52].

- **Wax content determination:** The wax content of the fiber can be evaluated using the Conrad method [53], which involves the following steps:

  - **Extraction of wax:** A known weight of the fiber is boiled in a mixture of equal parts of ethanol and ether for a specific duration. The solvent mixture dissolves the wax from the fiber and extracts it into the solvent.
  - **Filtration:** The solvent extract is then filtered through a filter paper to remove any insoluble impurities.
  - Evaporation: The filtered solvent extract is then evaporated in a pre-weighed dish under a vacuum to remove the solvent and leave behind the extracted wax.
  - **Weighing:** The dish with the extracted wax is then re-weighed to determine the weight of the extracted wax. The difference between the weight of the dish with extracted wax and the weight of the dish before extraction gives the weight of the extracted wax.
  - **Calculation of wax content:** The wax content of the fiber is calculated by dividing the weight of the extracted wax by the weight of the original fiber sample and multiplying the result by 100. This gives the percentage of wax in the fiber.

- **C (CP-MAS) nuclear magnetic resonance (NMR) spectroscopy analysis**: Solid-state nuclear magnetic resonance (NMR) spectroscopy is a powerful technique for studying the chemical structure and properties of natural cellulosic fibers. It can be used to analyze the degree of polymerization of cellulose chains, which is the number of repeating units in a polymer chain and can affect the physical and mechanical properties of the fibers. NMR spectroscopy can provide information about the average degree of polymerization of cellulose in the fibers, which can be used to estimate their properties. To perform solid-state NMR spectroscopy on the fibers, a magic angle sample spinner (MAS) is used, along with a 10 KHz rate and a frequency of 75.46 MHz, at room temperature. Here's a general procedure for analyzing natural fibers using NMR spectroscopy [54–57]:

  - **Sample preparation:** The natural fiber sample is first washed with a suitable solvent to remove any impurities and then dried and ground into a fine powder.
  - **Dissolution:** The fiber sample is then dissolved in a suitable solvent, such as dimethyl sulfoxide (DMSO) or deuterated dimethyl sulfoxide (DMSO-d6), to make a concentrated solution.
  - NMR spectrometer setup: The NMR spectrometer is calibrated and set up to analyze the sample. The sample is placed in an NMR tube and inserted into the spectrometer.
  - **Spectral acquisition:** The NMR spectrometer is used to acquire the spectrum of the fiber sample. The spectrum is recorded by varying the magnetic field strength and radio frequency and measuring the energy absorbed and emitted by the sample.
  - Data analysis: The NMR spectrum is analyzed to determine the chemical shifts and peak intensities of the various components of the sample. The chemical shifts can provide information about the molecular structure of the fiber, including the types of chemical bonds present and their spatial arrangements.
  - **Interpretation of results:** The NMR data is interpreted to gain insights into the molecular structure and properties of the natural fiber. For example, the degree of crystallinity, molecular orientation, and chemical modifications can be determined using NMR spectroscopy.

  Using NMR spectroscopy, researchers can gain a better understanding of the chemical structure and properties of natural cellulosic fibers, which can help in developing new applications and improving existing ones.

## 3.2 Physical properties

### 3.2.1 Fiber Diameter Measurement

The average diameter of the fiber is measured generally using an optical microscope [58]. The measurement is made for a minimum of 25 fiber samples. Measurements should be made randomly along the fiber at several locations. The Weibull distribution statistical analysis is mostly used to examine the likelihood of the fiber average diameter. [59–61].

### 3.2.2 Density Measurement

The density of the fiber is generally measured using a pycnometer [62, 63]. For the first five days, natural cellulosic fibers should be placed in silica-packed desiccators to remove the moisture from the fibers. Following that, they should be chopped into pieces no larger than 5 mm and put in the machine. Before starting the experiment, the fibers are to be immersed in a toluene-filled container for roughly 2 hours to remove any microbubbles from the fibers. The density of fibers ($\rho$) was obtained through the Eqs [1] and [2]:

$$\rho = \frac{m}{V} \tag{1}$$

where $m$ is the mass of the fiber and $V$ is the volume of the pycnometer.

$$\rho_{BF} = \frac{m_2 - m_1}{(m_3 - m_1) - (m_4 - m_2)} \rho_T \tag{2}$$

# 4 Surface Modification Methods

The natural cellulosic fibers extracted from plant material often require treatment to modify their surface properties and enhance their compatibility with various matrices for improved performance in different applications. The treatment could be chemical or physical.

## 4.1 Chemical treatment

Recent research has explored various chemical treatment processes for natural cellulosic fibers. Chemical treatments can modify the surface properties of natural cellulosic fibers to improve their performance in various applications [29]. Here are some commonly used chemical treatment processes:

### 4.1.1 Alkali treatment

This process involves treating the fibers with alkalis, such as sodium hydroxide or potassium hydroxide, to remove impurities and increase the fiber's surface area. The treatment also introduces hydroxyl groups on the fiber surface, which can improve the fiber's hydrophilicity and reactivity. Alkali chemical treatment is a common method used to modify the properties of natural cellulosic fibers. The treatment involves soaking the fibers in a solution of strong alkalies, such as sodium hydroxide (NaOH), for a specific period. The alkali breaks down the hemicellulose and lignin components in the fiber, leaving behind a more pure form of cellulose. This process is known as mercerization. The alkali treatment can result in various modifications to the properties of the natural cellulosic fibers. The treatment can lead to an increase in the fiber's tensile strength, elongation at break, and stiffness. The treatment can also result in changes in the fiber's surface morphology, as well as its chemical and physical properties. The extent of the modification can be controlled by adjusting the concentration and duration of the alkali treatment. Higher concentrations of alkali and longer treatment times result in more significant modifications to the fiber's properties [64, 65].

### 4.1.2 Acetylation

Acetylation chemical treatment is a widely used method for modifying the properties of natural cellulosic fibers. The treatment involves the reaction of cellulose with an acetylating agent, such as acetic anhydride or acetic acid, in the presence of a catalyst. This results in the substitution of some of the hydroxyl groups on the cellulose chain with acetyl groups. The acetylation treatment can result in various modifications to the properties of natural cellulosic fibers. The treatment can lead to an increase in the fiber's water resistance, dimensional stability, and thermal stability. The treatment can also result in changes in the fiber's surface morphology, as well as its chemical and physical properties. The extent of the modification can be controlled by adjusting the concentration and duration of the acetylation treatment. Higher concentrations of acetylating agents and longer treatment times result in more significant modifications to the fiber's properties [66, 66].

### 4.1.3 Silane treatment

Silane treatment is a method used to modify the surface properties of natural cellulosic fibers. The treatment involves the reaction of the fiber with a silane coupling agent, such as 3-glycidoxypropyltrimethoxysilane (GPTMS), in a solvent, followed by drying and curing. The silane treatment can result in various modifications to the properties of natural cellulosic fibers. The treatment can lead to an increase in the fiber's hydrophobicity, as well as changes in its surface morphology and chemical properties. The coupling agent chemically bonds to the hydroxyl groups on the fiber surface, resulting in the formation of a siloxane layer on the fiber surface. The extent of the modification can be controlled by adjusting the concentration and duration of the silane treatment. Higher concentrations of coupling agents and longer treatment times result in more significant modifications to the fiber's properties [67, 68].

#### 4.1.4 Grafting

Grafting treatment is a process used to modify the surface properties of natural cellulosic fibers by introducing polymer chains onto the fiber surface. The process involves the chemical bonding of monomers or polymers onto the fiber surface via covalent bonds, resulting in the formation of a polymer layer on the fiber surface. The grafting process can be carried out using various techniques, such as radiation-induced grafting, chemical grafting, and enzymatic grafting. The choice of technique depends on the specific properties required for the fibers and the intended application. The grafting process can lead to various modifications in the properties of natural cellulosic fibers, such as increased hydrophobicity, improved mechanical properties, and enhanced thermal stability. The properties of the grafting layer can be controlled by adjusting the type and concentration of monomers or polymers used, as well as the reaction conditions [69–71].

#### 4.1.5 Bleaching

Bleaching is a common chemical treatment used to modify the properties of natural cellulosic fibers, such as cotton, bamboo, and hemp [72]. The process involves the removal of impurities, such as lignin and hemicellulose, and the brightening of the fiber's color [73, 74]. Bleaching treatment is carried out using various chemical agents, such as hydrogen peroxide, sodium hypochlorite, and chlorine dioxide [75]. The choice of bleaching agent depends on the specific requirements of the fiber and the intended application. The bleaching process can lead to various modifications in the properties of natural cellulosic fibers, such as an increase in brightness, improved dyeability, and enhanced mechanical properties. However, bleaching can also weaken the fibers if not carried out properly. The extent of the modification depends on various factors, such as the type and concentration of the bleaching agent, the duration of the treatment, and the temperature and pH of the treatment [76]. However, there are concerns about the environmental impact of the chemicals used in the process, and efforts are being made to develop more sustainable alternatives [77]. One alternative to traditional bleaching methods is the use of eco-friendly bleaching agents, which have a lower environmental impact. Another approach is the use of enzymatic bleaching, which utilizes enzymes to remove impurities from the fibers, without the need for harsh chemicals. Enzymatic bleaching has shown promising results in terms of improving the properties of natural cellulosic fibers while reducing the environmental impact of the process [78–81]. Overall, chemical treatment plays a critical role in modifying the properties of natural cellulosic fibers, making them more suitable for various applications. However, it is important to consider the environmental impact of the chemical processes used, and efforts should be made to develop more sustainable and eco-friendly methods.

### 4.2 Physical treatment

Physical treatments can also be used to modify the surface of natural cellulosic fibers to improve their compatibility with other materials or enhance their properties. These methods often provide an environmentally friendly alternative to chemical treatments [82]. Some common physical treatment methods include corona treatment, plasma treatment, and UV/ozone treatment [32].

#### 4.2.1 Corona treatment

Corona treatment is an electrical discharge process that involves applying high voltage to an electrode placed near the surface of the fibers. This results in the formation of a corona discharge, which generates reactive species such as ozone and other oxygen-containing compounds. These reactive species modify the surface of the fibers by introducing polar groups, thus increasing their surface energy and enhancing their adhesion to polymer matrices. Corona treatment is a fast and effective method for improving the interfacial bonding between natural fibers and various polymer matrices [32, 83, 84].

#### 4.2.2 Plasma treatment

Plasma treatment involves the use of low-pressure, non-thermal plasma to modify the surface of natural cellulosic fibers. The plasma is generated by applying an electric field to a gas (such as oxygen, nitrogen, or argon) at low pressure, which results in the formation of reactive species. These reactive species interact with the surface of the fibers, leading to the introduction of functional groups, surface etching, or crosslinking. Plasma treatment can significantly improve the surface properties of natural fibers, including wettability, adhesion, and chemical resistance. This method is considered environmentally friendly, as it does not require the use of hazardous chemicals [85–88].

#### 4.2.3 UV/Ozone treatment

UV/ozone treatment is a photochemical process that utilizes ultraviolet (UV) radiation in the presence of ozone to modify the surface of natural cellulosic fibers [89, 90]. The UV radiation generates highly reactive ozone molecules, which react with the fiber surface, introducing polar groups such as hydroxyl, carbonyl, and carboxyl groups. These functional groups increase the surface energy of the fibers and improve their compatibility with polymer matrices. UV/ozone treatment is an environmentally friendly method that can be easily implemented for large-scale production [89, 91–94].

# 5 Characterization Techniques

## 5.1 Mechanical properties

Mechanical properties are crucial factors in determining the performance of natural cellulosic fibers in various applications, such as reinforcing composites, textiles, and packaging materials. These properties include tensile strength, flexural strength, and impact strength, which can be evaluated using standardized testing techniques [95–97].

### 5.1.1 Tensile strength testing

Tensile strength is a measure of a material's ability to withstand tension or pulling forces. Tensile strength testing involves applying a uniaxial tensile force to a fiber or a fiber bundle until it breaks. This test is typically performed using a universal testing machine (UTM) equipped with suitable grips and a load cell to measure the force applied. The tensile strength is calculated by dividing the maximum load by the initial cross-sectional area of the fiber or bundle. The results provide insights into the fiber's potential to reinforce composite materials and its performance in textile applications [98–101].

### 5.1.2 Flexural strength testing

Flexural strength, also known as bending strength, is an indicator of a material's ability to resist deformation under bending loads. Flexural strength testing is performed using a three-point or four-point bending test setup, in which a fiber-reinforced composite specimen is subjected to bending by applying a load at one or two points while supported at two or three points, respectively. The flexural strength is calculated by dividing the maximum bending load by the initial cross-sectional area of the specimen. This test is particularly useful for evaluating the performance of natural fiber-reinforced composites in applications where bending loads are expected [98–101].

### 5.1.3 Impact strength testing

Impact strength is a measure of a material's ability to absorb energy during sudden impacts or shocks. Impact strength testing is typically performed using an Izod or Charpy impact tester, in which a pendulum with a known mass and velocity strikes a notched specimen. The energy absorbed by the specimen during fracture is calculated from the difference in the pendulum's initial and final potential energy. Impact strength testing is critical for understanding the performance of natural fiber-reinforced composites in applications where they may be subjected to impact loads or dynamic forces [98–101].

## 5.2 Morphological analysis

Morphological analysis techniques, such as scanning electron microscopy (SEM) and transmission electron microscopy (TEM), are vital for understanding the structure and surface characteristics of natural cellulosic fibers, which can greatly influence their properties and performance in various applications [102].

### 5.2.1 Scanning Electron Microscopy (SEM)

SEM is a widely used technique for investigating the surface morphology and microstructure of natural cellulosic fibers. SEM utilizes a focused electron beam to scan the fiber surface, generating secondary and back scattered electrons that are collected to form high-resolution images. The SEM technique not only allows for the visualization of fiber surfaces, defects, and the fiber-matrix interface in composite materials, providing valuable insights into the fiber's processing, treatment, and performance but also helps one to investigate the effect of morphology on the mechanical properties of the material. Several researchers to date have used SEM images for detailed learning of natural fiber's morphological structure. One such example is depicted in Figure 1, wherein the researchers utilized the obtained SEM images to comprehensively investigate the effect of morphological structure of various available natural fiber on their tensile properties [103].

### 5.2.2 Transmission Electron Microscopy (TEM)

TEM is a powerful technique for characterizing the internal structure of natural cellulosic fibers at the nanoscale. In TEM, a high-energy electron beam is transmitted through an ultra-thin specimen, and the resulting interactions between the electrons and the specimen's atoms are used to form high-resolution images. TEM enables the visualization of the internal structure of fibers, including the arrangement and orientation of cellulose microfibrils and the presence of other components such as hemicellulose and lignin. This information is essential for understanding the relationship between the fiber's internal structure and its mechanical, thermal, and chemical properties. An example of TEM image used by a set of researchers who investigated the effect of silver nanoparticles in cotton fiber is depicted in Figure 2 [104].

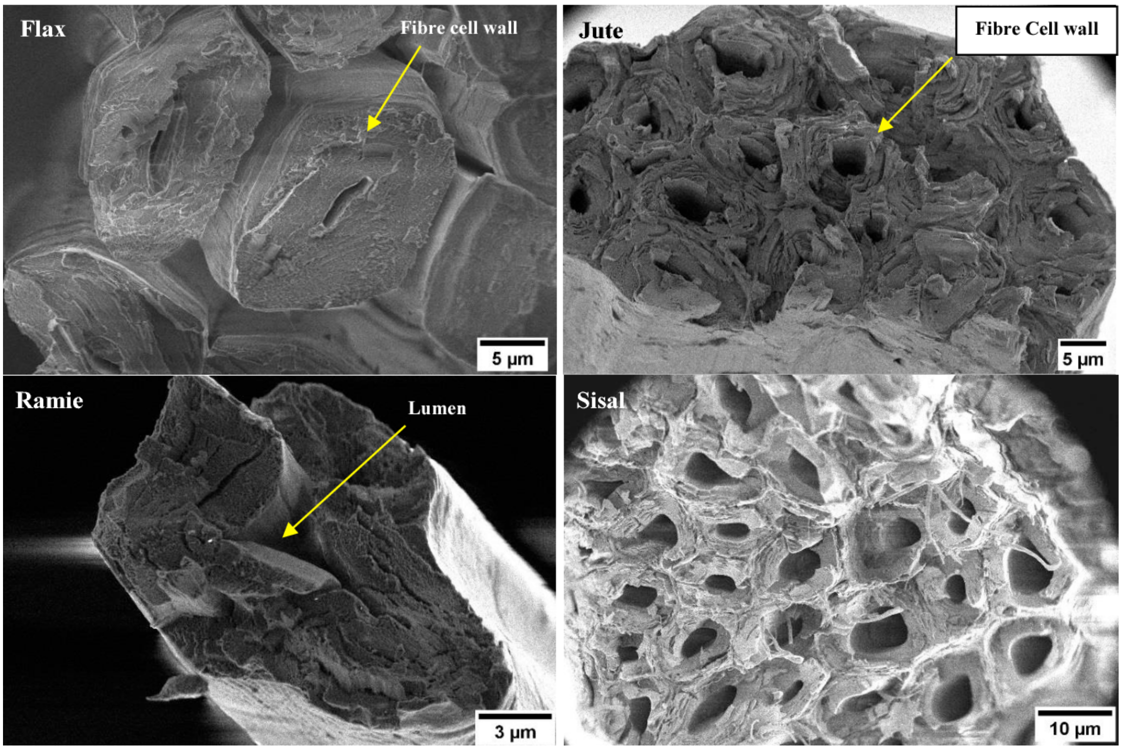


Figure 1: SEM images of the cross section of various natural fibers [103].

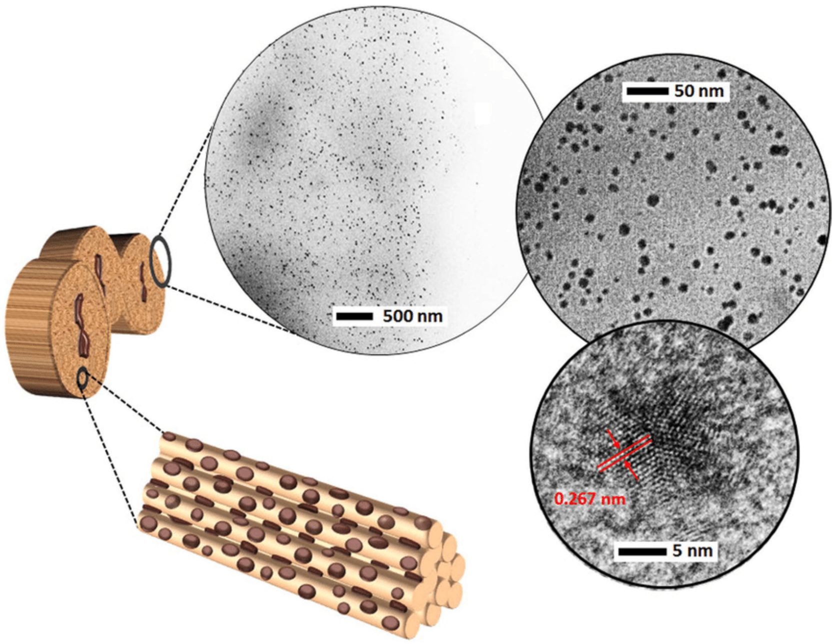


Figure 2: TEM image representing cross-section of silver-cotton nanocomposite fiber[104].

### 5.3 Fourier Transform Infrared Spectroscopy (FTIR) Analysis

Fourier Transform Infrared Spectroscopy (FTIR) analysis is a powerful technique used to study the chemical structure and composition of natural cellulosic fibers. FTIR can detect the presence of chemical functional groups in fibers, such as hydroxyl, carbonyl, and ether groups, which can affect their properties, including their reactivity and adhesion to other materials. FTIR is commonly used in recent research papers to investigate the functional groups and molecular vibrations of various natural cellulosic fibers. An infrared spectrometer with a Fourier transform can be used to create an infrared absorption spectrum in the frequency range between 500 $cm^{-1}$ and 4000 $cm^{-1}$ in total reflectance mode. The FTIR spectrum is obtained by scanning the fibers at a resolution of 4 $cm^{-1}$ and a scan rate of 32 scans. Figure 3 shows the FTIR spectra of some natural fibers as summarized by Guimares et al. [105]. The general procedure for FTIR analysis of natural fibers includes sample preparation, instrument setup, data acquisition, data analysis, and interpretation of results. The natural fiber sample is prepared by grinding it into a fine powder and pressing it into a thin, flat pellet. The pellet is then placed onto the sample holder for FTIR analysis.

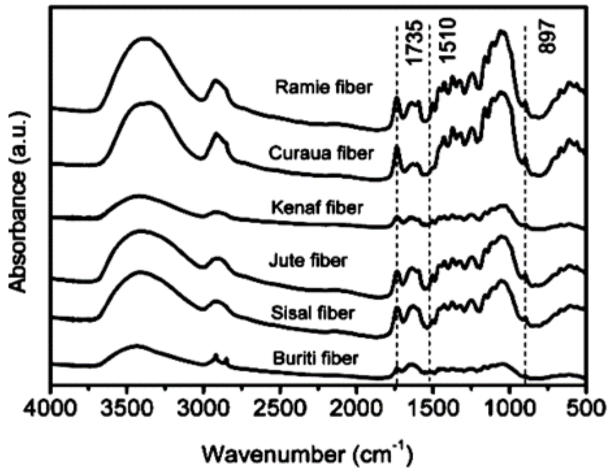


Figure 3: FTIR spectra of Ramie, Curaua, Kenaf, Jute, Sisal, and Buriti fibers [105].

The FTIR instrument is calibrated and set up for analysis of the fiber sample. The appropriate IR source is selected, and the instrument is adjusted to the desired resolution and range. The FTIR instrument is used to collect infrared spectra from the fiber sample. A background spectrum is recorded before the sample is analyzed. The sample is then scanned, and the absorbance or transmittance of the IR radiation is measured at each wavelength. The FTIR spectrum is analyzed to determine the chemical structure and composition of the natural fiber. The peaks in the spectrum are identified and compared to reference spectra to identify functional groups and chemical bonds present in the sample. The FTIR data is interpreted to gain insights into the chemical structure and composition of the natural fiber. For example, FTIR can be used to study the effects of chemical treatments or environmental conditions on the fiber structure and composition [106–108].

### 5.4 X-ray diffraction (XRD) analysis

X-ray diffraction (XRD) is a widely used technique for investigating the crystalline structure of natural cellulosic fibers. By measuring the diffraction of X-rays by the atoms in the fiber's crystal lattice, XRD can provide information on the degree of crystallinity, crystal size, and crystal structure of the fibers. To perform XRD analysis of natural fibers, the fibers are first ground into a fine powder and pressed into a thin, flat pellet. The pellet is then placed onto the sample holder of the XRD instrument, which is calibrated and adjusted to the desired resolution and range. The XRD instrument is then used to collect X-ray diffraction patterns from the fiber sample. The sample is scanned over a range of angles while the intensity of the diffracted X-rays is measured. The XRD pattern is then analyzed to determine the crystalline structure of the natural fiber. The diffraction peaks are identified and compared to reference patterns to determine the crystal structure and size of the fiber. XRD data can provide insights into the crystalline structure and properties of natural fibers, such as the effects of chemical treatments or environmental conditions on the fiber's crystal structure and degree of crystallinity. Figure 4 shows XRD patterns of fibers from banana, sugarcane bagasse, and sponge gourd obtained by a set of researchers who intended to investigate the structure and crystallinity indices of various plant fibers [105].

### 5.5 Evaluation of Crystalline Index (CI) and Crystallite Size (CS)

The degree of crystallinity in natural cellulosic fibers can be determined by calculating the crystalline index (CI) using the peak height method [109, 110]. The empirical equation [111] shown in Eq [3] can be used to calculate the CI.

$$\mathrm{CI} = \frac{I_{200} - I_{\mathrm{AM}}}{I_{200}} \tag{3}$$

Here, $I_{200}$ refers to the maximum intensity of the 200 lattice plane at $2\theta$ angle between 22° and 23°, and $I_{\mathrm{AM}}$ represents the amount of noncrystalline or amorphous material measured by the height of the valley of the minimum between the peaks, at an angle of $2\theta$ about 18°. The crystallite size (CS) of natural cellulosic fibers can be determined using Scherrer's formula [71] as shown in Eq [4]:

$$\mathrm{CS}_{200} = \frac{k\lambda}{\beta_{200}\cos\theta} \tag{4}$$

Here, $k = 0.89$ is the Scherrer's constant, $\lambda = 0.1541$ nm is the wavelength of the radiation, $\beta_{200}$ refers to the peak's full width at half-maximum in radians, and $\theta$ indicates the corresponding Bragg angle.

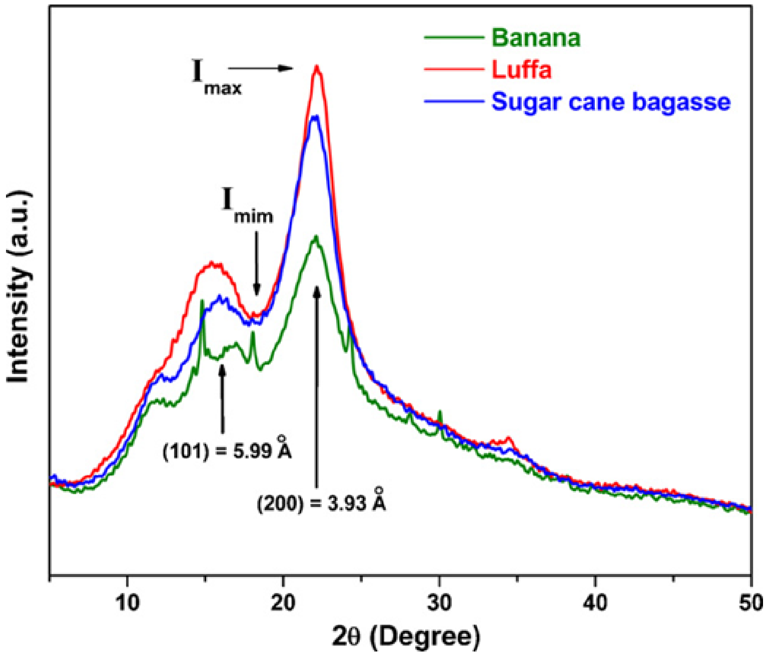


Figure 4: X-ray diffraction patterns of various plant fibers [105].

### 5.6 Atomic force microscopy (AFM) analysis

Atomic force microscopy (AFM) is a powerful technique used to study the morphology and physical properties of natural cellulosic fibers at the nanoscale. AFM analysis can be performed using an AFM instrument with image processing software to assess the roughness of natural cellulosic fibers. The surface roughness parameters, such as average surface roughness ($S_a$), Root mean square roughness ($S_q$ or $S_{rms}$), Ten points average roughness ($S_z$), skewness ($S_{sk}$), and kurtosis ($S_{ku}$), can be determined. The resolution range of the scanner scale in the x, y, and direction is set to 10 $\mu$m × 10 $\mu$m × 70 $\mu$m. AFM has been used to study the surface morphology, topography, and mechanical properties of cellulosic fibers in recent research papers. The high-resolution images of the fiber surface provided by AFM can reveal details such as fiber diameter, roughness, and surface defects. These features can affect the fiber's mechanical and physical properties, and studying them can help to understand the performance of the fibers in various applications [23]. To perform AFM microscopy analysis of natural fibers, the sample is first washed with a suitable solvent to remove any impurities and then mounted onto a suitable substrate for AFM imaging. The AFM is calibrated and set up for imaging of the sample. The AFM probe is brought into contact with the sample, and the tip-sample interaction is measured to provide a topographic image of the sample surface. The AFM tip is scanned across the sample surface to obtain a topographic image of the fiber. The AFM can provide information on the surface roughness, fiber diameter, fiber cross-section, and surface morphology of the fiber. In addition to topographic imaging, AFM can also be used to measure the mechanical properties of the fiber, such as stiffness, adhesion, and elasticity. This is achieved by applying a known force to the AFM tip and measuring the resulting deformation of the fiber. The AFM images and force measurements are analyzed to determine the morphology and physical properties of the natural fiber. For example, the fiber diameter, length, and orientation can be determined from the AFM images, while the mechanical properties can be determined from the force measurements. AFM data is interpreted to gain insights into the morphology and physical properties of the natural fiber. For example, AFM can be used to study the effects of chemical treatments or environmental conditions on fiber morphology and properties. Figure represents an AFM image used by set of researchers to investigate the effect of chemical (NaOH) treatment on the sisal fibers at different scan sizes [26].

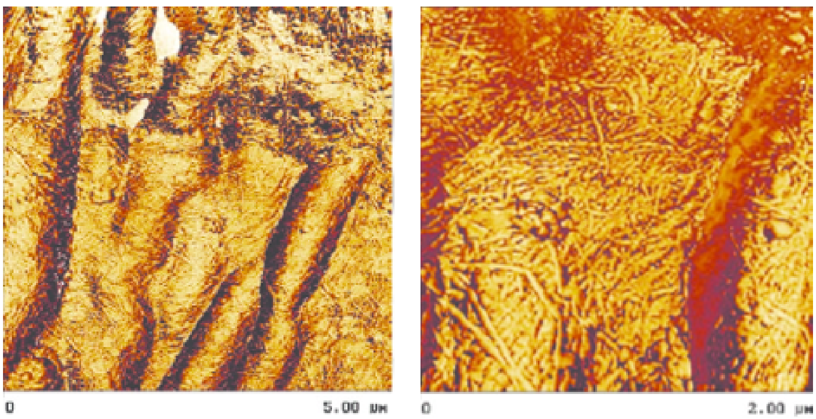


Figure 5: AFM images of NaOH treated sisal fiber at scan size of 5 and 2 microns [26].

# 6 Conclusion

In conclusion, the methods and techniques for characterizing natural cellulosic fibers have developed substantially, offering a more comprehensive understanding of their properties and potential uses. The extraction processes play a crucial role in obtaining fibers with desired properties, impacting their morphology, crystallinity, and purity. Morphological and structural analysis through scanning electron microscopy (SEM) and transmission electron microscopy (TEM) are widely employed, along with X-ray diffraction (XRD) and Fourier-transform infrared (FTIR) spectroscopy for analyzing crystallinity and chemical composition. Mechanical properties are assessed through tensile testing, flexural strength testing, and impact strength testing. Advanced techniques, such as atomic force microscopy (AFM), confocal Raman spectroscopy, and X-ray photoelectron spectroscopy (XPS), provide deeper insights into the surface chemistry and interactions of natural cellulosic fibers. The ongoing refinement of these techniques will be crucial for the advancement and commercialization of natural cellulosic fibers as sustainable and eco-friendly alternatives to conventional materials. Despite the progress in characterizing natural cellulosic fibers, there is still a need for further development in this field. Future researchers should focus on exploring innovative extraction and surface modification methods to improve the properties and performance of these fibers in various applications.

Additionally, the development of new characterization techniques and the refinement of existing methods will enable a more in-depth understanding of the relationships between fiber properties, processing conditions, and performance in end-use applications. The exploration of new applications and markets for natural cellulosic fibers, such as in energy storage, filtration, and biodegradable materials, will also open up new research areas and commercial opportunities. By advancing the knowledge and technology surrounding natural cellulosic fibers, researchers can help promote the transition to a more sustainable and eco-friendly future.

## Declaration of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Author Contribution

**Yashaarth Kaushik**: Conceptualization, Investigation, Methodology, Writing - original draft, Writing - review and editing; **Suraparb Keawsawasvong**: Data curation, Formal analysis, Investigation, Methodology, Writing - review and editing; **Nilakshman Sooriyaperakasam**: Data curation, Formal analysis, Investigation, Methodology, Writing - review and editing; **Udit Rathee**: Investigation, Methodology, Validation, Writing - review and editing; **Nithesh Naik**: Conceptualization, Methodology, Project administration, Supervision, Writing - original draft, Writing - review and editing.

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