Journal of Tropical Forest Science 37(2): 215–223 (2024)
https://doi.org/10.26525/jtfs2024.36.2.215
ISSN: 0128-1283, eISSN: 2521-9847

ANALYSING THE ESCALATION OF FOREST FIRE IN INDIA: EXPLORING CAUSAL FACTORS AND MITIGATION STRATEGIES

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Submitted July 2023; accepted September 2023

Forest fire is one of the main factors of forest degradation that affects the social, economic, and cultural settings of forest-dependent people. India has 24.64% of its geographical area under tree and forest cover. Among forests, approximately 55% are deciduous forest, highly susceptible to forest fire primarily driven by escalating human activities and their associated impacts. Based on the literature survey and secondary data sources, this paper assesses the trend and pattern of forest fires, their associated causes and why forest fires still occur in India on a larger scale. The findings of the study reveal a rapid increase in forest fires over time, from 18,719 in 2001 to 111,267 in 2021 according to MODIS sensor data with the highest frequency in March and April. The central and north-eastern states of India have experienced the highest fire incidents, causing a massive loss of property, lives, and natural resources. This study demonstrates that the causes of fire vary significantly from location to location and season to season. The concluding section of the study recommends measures to deal with the economic vulnerability of locals, resource availability and adaptation for forest fires in India. Furthermore, this study is adding fresh insights to the discourse on forest fires and suggested possible mitigation strategies and potential solutions which can be useful for other similar geographical contexts.

Keywords: Forest fire, causes, mitigation strategies, India

INTRODUCTION

India is one of the world's biodiversity hotspots, with 0.809 million square km area under the regime of forest and tree cover, consisting of 24.64% geographical area of the country, among which 5.26% is proclaimed as a protected area (ISFR 2021). However, the health of the forest ecosystem in India is confronted with a growing challenge due to escalating human activities and their consequent impacts (Jha et al. 2022, Richards et al. 2022, Meher 2023). Consequently, the forest ecosystems of India are experiencing a gradual decline, further increased by recurrent occurrences of forest fires with varying intensities and frequencies over time (Roy 2003, Jain et al. 2021, Dhar et al. 2023). The previous studies conducted by Curtis et al. (2018) and Kumar et al. (2022) have revealed that the deteriorating state of India's forest ecosystems is due to the forest fires. These fires, frequently ignited by human-induced activities within the natural forest ecosystem, have significantly accelerated the process of forest cover degradation (Saha 2002, Puri et al. 2011, ISFR 2021, Jain et al. 2021). The work of Kodandapani et al. (2008) and Qayum et al. (2020) underscores the critical role of forest fires in this context. The repercussions of this degradation are multifaceted. In particular, forest fires exert profound implications on the socio-economic and cultural fabric of communities who reliant on forest ecosystems. Moreover, the structure and composition of the forest cover exposed to degradation as a result of such forest fires. In light of these interrelated concerns, it becomes imperative to address the underlying causes of forest fires and their subsequent impacts on both the environment and society.

The majority of forest ignition in India occurs mainly in summer and spring season

from February to June (Srivastava & Garg 2013). The intensity and spread of forest fires intricately regulated by a confluence of both natural and anthropogenic factors. Among the natural factors, topographical features, temperature patterns, precipitation levels, wind dynamics, humidity levels, cloud cover, types of vegetation, soil moisture content, forest floor litter, and fuel moisture content play pivotal roles (Eslami et al. 2021). On the contrary side, anthropogenic factors include a spectrum of activities such as agriculture practices, animal grazing, ecotourism services, illegal encroachments and construction, urban growth, industrialization, and the development of infrastructural services. Notably, within the Indian context, around 95% of forest fires are a result of human activities, either accidental or deliberate (Roy 2003, Srivastava & Garg 2013, Satendra & Kaushik 2014).

In India, around 55% of its forest cover fall under the regime of deciduous forest type, which are highly susceptible to wildfires, with surface and sub-surface fires being the most common occurrences (Roy 2003, Joseph et al. 2009, ISFR 2019, Menon & Vishnu 2022). According to ISFR 2021, the number of forest fire alerts has increased rapidly in the recent years recorded by Moderate Resolution Imaging Spectroradiometer (MODIS) sensor data. Similarly, Visible Infrared Imaging Radiometric Suits (VIIRS) sensor also indicates a high surge in fire alerts. These increased fire occurrences are resulting in colossal losses of physical assets, life forms, and biodiversity. The estimated loss due to fire in India is about USD 100 Million annually (Srivastava & Garg 2013).

The re-occurrence of forest fire every year affects the natural setting of the forest cover and the socioeconomic well-being of the local communities reliant on them. It also creates the insecurity of livelihood (Kim et al. 2019) due to insufficiency or loss of biodiversity, non-timber forest products (NTFPs), fuel wood, grazing lands, loss of fodder, crops, and loss of tourism. The repercussion of a wildfire is not only limited to the social-economic and ecological loss but also influences the cultural settings of the locals and forest dwellers. The complexity regarding the mitigation and control of fire regimes and their associated losses within the geographical context of India is majorly attributed to the dearth of comprehensive studies into the historical trends and patterns of fire incidents, considering both the human and environmental losses (Roy 2003). This insufficiency of empirical evidence hinders the implementation of effective strategies to curtail and manage the occurrence of fires and their associated repercussions. By considering these challenges and limitations, this present study analyses the secondary data sources which mainly includes scientific reports, existing literature, and scholarly contents to assess the trends and patterns of fire in India in the context of the recent years. It reveals India's comprehensive forest fire situation, its potential causes, and suggesting viable fire suppression measures. This work is contributing new dimension in this direction by considering various determinants which are affecting fire occurrences and concerned losses. Additionally, it sheds lights on the corrective actions against fire to improve forest ecosystem, local people's socio-economic and cultural lives by increasing their economic viability, resource availability, adaptation, mitigation strategies, and participation.

MATERIALS AND METHODS

This study is based on the secondary data sources and other multiple sources of evidence of the previous studies has been used. For analysing the spatio-temporal changes in the regime of forest fire over the period of time, secondary data sources have been employed, which retrieved from the National Aeronautics and Space Administration (NASA) Fire Information for Resource Management System This data includes the incidents of forest fire recorded by MODIS and VIIRS sensors from 2001 to 2022. The rationale for using both sensors is underpinned by the strategic advantages they collectively provide. The MODIS sensor is reliable source of providing long-term temporal data of fire incidents because of its vast temporal extent, which includes data from the year 2000 onwards. It possesses an ability to identify large fires, made possible by a spatial resolution of 1 km, significantly expands its usefulness (Urbanski et al. 2009). While the VIIRS sensor excels in the detection of small fire occurrences due to its better spatial resolution of 350 metres (Schroeder et al. 2014). However,

the VIIRS data is only accessible from 2012 and onwards, indicating a limited historical scope compared to MODIS sensor. Thus, to lessen the inherent limitations brought on by the restricted historical availability of fire event records, a coordinated deployment of data from both sensors has been planned for this study. The study aims to thoroughly address temporal and spatial patterns, enabling a more detailed knowledge of fire dynamics by combining the capabilities of MODIS and VIIRS sensors.

The processing and analysis of the data has been carried using the Arc-GIS (version 10.3) and Microsoft excel software. This study employs diverse secondary sources to investigate the causes of increasing frequency of fires in recent years, analyze mitigation strategies, and explore potential solutions. The major source of information includes, peer-reviewed journal articles, reports from regional institutions as well as state, national, and international level assessments focused on forests and wildfires. These comprehensive data sources serve as the basis for analyzing the aforementioned aspects related to the increasing incidence of fires.

RESULTS AND DISCUSSION

Trend of forest fire in India

The trend of forest ignition is alarming, leading to more fire incidents and larger burned areas (Joseph et al. 2009). There are several factors responsible for increasing forest fires in India. Among them, the anthropogenic activities are one of the leading causes of this phenomenon. Forest fire incidences has heightened drastically in the recent years compared to the previous years. The number of fire incidents recorded by MODIS sensors was around 1400 in the year 2000, and in the year 2022 it increased to 62,946 (Figure 1A). The VIIRS sensor reported, 479,281 fire incidents in India during 2022 which is a very high and concern number (Figure 1B). As VIIRS sensor has fine resolution compared to the MODIS sensor it denotes that VIIRS is more effective in detecting small scale fire and MODIS plays a very satisfactory role in monitoring the large scale forest fire. However, both the sensors conveying that the fire phenomena are rapidly increasing in India.

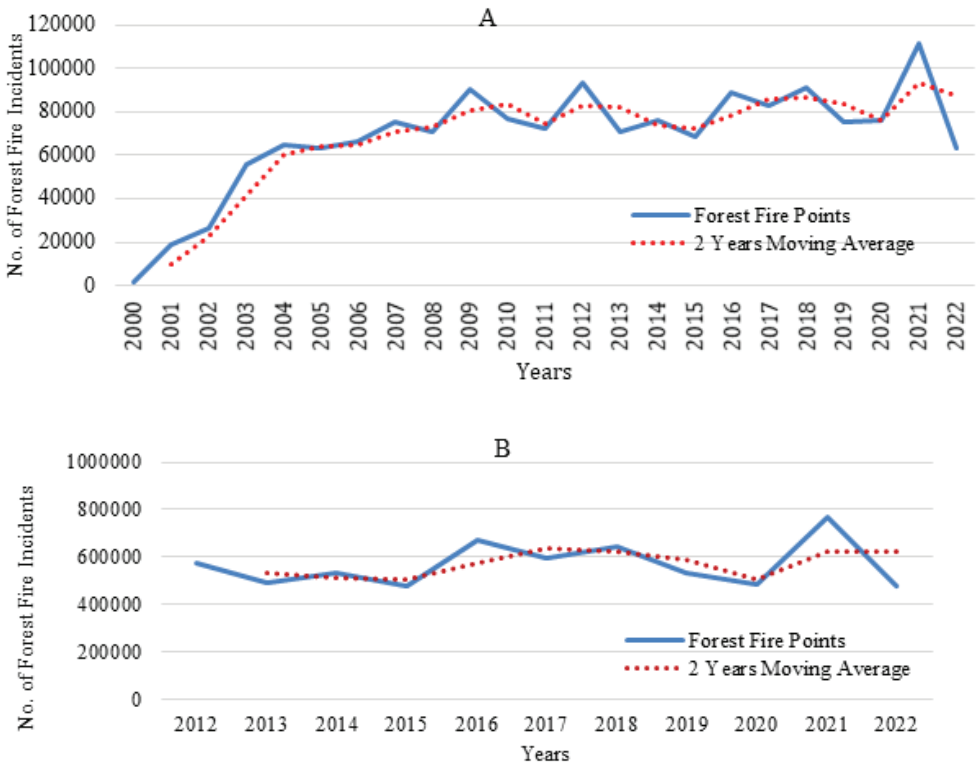

Figure 1 Number of forest fire incidents recorded by MODIS (A) and VIIRS (B) with two year moving average

Seasonal variations in fire trend

The wildfire phenomena in India are uneven with respect to seasons and mainly have a dominance in a few months. In continuation of the research findings of Roy (2003) and ISFR (2021), the present study similarly identifies a peak occurrence of fire incidents during the months of March and April (Figure 2). However, the significant number of fire incidents have also been recorded in the month of February and May. The major reason behind the high incidents of forest fire during February to May are summer season which provides dry fuel material to fire due to wind flow, high temperature and less precipitation conditions in India. Along with that fire incidents are also recorded in the months of October, November, and December which majorly driven by less precipitation during these months and other associated causes including agriculture practices and crop residual burnings nearby the forests. Therefore, the increasing trend of forest fire in India is highly concentrated within a few months of summer and dry season. Figure 2 clearly demonstrates this.

Spatial pattern of forest fire in India and their associated causes

The spatial pattern of fire in India is heterogenous in nature and it changes as per space and time throughout the country. According to the ISFR (2021), around 23% of forest cover in India comes under high to extreme prone to fire category zone. Among them, Central Indian and North-eastern states stand for 76% of the forest fire incidents in the last decade.

Central Indian region

From the year 2009 to 2018, Odisha stood first in the list of India's most forest fire affected states with respect to fire incidents, followed by Chhattisgarh and Madhya Pradesh (Pavithra 2019). As per ISFR (2021), Odisha, Chhattisgarh, Madhya Pradesh, Maharashtra, and Jharkhand have the most extensive fire occurrence incidents in India. The major factors behind this occurrence of fire incidents in these states is due to less rainfall and high temperature (ISFR 2021). This region is also covered with deciduous forest which are shedding its leaves just before the advent of the summer season and these leaves are highly susceptible to fire incidents (Bahuguna & Singh 2002).

The anthropogenic activities by the locals are further contributing to the process. Around 1.6 billion people rely on the forest for their income and livelihood through different commodities like timber, food, fuelwood, fodder, NTFPs, housing, fencing, and ecosystem services (Jha et al. 2018). In India around 350–400 million, people directly rely on forest resources for their livelihood and sustenance support (MoEF 2010). This extended dependency of people on forest ecosystems is one of the primary causes of forest degradation (Roy 2003, Davidar et al. 2010). To get the NTFPs from the forest especially Mahua flowers, they cleared the forest to pick up the

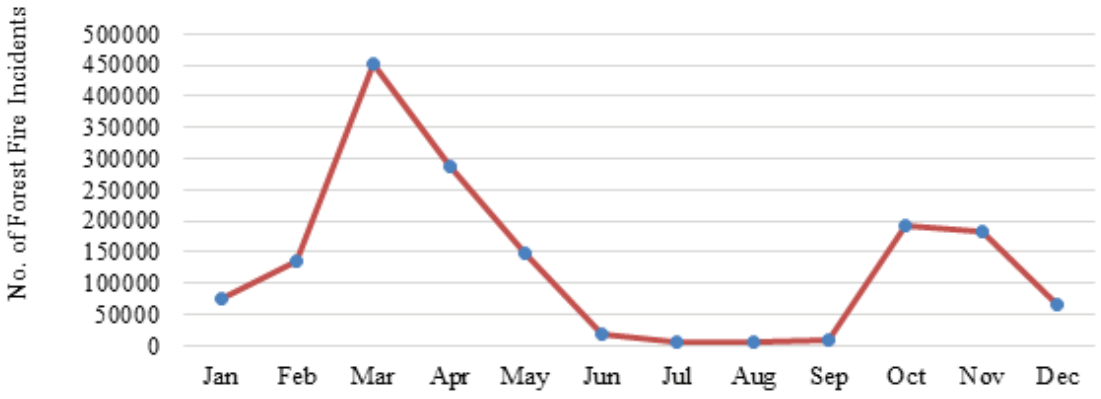

Figure 2 Seasonal variation in forest fire incidents recorded by MODIS sensor (2000-2022)

Mahua flowers effectively. They often set fire intensely for the Mahua flower collection and to get new fodder for their animal. However, due to the immense availability of highly combustive materials in the form of dry leaves and favorable hot climatic conditions triggered the fire. It became unprecedented and uncontrolled and burned out the larger landscape, resulting in the loss of biodiversity, species regeneration, timber, fuelwood, fodder, wildlife habitat, water resources, human properties, and agricultural fields.

North-Eastern and Northern Himalayan region

Ahmad et al. (2018), in his study found that the highest forest fire frequency recorded in Mizoram, and among the top ten highest wildfires states, four to five lie in the north-eastern states during 2017-18. As per the number of fire incidents, two of the top ten states (Mizoram and Assam) come from the north-eastern states (ISFR 2021). In the context of the North-East, the leading cause of the fire is shifting cultivation or Jhuming agriculture (in this agriculture practice, the land is cleared by fire to make soil more productive for agriculture). Two or three year later, when the soil starts losing its productivity, then they start searching for another land for agriculture and repeat the same practice of land burring for productive agriculture. It is a practice of poor or marginalized farmers or ethnic tribal groups to sustain their livelihoods (Srivastava & Garg 2013, Chandra & Bhardwaj 2015, Ahmad et al. 2018, Wang et al. 2021). Forest fires have also scorched Arunachal Pradesh, Manipur, Meghalaya, Nagaland, and Tripura, among other states. It is estimated that forest fire affects around 4.35 million hectares of land in the north-eastern states (Chandra & Bhardwaj 2015).

Furthermore, the northern Himalayan states of India namely Uttarakhand, Himachal Pradesh, and a few parts of Uttar Pradesh are also experiencing increasing number of fire incidents particularly during the fire season (ideally February to May). Wildfire is also dominant in the western regions of the Himalaya since it receives less rainfall than eastern part of the Himalaya. Fir (*Abies* spp.), spruce (*Picea smithiana*), *Cedrus deodara*, *Pinus roxburghii*, and *P. wallichiana* are among the Himalayan conifers that are prone to fire because they have highly flammable leaves that are ideal for forest ignition during the summer season. Hence, these forests play a major role in fire incidents in this region (Mamgain et al. 2022).

Other states

The other states of India such as Andhra Pradesh and Telangana also suffer from the impact of forest fires. From Nov 2020 to June 2021, Andhra Pradesh and Telangana recorded 3565 forest fire incidents which resulting in the loss of forest resources and human property (ISFR 2021). To some extent, Kerala and Tamil Nadu's forest cover is also getting affected by the forest fire, which disrupts the natural settings of the forest ecosystem. In Kerala, the natural cause of setting the fire is prominent compared to the country's central, western, and eastern regions (Ajin et al. 2016). Therefore, forest fires in India exhibit a diverse range in terms of extent, degree, severity, pattern, and path, with human-engineered activities playing a significant role in shaping fire size and distribution, while weather and climate variability also contribute (Roy 2003).

In a nutshell, the causes of fire in India vary with the places and associated human existence practices for living across the country. Most forest fire in India happen due to the activities for livelihood generation (marginal farmers, poor tribal people, and locals). According to Srivastava and Garg (2013), the principal and significant factors for pushing the fire to a more considerable spatial extent and intensity are highly combustible (dry leaves of tropical deciduous forests) materials, human-induced practices, and ideal weather conditions for fire. In addition, strict rules and regulations for forest dwellers, non-inclusive policies, fortress conservation (conserving forest only within the boundary or strong demarcation between humans and forests), unpaid indigenous services, and the impossibility of incorporating locals into fire control initiatives, lack of forest fire controlling and patrolling stations, personnel, motivation, and rewards from the government are the additional factors of escalating fire regime in India.

Forest fire monitoring and controlling programmes in India

During colonization, the primary practice of controlling and mitigating fire efforts primarily involved managing and clearing dry and making forest fire lanes (to clear or remove the middle portion of litter to break the continuity and chain of ignition). Nowadays, geospatial technologies have a very prominent role in monitoring, detecting, controlling, and responding to forest fires in remote and inaccessible areas with near real-time data (Roy 2003, Reygadas et al. 2019. Szpakowski & Jensen 2019, Qayum et al. 2020). The NASA launched its first MODIS sensor on the Terra 1999 and Aqua 2002 satellites and VIIRS on the Suomi National Polar-Orbiting Partnership (S-NPP) satellite 2012 to detect hotspot areas across the world. Global satellites also have a significant role in forest fire monitoring, controlling, responding, and assessing burnt loss (Artés et al. 2019).

In India, the Near-Real-Time Monitoring of Forest Fires alerts and monitoring have been using MODIS data since 2004. Subsequently, in 2017 it began using VIIRS Sensor data from the SNPP 2012 satellite. The VIIRS sensor is three times more detailed than MODIS sensor, hence efficiently reporting small scale forest fire incidents. Forest Survey of India demonstrated the alerting and monitoring process of forest fire. There are numerous forest fires controlling programmes and systems have been launched by the Indian government under the domain of the FSI as per the requirements and feasibility of the forest fire system such as Forest Fire Alerts System (FAST), Large Forest Fire Monitoring System (LFFMS), Fire Weather Index (FWI), and Forest Fire Prone Area Identification System (Annual Report 2020-21).

Forest ignition is a one of the leading causes of forest destruction in India. The annual re-occurrence of forest ignition in the numerous corners of the country leads to the massive loss of forest cover, NTFPs, species richness, sapling, biodiversity, water resources, food, fuel, and livelihood sources, ecotourism, natural habitats of fauna and environmental degradation for long-run perspective. The quantification of intangible losses caused by forest fires in India is a very challenging task. More than 95% of fire incidents occur in India because of human-induced factors (Bahuguna & Singh 2002). In contemporary times, the pace of forest fires has escalated significantly compared to earlier years. Several factors are responsible for fire escalation since last two decades, in which major are the rapid change in land use land cover matrix, increasing population (in forested areas or nearby forest premises), technological growth, economic development, and poverty.

Even after the advancement of geospatial technologies and government initiatives, the number of fire events in India is still increasing. This is cause for considerable concerns. There is a strong need to form policies and programmes with the adequate inclusion of indigenous knowledge of controlling fire and their participation in fire-controlling mitigation and responding plans, policies, and programmes. So that it can minimise the tangible and intangible losses caused by forest fires in the different seasons and various regions of the country.

In-depth regional level studies are required to assess, monitor, and examine the role of different agents of fire and its socio-economic, cultural, ecological, and eco-aesthetic values. It is also much significant in the current scenario to know the effect of climate alteration and global warming on the ignition regime and vice versa. These regional studies would be constructive for forest fire mitigation, response, and adoption through robust planning, strategies, programmes, and policies (Barmpoutis et al. 2020). A holistic plan involving forest residents for forest preservation and restoration after fire occurrences should be adopted for better, rapid, and more effective recovery of the forest ecosystem and human property losses (Chandra & Bhardwaj 2015).

Based on a thorough review of the relevant literature about the different dimensions of the forest fire regime in India and associated causal factors, this study recommends measures to deal with the economic vulnerability of locals, resource availability, and adaptation and mitigation strategies for forest fires as follows:

1. In India, most of the forest fires are associated with NTFPs collection. Hence, we need to develop a policy that lessens the dependence of the locals on NTFPs and provides other alternatives for earning livelihoods. It will decrease the competition among locals for

NTFPs collection and ultimately reduce the human-induced fire incidents in forested areas.

2. The formulation of the local interest-oriented policies and forest conservation programmes encourages them to contribute more to the conservation of forests from fire.

3. Each village community forest committee members should be paid for their incomparable contribution to controlling forest fires during fire season.

4. In the hilly villages of Uttarakhand, Himachal Pradesh, and other Himalayan regions, the state or central government should initiate the scheme to provide mini ponds to the villagers in case of wildfire. These ponds can be utilized, and the losses caused by fire can be minimised. These kinds of initiatives must be encouraged throughout the country.

5. Based on the proneness of the forest to fire, wildfire watcher towers should be installed and monitored during the fire season so we can trace the fire promptly and mitigate the loss.

6. The Indian Forest fire guards are using very traditional instruments for controlling forest fires which are outdated and less effective in controlling the hazardous nature of fire. The government should have provided well-functioned modern GPS-installed instruments and well-structured dresses. Hence, they can go to the core portions of ignited areas and mitigate the loss effectively.

7. The wildfire policies should be more inclusive and apply local and traditional knowledge to control the forest fire efficiently.

8. The collection of dry wood or fuel wood should be allowed to the locals or forested people, which will ultimately decrease the fuel load in the forest, resulting in lessening the fire's intensity and areal extent.

9. The government should encourage organic farming through subsidies and restrict slash-and-burn agricultural practices.

10. The construction of developmental infrastructure, i.e., rail and road networks nearby forested areas, should be well-formulated and sustainable.

11. Restricted tourism in highly vulnerable areas during the fire or intense summer seasons will help mitigate fire incidents.

12. The diffusion of information about the importance of the forest ecosystem in our daily lives through different mediums should be encouraged.

CONCLUSION

India's central and north-eastern states have reported the highest forest fire incidents. In the central region the major causes behind the occurrence of fire involves the collection of NTFP by the locals of the region. While in the north-eastern states, the leading cause of the fire is shifting cultivation and traditional practices of agriculture. In the northern and western regions of the country, the presence of highly combustive vegetation, hot weather conditions, human-induced activities like animal grazing, increased footfall of tourists, human-wildlife conflicts, and conflicts between local populations and forest officials creates and resulting in the increasing pace of ignition. We can also trace the scattered and uneven occurrence of forest fire in other states of India such as Andhra Pradesh, Telangana, Kerala, and Tamil Nadu driven by human associated practices.

Therefore, for better control and mitigation of the losses caused by forest fires, the bottom-up approach should be adopted instead of the top-down approach. As it is reported that more than 95% of forest fire incidents happen due to the movement and activities of local or indigenous people, hence, it becomes important to focus on the root cause of these anthropogenic activities. We need to have adequate precautionary, early warning and response strategies must be well-planned and carefully integrated. These plans, policies, and programmes must be created with local stakeholders' active participation and collaboration.

ACKNOWLEDGEMENTS

We are thankful to the suggestions of Monika, Ferenc Jankó, Arijit Roy, Tapas, Atif, and Mashkoor Ahmad for their invaluable suggestions and reviewing this manuscript. We are also thankful to the editor of JTFS journal and the anonymous reviewers for providing their erudite suggestions.

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