Plant-Derived Smoke as a Natural Growth Regulator: Chemical Signals, Seed Priming Mechanisms and Prospects for Climate-Resilient Crop Establishment

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Abstract—**Plant-Derived Smoke (PDS) has emerged as an effective natural biostimulant influencing seed germination, early seedling growth, and stress resilience across a wide range of plant species. Originally identified as an ecological trigger for post-fire regeneration in fire-prone ecosystems, smoke-mediated growth regulation has gained increasing relevance in agriculture and horticulture. PDS contains a complex mixture of bioactive compounds, among which karrikins especially karrikin-1 (KAR_1) are key regulators of seed dormancy release, germination efficiency, and early developmental processes at very low concentrations.**

Beyond germination, growing evidence indicates that PDS modulates diverse physiological, biochemical, and molecular pathways involved in plant growth and abiotic stress tolerance. It influences hormonal signalling networks and enhances plant responses to stresses such as salinity, drought, flooding, and heavy metal toxicity. However, despite substantial progress, several important aspects remain poorly understood. These include the effects of burning different plant parts on smoke bioactivity, the comparative efficacy of refrigerated and non-refrigerated smoke solutions, concentration-dependent (hormetic) responses, and the application of PDS-based seed priming for off-season crop establishment under unfavourable climatic conditions.

This review synthesizes current knowledge on the chemical nature of PDS, its mechanisms of action, and its applied significance, with special emphasis on these underexplored dimensions. By integrating ecological perspectives with agronomic and seed biotechnology approaches, the review highlights PDS as an eco-friendly, low-input growth regulator with strong potential for sustainable and climate-resilient agriculture. Key research gaps are identified, and future directions are proposed to support standardization, optimization, and wider adoption of PDS technology.

Index Terms—**Plant-Derived Smoke (PDS); karrikins; seed priming; plant growth regulation; biostimulants; sustainable agriculture**

I. INTRODUCTION

Seed germination and early seedling establishment are among the most critical and vulnerable phases of the plant life cycle, exerting a decisive influence on plant growth, stand uniformity, and final crop productivity. These early developmental stages are highly sensitive to environmental cues and stresses, including temperature extremes, water availability, salinity, nutrient imbalance, and soil contamination. In the context of global climate change, increasing frequency of droughts, floods, heat waves, and soil degradation has further intensified constraints on successful crop establishment. Consequently, there is a growing demand for innovative, eco-friendly growth-regulatory strategies that enhance seed performance and early plant vigor under both optimal and suboptimal conditions.

Plant growth regulation traditionally relies on synthetic plant growth regulators, fertilizers, and chemical seed treatments. Their excessive or prolonged use has raised serious environmental and ecological concerns, including soil degradation, water pollution, and negative impacts on non-target organisms. In recent years, attention has shifted toward natural biostimulants that regulate plant growth processes through physiological and molecular modulation rather than direct nutrient supplementation. Within this emerging paradigm, seed priming has gained prominence as a simple, cost-effective, and farmer-friendly technique to improve germination uniformity, seedling vigor, and stress tolerance.

Seed priming involves controlled hydration of seeds to initiate metabolic processes associated with germination without allowing radicle emergence. This pre-germinative conditioning enhances enzymatic activity, repair mechanisms, and hormonal balance, enabling seeds to germinate more rapidly and uniformly upon sowing. Various priming agents have been explored, including hydropriming, Osmo priming, hormonal priming, and the use of natural extracts. Among these, PDS has emerged as a unique and powerful biostimulant capable of regulating seed germination and early growth at remarkably low concentrations.

A major breakthrough in smoke biology was the identification of karrikins, a group of butenolide compounds formed during the combustion of plant material. Among them, karrikin-1 (KAR_1) has been recognized as the most potent germination stimulant. Karrikins act at nanomolar to picomolar concentrations and regulate seed germination, seedling photomorphogenesis, and early growth by interacting with specific signaling pathways. Beyond germination, accumulating evidence indicates that plant-derived smoke influences a broad spectrum of physiological and biochemical processes, including antioxidant activity, osmotic adjustment, photosynthetic efficiency, and stress-responsive gene expression.

Despite substantial progress in understanding the biological activity of plant-derived smoke, several important aspects remain inadequately explored, limiting its translation into standardized agricultural practices. Most studies have focused on smoke generated from mixed plant biomass or leaves, with little attention paid to the contribution of individual plant parts such as stems, roots, or reproductive organs. Given the pronounced biochemical heterogeneity among plant organs, the nature and concentration of smoke-derived compounds are likely to vary depending on the source material, potentially influencing growth-regulatory outcomes.

Similarly, the issue of storage stability and handling of smoke solutions has received limited systematic investigation. While smoke water is often reported to retain biological activity for extended periods, comparative evaluations of refrigerated versus non-refrigerated storage conditions are scarce. This gap is particularly relevant for practical field applications and commercialization, especially in resource-limited settings where cold storage may not be feasible.

Another critical yet under-addressed dimension of PDS research is concentration-dependent response behavior. Smoke solutions typically exhibit hormetic effects, where low concentrations stimulate growth while higher concentrations may inhibit germination and seedling development due to the presence of antagonistic compounds.

Furthermore, the potential application of PDS-based seed priming for off-season crop establishment remains largely conceptual, with limited empirical validation. As climate variability increasingly disrupts traditional sowing calendars, strategies that enable successful germination and establishment under non-ideal seasonal conditions are urgently required.

In this context, the present review critically synthesizes current knowledge on plant-derived smoke as a natural growth regulator, with a focus on its chemical basis, physiological and molecular mechanisms, and applied significance in seed priming and early crop establishment. Particular emphasis is placed on underexplored yet strategically important aspects, including the influence of plant part selection on smoke bioactivity, storage dynamics of smoke solutions, concentration-dependent growth responses, and the feasibility of PDS-mediated off-season planting. By integrating ecological insights with agronomic and seed biotechnology perspectives, this review aims to provide a comprehensive framework for advancing plant-derived smoke from experimental studies toward practical, climate-resilient agricultural applications.

II. PLANT-DERIVED SMOKE: CHEMICAL COMPOSITION AND BIOACTIVE MOLECULES

PDS is a chemically complex mixture generated during the incomplete combustion of plant biomass. The biological activity of smoke arises from the interaction of numerous volatile and water-soluble compounds produced during thermal degradation of cellulose, hemicellulose, lignin, and secondary metabolites. Combustion of plant material generates thousands of compounds, including phenolics, aldehydes, ketones, organic acids, nitrogen-containing compounds, and various hydrocarbons. Many of these compounds dissolve readily in water, forming smoke water or plant-derived smoke solution that can be applied directly to seeds or plants. However, not all smoke constituents are biologically active, and only a fraction contribute to growth regulation.

The chemical profile of smoke is influenced by several factors, including plant species, plant part used, moisture content, combustion temperature, and oxygen availability. These variables determine the relative abundance of stimulatory versus inhibitory compounds, thereby affecting the net biological response. Importantly, smoke should not be viewed as a single growth regulator but rather as a dynamic chemical system in which multiple compounds interact synergistically or antagonistically.

2.1 Karrikins: Central Growth-Regulatory Signals

The discovery of karrikins marked a major milestone in understanding smoke-mediated plant growth regulation. Karrikins are a family of butenolide compounds formed during the combustion of plant cellulose and other carbohydrates. Among the identified karrikins, KAR_1 is the most abundant and biologically active, exhibiting strong germination-promoting effects at extremely low concentrations. Karrikins regulate multiple aspects of early plant development, including seed dormancy release, germination rate, seedling photomorphogenesis, and hypocotyl elongation.

The biochemical heterogeneity among plant species and organs directly influences smoke chemistry. Leaves, stems, roots, and reproductive structures differ markedly in cellulose, lignin, and secondary metabolite composition, leading to variation in combustion products. Leaves generally combust at lower temperatures and may favour the formation of karrikins, whereas lignified tissues such as stems and bark may generate higher concentrations of phenolics and inhibitory compounds.

Despite its importance, systematic evaluation of how individual plant parts affect smoke composition and growth-regulatory activity remains limited. Most existing studies rely on mixed biomass or leaf material, leaving a significant knowledge gap regarding the optimization of smoke source material. Addressing this gap is critical for standardizing PDS preparation and enhancing its reproducibility and effectiveness in agricultural applications.

2.2 Methods of Smoke Generation and Influence of Plant Material

PDS solutions are typically produced by burning dried plant material and dissolving the resulting smoke in water, allowing water-soluble bioactive compounds to be captured efficiently. While the basic principle is simple, methodological variations in smoke generation can significantly influence the chemical composition and biological efficacy of the resulting solution. These variations include the type and amount of plant material used, combustion temperature, oxygen availability, duration of burning, and the design of the smoke-collection apparatus.

Laboratory-scale systems commonly involve controlled combustion of plant biomass in a closed or semi-closed chamber, with smoke channelled into distilled water through tubing. Such systems allow reproducibility and minimize contamination, making them suitable for seed biology and plant growth studies. In contrast, open-air or semi-open systems are often used in larger-scale experiments but may introduce variability due to fluctuating environmental conditions. Regardless of the system employed, complete combustion until smoke production ceases is generally recommended to ensure maximal release of smoke-derived compounds.

Despite widespread use, there is no universally accepted standard protocol for smoke solution preparation. As a result, inter-study comparisons remain challenging, underscoring the need for methodological harmonization to advance plant-derived smoke research toward applied growth regulation.

III. INFLUENCE OF INDIVIDUAL PLANT PARTS ON SMOKE COMPOSITION

While most studies use mixed plant biomass or leaf material, plants exhibit pronounced biochemical heterogeneity across organs such as leaves, stems, roots, bark, and reproductive structures. These differences have important implications for smoke chemistry and, consequently, biological activity. Leaves generally contain higher proportions of carbohydrates and lower lignin content, potentially favouring the formation of karrikins during combustion. In contrast, woody tissues such as stems and bark are richer in lignin and phenolic compounds, which may yield higher levels of inhibitory substances upon burning.

Despite this rationale, systematic investigations comparing smoke derived exclusively from individual plant parts are notably scarce. Existing evidence suggests that smoke generated from leaves often produces stronger germination and growth-promoting effects than smoke derived from mixed or lignified biomass. However, the potential contribution of roots and reproductive structures remains largely unexplored.

Root tissues are of particular interest, as they accumulate distinct metabolites and mineral elements absorbed from the soil. Combustion of roots may generate unique smoke profiles influenced by edaphic factors, offering an opportunity to investigate site-specific smoke bioactivity. Similarly, inflorescences and seeds contain specialized metabolites that could influence smoke chemistry in novel ways. Exploring these dimensions could reveal plant-part-specific strategies for enhancing the growth-regulatory potency of smoke solutions.

Moreover, plant-part specificity could contribute to the standardization of smoke solution preparation, a critical requirement for large-scale agricultural adoption. Establishing guidelines for biomass type, moisture content, and combustion conditions would facilitate reproducibility across laboratories and field settings, addressing a major limitation in current PDS research.

Despite growing interest in plant-derived smoke, methodological gaps persist. Comparative studies evaluating smoke solutions derived from different plant organs under identical combustion conditions are urgently needed. Integration of chemical profiling techniques, such as gas chromatography–mass spectrometry, with biological assays would enable correlation of specific compounds with growth-regulatory outcomes. Additionally, research should explore scalable and farmer-friendly smoke generation methods that maintain bioactivity while minimizing variability. Developing standardized, low-cost smoke production systems could accelerate the translation of PDS technology from experimental studies to practical applications in plant growth regulation.

IV. STORAGE STABILITY OF PLANT-DERIVED SMOKE SOLUTIONS: REFRIGERATED VERSUS NON-REFRIGERATED CONDITIONS

For PDS to be effectively integrated into plant growth regulation and agricultural practice, its stability during storage is a critical consideration. Unlike many synthetic growth regulators that have well-defined shelf lives and storage requirements, PDS solutions are often prepared fresh or stored empirically without standardized guidelines. Most experimental studies report storage of smoke solutions at low temperatures, typically under refrigeration or freezing, but systematic evaluations of how storage conditions influence biological efficacy remain limited.

The stability of PDS solutions is largely attributed to the chemical nature of karrikins, which are considered the primary growth-regulatory constituents. Karrikins are relatively small, chemically stable butenolide molecules that exhibit resistance to thermal degradation and hydrolysis under a wide range of conditions. Their melting point and structural rigidity suggest that they are unlikely to undergo rapid decomposition at ambient temperatures.

In addition to karrikins, smoke solutions contain cyanohydrins, phenolics, and organic acids that may exhibit varying degrees of stability. Some of these compounds could potentially undergo slow oxidation, polymerization, or microbial transformation during storage, particularly under non-sterile conditions. The net growth-regulatory effect of stored PDS therefore depends on the balance between the persistence of stimulatory compounds and any degradation or accumulation of inhibitory substances. Cyanohydrins can decompose to release small amounts of cyanide, which at low concentrations has been shown to promote germination by modulating respiratory activity and reactive oxygen species (ROS) signaling. This controlled cyanide signaling may act synergistically with karrikins to enhance metabolic activation during early germination.

4.1 Refrigerated Storage: Advantages and Limitations

Refrigeration is commonly employed to preserve smoke solution bioactivity, with storage temperatures typically ranging from 4 °C to −20 °C. Low-temperature storage is assumed to minimize chemical degradation and microbial growth, thereby maintaining consistent growth-regulatory effects over extended periods. Several studies have reported that smoke solutions stored under refrigerated conditions retain germination-promoting activity for months or even years, supporting the notion of long-term stability.

However, refrigerated storage introduces logistical challenges. Cold storage increases operational costs, limits accessibility for farmers and small-scale users, and complicates transport from laboratories to field sites. Furthermore, reliance on refrigeration may restrict the use of PDS in regions where electricity or cold-chain infrastructure is unreliable. These constraints highlight the need to evaluate alternative storage strategies.

4.2 Non-Refrigerated Storage: An Underexplored Opportunity

Despite the widespread assumption that refrigeration is essential, there is surprisingly little empirical evidence demonstrating a loss of PDS efficacy under ambient storage conditions. Smoke solutions are produced at elevated temperatures during combustion, raising the possibility that freshly prepared solutions may be immediately applicable without cooling. Moreover, the inherent stability of karrikins suggests that short- to medium-term storage at room temperature may not significantly compromise growth-regulatory activity.

Preliminary observations indicate that PDS solutions can retain bioactivity even when stored under non-refrigerated conditions, although the duration and consistency of this effect remain unclear. Factors such as light exposure, container material, microbial contamination, and solution concentration may influence stability and should be systematically evaluated. Comparative bioassays using freshly prepared, refrigerated, and ambient-stored smoke solutions are notably scarce and represent a critical research gap.

Future research should prioritize systematic comparisons of refrigerated and non-refrigerated smoke solutions across multiple crop species and developmental stages. Chemical profiling combined with germination and growth assays would allow identification of storage-induced changes in smoke composition and bioactivity. Studies should also explore the use of simple preservation strategies, such as filtration, sterilization, or antioxidant additives, to enhance ambient stability without compromising eco-friendliness.

Establishing evidence-based storage guidelines will be a decisive step toward standardizing PDS as a reliable growth regulator. Such guidelines would not only facilitate experimental reproducibility but also support the transition of plant-derived smoke from laboratory research to practical agricultural application.

V. CONCENTRATION-DEPENDENT GROWTH REGULATORY RESPONSES: HORMESIS AND DOSE OPTIMIZATION

One of the defining features of PDS is its concentration-dependent biological activity. Numerous studies have demonstrated that smoke solutions and isolated karrikins elicit biphasic responses, where low concentrations stimulate seed germination and early seedling growth, whereas higher concentrations may inhibit these processes. This phenomenon is characteristic of hormesis, a well-recognized principle in plant growth regulation whereby a compound exerts beneficial effects at low doses and adverse effects at higher doses.

Extensive experimental evidence indicates that highly diluted smoke solutions or nanomolar concentrations of KAR_1 are sufficient to trigger robust germination and growth responses. These low-dose effects include increased germination percentage, accelerated germination rate, enhanced seedling vigor, and improved early biomass accumulation. Such responses have been observed across a broad taxonomic range, including cereals, legumes, vegetables, and medicinal plants.

At the physiological level, low concentrations of PDS are associated with enhanced enzymatic activity, improved mobilization of seed reserves, and increased antioxidant capacity. These changes collectively promote rapid and uniform germination, which is a key determinant of successful crop establishment. Importantly, the effectiveness of PDS at extremely low concentrations makes it an economically attractive growth regulator, as only minimal quantities are required to achieve desired outcomes.

In contrast, higher concentrations of smoke solutions may exert inhibitory effects on germination and seedling growth. Such inhibition is often attributed to the presence of antagonistic compounds, including substituted butenolides, phenolics, and other combustion-derived metabolites that accumulate at higher doses. These compounds may interfere with hormonal balance, disrupt cellular redox homeostasis, or impair membrane integrity, thereby counteracting the positive effects of karrikins.

Priming protocols must balance sufficient exposure to stimulatory signals with avoidance of inhibitory effects. This balance can be achieved by optimizing dilution ratios, exposure duration, and application methods. In practice, smoke solutions are often diluted to very high degrees, sometimes exceeding 1:1000 or even 1:5000, to ensure that stimulatory compounds dominate.

However, such high dilutions may be impractical for large-scale application and may increase preparation time and resource use. Understanding the chemical composition of smoke solutions derived from different plant materials and storage conditions could allow the use of moderately higher concentrations without triggering inhibition. This represents an important area for future research with direct implications for the feasibility of PDS-based growth regulation.

VI. CHALLENGES OF OFF-SEASON CROP ESTABLISHMENT

Off-season crop production is increasingly viewed as a strategic approach to stabilize food supply, improve farmer income, and optimize land use. However, off-season planting is often constrained by unfavourable environmental conditions such as low or high temperatures, irregular rainfall, salinity buildup, and poor soil moisture. These factors significantly impair seed germination, seedling emergence, and early growth, leading to uneven crop stands and increased risk of crop failure.

Traditional approaches to off-season cultivation rely heavily on protected environments, chemical inputs, or energy-intensive practices, which may not be accessible or sustainable in many agricultural systems. Therefore, growth-regulatory interventions that enhance seed performance under suboptimal seasonal conditions are urgently needed. In this context, PDS offers a promising, low-input strategy for improving off-season crop establishment.

6.1 Potential of PDS-Based Seed Priming for Off-Season Planting

The growth-regulatory properties of PDS, particularly its ability to enhance germination and stress tolerance, make it well suited for off-season planting applications. Seed priming with PDS can advance physiological readiness, enabling seeds to germinate rapidly even when environmental conditions are marginal. This advantage is critical for off-season sowing, where delayed or uneven germination can severely compromise crop success.

Evidence from stress physiology studies suggests that PDS-primed seeds exhibit improved performance under temperature extremes, salinity, and moisture stress conditions commonly encountered during off-season cultivation. Enhanced antioxidant capacity, improved hormonal balance, and activation of stress-responsive pathways collectively contribute to greater resilience during early establishment. These attributes suggest that PDS-based priming could extend planting windows and enable cultivation beyond traditional seasonal boundaries.

6.2 Growth Regulation under Temperature Extremes

Temperature stress is a major limiting factor in off-season crop production. Low temperatures can delay germination and slow metabolic processes, while high temperatures can accelerate seed deterioration and disrupt cellular homeostasis. PDS-mediated growth regulation may help mitigate these effects by enhancing metabolic activation and stabilizing cellular functions during germination.

Although direct evidence linking PDS to temperature stress tolerance is limited, the observed improvements in germination under various abiotic stresses imply a broader capacity for thermal resilience. By modulating hormonal and redox signaling, PDS priming may help seeds maintain growth competence under non-optimal temperature regimes. These potential warrants targeted investigation, particularly for crops sensitive to thermal stress.

VII. KNOWLEDGE GAPS, STANDARDIZATION CHALLENGES, AND FUTURE RESEARCH DIRECTIONS

Despite extensive evidence supporting the growth-regulatory potential of PDS, its translation from experimental research to routine agricultural practice remains limited. This gap arises not from a lack of biological efficacy but from unresolved methodological, mechanistic, and application-related challenges. Addressing these limitations is essential for establishing PDS as a reliable, standardized tool in plant growth regulation and seed technology.

7.1 Standardization of Smoke Generation Protocols

One of the most significant challenges in PDS research is the absence of standardized protocols for smoke generation and application. Variations in plant species, plant part selection, biomass quantity, moisture content, combustion temperature, and smoke collection methods result in substantial variability in smoke composition and bioactivity. Future research should prioritize the development of standardized, reproducible smoke generation systems. Comparative studies evaluating controlled combustion parameters under uniform conditions would facilitate identification of optimal protocols. Establishing reference smoke solutions with known chemical profiles could serve as benchmarks for experimental and applied studies.

7.2 Plant Species and Plant-Part Specificity

Although numerous plant species have been used to generate smoke solutions, systematic evaluation of species-specific and organ-specific effects remains limited. Most studies rely on mixed biomass or leaves, leaving the contribution of stems, roots, bark, and reproductive organs largely unexplored. Given the biochemical heterogeneity among plant organs, this represents a major knowledge gap with direct implications for optimizing growth-regulatory efficacy.

Future investigations should focus on isolating the effects of individual plant parts on smoke chemistry and biological activity. Integrating chemical profiling with bioassays will help identify the most effective biomass sources and enable selective utilization of plant material for smoke production.

7.3 Storage Stability and Shelf-Life Optimization

The long-term stability of PDS solutions under different storage conditions is another critical yet under-investigated aspect. While refrigerated storage is commonly employed, its necessity has not been conclusively demonstrated. Comparative studies assessing the chemical integrity and growth-regulatory efficacy of refrigerated versus non-refrigerated smoke solutions are urgently needed.

Such research should aim to establish evidence-based shelf-life guidelines and identify simple preservation strategies that maintain bioactivity under ambient conditions. Achieving this goal would significantly enhance the practical utility and accessibility of PDS technology.

7.4 Dose–Response Calibration and Crop-Specific Optimization

The hormetic nature of PDS responses necessitates precise dose optimization, yet concentration ranges vary widely across studies. Species-specific sensitivity, seed physiology, and environmental context all influence dose–response relationships. Without standardized calibration, the risk of suboptimal or inhibitory effects remains high. Future research should focus on developing crop-specific and context-specific PDS application guidelines. High-throughput screening approaches combined with physiological and molecular analyses could accelerate dose optimization and improve reproducibility across different cropping systems.

7.5 Research Needs for Off-Season Application

Despite its promise, the application of PDS for off-season crop establishment remains largely underexplored. Field trials across diverse agro-climatic regions are needed to evaluate the consistency and magnitude of PDS effects under real-world conditions. Such studies should assess not only germination and early growth but also yield, quality, and economic viability.

Integrating PDS priming with other climate-smart agricultural practices, such as optimized sowing dates, irrigation management, and cultivar selection, could further enhance off-season production systems. Addressing these research needs will be essential for translating the growth-regulatory potential of PDS into tangible food security benefits.

VIII. CONCLUSION

Plant-Derived Smoke represents a unique and powerful class of natural growth regulators that bridge ecological insight with modern plant science and agriculture. Accumulated evidence clearly demonstrates that smoke-derived compounds, particularly karrikins, exert profound regulatory effects on seed germination, early seedling development, and stress resilience at exceptionally low concentrations. Unlike conventional growth regulators that act primarily through direct hormonal supplementation or nutrient input, PDS functions as a signaling system that modulates endogenous developmental and stress-response pathways.

This review highlights several underexplored yet strategically significant dimensions that will determine the future applicability of PDS technology. These include the influence of individual plant parts on smoke bioactivity, the feasibility of non-refrigerated storage without loss of efficacy, precise concentration optimization within hormetic response ranges, and the use of PDS-based priming to facilitate off-season crop establishment. Addressing these gaps will be essential for transforming PDS from an experimental biostimulant into a standardized, field-ready growth-regulatory intervention.

From a sustainability perspective, plant-derived smoke offers several advantages. It can be produced from locally available plant biomass or agricultural residues, requires minimal quantities for biological activity, and aligns with environmentally responsible farming practices. Its integration into seed technology and crop establishment strategies could reduce dependence on synthetic chemicals while enhancing resilience and productivity in both conventional and low-input agricultural systems.

In conclusion, plant-derived smoke represents an ecologically inspired, scientifically validated, and agriculturally relevant growth regulator with substantial untapped potential. Advancing its application will require interdisciplinary research integrating plant physiology, molecular biology, analytical chemistry, agronomy, and socio-economic assessment. With appropriate standardization, mechanistic refinement, and field validation, PDS-based technologies could play a meaningful role in sustainable plant growth regulation and climate-resilient agriculture.

List of Abbreviations

S. No.	Abbreviations	Meaning
1.	KAR_1	Karrikin-1
2.	PDS	Plant-Derived Smoke
3.	ROS	Reactive Oxygen Species

Declarations

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Data availability

This is a review article and no data was generated during manuscript preparation.

Competing interests

The authors have no competing interests to declare.

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Authors' contribution

P.P. contributed for the idea of the research article and critically revised the work. D.P. helped perform literature research and data analysis. All authors read and approved the final manuscript.

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