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Climate Change and Dravyaguna: Impact on Medicinal Plant Potency and Distribution

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ABSTRACT

Medicinal and aromatic plants (MAPs) are important for both modern medicine and traditional systems like Ayurveda. Climate change is having a big impact on their health, availability, and effectiveness. The way these plants grow, where they grow, and how long they live are all being affected by changes in the world's temperatures, rainfall patterns, and levels of CO_2 and ozone in the air. More importantly, these environmental stressors are messing up the synthesis and makeup of secondary metabolites, which are the chemicals that give plants their medicinal properties. When a plant is stressed, it may make more phytochemicals as part of its defense response. But a lot of other changes make the phytochemicals less effective or change how they work as medicines, which makes them less reliable in both traditional and modern medicine. These changes make problems like overharvesting, habitat loss, and ecological degradation worse. They put many important species at risk of extinction or endangerment. The effects are far-reaching, affecting not only biodiversity but also global health security and the long-term future of herbal medicine. This essay talks about how climate change affects Dravyaguna, which is the Ayurvedic way of understanding the properties of plants that can be used as medicine. It does this by studying how climate change affects plant resilience, phenology, and metabolic responses. The goal of this review is to help us better understand the problems that climate change will cause and to help us plan for the future to protect the effectiveness and availability of medicinal plants for future generations. It stresses the need for focused research, conservation strategies, and farming methods that can adapt.

KEYWORDS:- Medicinal Plants, Climate Change, Secondary Metabolites, Dravyaguna, Phenology

Introduction

Climate change has become one of the world's biggest problems in the last 20 years. It has a big impact on the environment and people [1]. People's greenhouse gas (GHG) emissions are now known to be the main cause of this, which is making the climate change and temperatures rise around the world [2]. Ecosystems on every continent are starting to change in big ways, even when the temperature only goes up by 1°C [3]. Changes in rainfall, more droughts and floods, and extreme weather events are all examples of these problems. All of these things have an effect on how plants grow, how much they produce, and where they grow [4].

Medicinal and aromatic plants (MAPs) are especially at risk from these changes because they have been an important part of many cultures' healthcare systems. For generations, people have used these plants in traditional medicine to stop and treat diseases, even outbreaks. Their secondary metabolites are what make them good for healing [5,6]. About 80% of people around the world use traditional plant-based medicine. In India alone, there are about 7,500 plants that are known to have healing properties [7–9]. But climate change is already changing these plants' biochemistry, how they grow, and where they live, which could make them less useful as medicine and make them more likely to go extinct [10–12].

Researchers have found that stressors like high CO_2 levels, heat, drought, and ozone change the way plants make secondary metabolites, which are the chemicals that make plants useful for medicine [13,14]. Dravyaguna, the Ayurvedic science that studies and classifies medicinal plants based on their properties and effects, is especially worried about this. Recent studies and traditional ecological knowledge both show that wild medicinal plant populations are quickly declining, especially in dry and mountainous areas [15–18].

Even though medicinal plants are important, there isn't a lot of research on how climate change affects them compared to other crops [19]. We need to do more in-depth, region-specific studies right away because many of these species are important to the world's health and economy. A full understanding of how climate stressors affect the distribution, potency, and survival of medicinal plants is necessary for conservation efforts, adaptive cultivation strategies, and policy interventions [20].

The purpose of this review is to find out how climate change affects the timing, chemical makeup, and range of medicinal plants. It also says that we should protect the healing properties of these plants by combining traditional knowledge systems like Dravyaguna with modern ecological research.

Therapeutic Role of Secondary Metabolites in Medicinal and Aromatic Plants

The Healing Powers of Secondary Metabolites in Plants That Are Used for Medicine and Scent

Plants have learned how to make secondary metabolites, which are bioactive compounds that don't directly help with growth or development but are very important for the environment and medicine [21]. These chemicals tend to show up when the environment is under stress, like when there is a drought, heat, or an attack by microbes [22]. Even though they only happen in some species, their production is a key adaptive feature that makes many plants useful for medicine.

Glycosides are a large group of secondary metabolites. Sugars that are connected to things that aren't carbohydrates make them up. Cardiac glycosides, for example, are used to treat heart failure and arrhythmias. These are just a few of their many medical uses. Digitalis purpurea, D. lanata, Nerium oleander, and Convallaria majalis are all well-known plants that can be used as sources [23,24].

Flavonoids and proanthocyanidins are common plant pigments that are very important for keeping people healthy and protecting them from free radicals. The Fabaceae family includes isoflavones, which are a type of plant. People really like them because they can mimic estrogen [25]. Tannins, which can be either condensed or broken down by water, help keep plants safe. Most of them are in the Fagaceae and Polygonaceae families [24]. Another important group is pyrrolizidine alkaloids. They have a lot of different biological effects, such as protecting nerves and fighting cancer [26].

Understanding Climate Change and Its Origins

The sun, air, oceans, and land all work together in different ways to change the climate on Earth. It shows how things like wind, temperature, and rain have changed over time. The World Meteorological Organization (WMO) says that climate is usually looked at over a 30-year period to see how it has changed over time. A lot of people call it "average weather."

Climate is a broader term that includes both the current state of the Earth's climate systems and a statistical overview of them. Climate change is when the average or range of climatic factors changes a lot over a long period of time. The World Health Organization says that climate change is a change in the weather that lasts for decades or longer and is easy to see. The Intergovernmental Panel on Climate Change (IPCC) says that climate change is any change in the climate that lasts for a long time and is caused by either natural processes or people. The UN Framework Convention on Climate Change (UNFCCC), on the other hand, looks at how people change the climate. It says that a change in climate is one that is caused directly or indirectly by human actions that change the composition of the atmosphere and is bigger than the natural changes that happen over similar time periods. [45]

Phenological and Ecological Shifts in Medicinal Plants Due to Climate Change

Climate change is causing big changes in the seasonal patterns of plant life cycles. This is called *phenological change*. Things like bud burst, leaf unfolding, flowering, fruit formation, and leaf fall are getting messed up, especially in medicinal plants that have adapted to certain weather patterns [46]. The start of spring and the length of the growing season are changing as the world's temperatures rise. When CO_2 and temperature levels are higher, for example, Trifolium repens flowers 1 to 11 days earlier [47]. Aconitum heterophyllum blooms earlier, and Valeriana jatamansi and Hypericum perforatum grow faster when the environment changes in the same way [48–50].

These biological changes are a part of a bigger problem: the world is getting warmer. More greenhouse gases, such as CO_2, methane, nitrous oxide, and chlorofluorocarbons, have been released into the air since the Industrial Revolution. This has messed up the balance of the atmosphere and climate systems [51,52]. In 1765, there were 280 parts per million (ppm) of CO_2 in the air. By 2000, that number had risen to 364 ppm. It's hard to say exactly how these changes affect global temperature trends because all of Earth's systems are connected, but the overall effect is clear [53].

Plants that are used for medicine, especially those that are native to a certain area, are very fragile. More rain, longer and hotter summers, weaker dry seasons, and more storms, as well as habitat loss and pollinator loss, are all big threats to their survival and spread [54,55]. Not only do these changes hurt biodiversity, but they also make it harder for people to get to traditional medicines that help people all over the world. These changes in the life cycle events are examples of how climate change affects the whole environment. As we will see in the next section, environmental stressors not only change where and when plants grow, but they also change how plants work and how they make medicine.

Effects of Environmental Stress on Medicinal Plants

Environmental stressors such as elevated carbon dioxide (CO_2), ozone (O_3), ultraviolet (UV) radiation, high temperatures, salinity, and atmospheric pollutants like sulfur dioxide (SO_2) have a profound influence on the growth, physiology, and metabolic profiles of medicinal plants. While some of these factors may initially stimulate plant defense mechanisms and lead to enhanced production of certain secondary metabolites, prolonged or extreme exposure often results in detrimental impacts—ranging from impaired photosynthesis and reduced biomass to delayed germination and altered phytochemical content.

Elevated CO_2, for example, can boost photosynthetic activity and increase the production of compounds like flavonoids and alkaloids, yet it also contributes to global warming, compounding other stress effects. Ozone, despite its protective role against UV rays in the upper atmosphere, becomes a harmful pollutant at ground level, damaging leaf tissue and altering phenolic content in many herbs. High temperatures can reduce chlorophyll levels and

disrupt enzyme activities, while inducing osmolyte accumulation as a stress adaptation. Similarly, UV radiation may trigger the synthesis of antioxidant metabolites but can damage DNA and cellular proteins. Salinity and toxic gases like SO_2 hinder germination, stunt growth, and disrupt secondary metabolite pathways crucial for medicinal value.

Understanding how different environmental stressors affect medicinal plants is essential for safeguarding both biodiversity and the quality of herbal resources. The following table summarizes case studies and research findings that highlight specific plant responses to these stressors, particularly in relation to changes in their phytochemical compositions and therapeutic potential.

Table 1: Effects of Environmental Stress on Medicinal Plants [45] [56]

Stress Type	Affected Medicinal Plant	Observed Changes in Secondary Metabolites
Elevated CO_2	Catharanthus roseus	↑ Phenolics, Flavonoids, Tannins, Alkaloids
	Zingiber officinale	↑ Flavonoids, Phenolics
	Digitalis lanata	↑ Digoxin, Cardenolides
	Papaver setigerum	↑ Morphine, Codeine, Papaverine, Noscapine
	Mentha piperita	↑ Flavonoids (with moderate CO_2)
	Artemisia annua	↑ Artemisinin
	Ocimum basilicum, Thymus vulgaris	↑ Biomass, fresh weight, formal leaf and root numbers
Elevated CO_2 + Temp	Hypericum perforatum	↓ Hypericin concentration, advanced phenological stages
Elevated O_3	Salvia officinalis	↑ Gallic acid (2x), Caffeic acid (8x), Rosmarinic acid (+122%)
	Melissa officinalis	↑ Phenolics, Anthocyanins, Tannins
	Pueraria thomsnii	↑ Puerarin, ABA
	Hypericum perforatum	↑ Hypericin, Phenols, Flavonoids (Quercetin, Kaempferol)
	Capsicum baccatum	↓ Capsaicin, ↑ Dihydrocapsaicin
Drought Stress	Centella asiatica	↑ Terpenoids, Phenolics, Alkaloids, etc.
	Scutellaria baicalensis	↑ Baicalin under mild stress, ↓ under severe
	Glycyrrhiza glabra	↑ Glycyrrhizin (mild/moderate stress), ↓ (severe)
	Mentha piperita, Catharanthus roseus	↓ Phenols, Flavonoids, Saponins; ↑ Tannins, Terpenoids, Alkaloids
Cold Stress	Foeniculum vulgare	↑ Antioxidant activity, changes in chlorophyll & β-carotene
	Withania somnifera	↑ Withanolides under low temperature
	Cistus incanus, Teucrium polium, etc.	Activated antioxidant responses, seasonal dimorphism

These findings underline the necessity for adaptive cultivation strategies and conservation planning. By monitoring the influence of environmental stressors on medicinal plants, researchers and policymakers can better protect traditional medicine sources and ensure their sustainability for future generations

Vulnerability and Extinction Risks of Medicinal Plants

Many medicinal plant species are increasingly at risk due to both climate change and anthropogenic pressures. Over the past 250 years, approximately 600 plant species have gone extinct globally, signaling a major biodiversity crisis [57]. Climate projections for Kenya indicate that 14–24% of anti-

malarial plant species may become Critically Endangered (CR) and 14–29% Endangered (EN) under all future scenarios [58]. This highlights the vulnerability of medicinal flora even under optimistic climatic models.

In addition to climate factors, human activities such as habitat destruction, fragmentation, and land conversion contribute significantly to plant loss, resulting in small, isolated populations more prone to extinction [59,60]. Other threats include the spread of invasive species and exotic pathogens, which destabilize native ecosystems and affect native plant health [61].

Medicinal plants with high commercial value are particularly endangered due to overharvesting. A prime example is American ginseng (*Panax quinquefolius* L.), widely used for treating fatigue, hypertension, and respiratory infections. The species is heavily exported to China, and due to rising demand, has suffered from declining stature, abundance, and illegal harvesting, threatening its sustainability [62].

Climate change may also render some current habitats unsuitable, forcing species to either adapt, migrate, or face decline [63,64]. Some species may find more favorable conditions and expand their range, but this often leads to increased competition in new environments. According to Lamprecht et al., many species are shifting their ranges to higher latitudes or elevations, disrupting existing ecological balances [65].

Another growing concern is the disruption of plant-pollinator relationships due to shifting phenologies. As climate alters flowering times and pollinator behavior, reproductive success in many species is threatened [66]. This is compounded by drastic declines in insect populations caused by habitat loss and chemical pollution [67].

Conclusion and Recommendations

Medicinal and aromatic plants have served as vital components of human health and traditional medicine for centuries, even amid rapid advancements in the modern pharmaceutical industry. However, these valuable resources are now under increasing threat from climate change, environmental stressors, and unsustainable human practices.

This review highlights how climate-related stressors—such as heat, drought, elevated CO_2, ozone, salinity, and cold—affect the growth, distribution, and most critically, the production of secondary metabolites that give medicinal plants their therapeutic potency. These stressors can lead to physiological disturbances, oxidative damage, and metabolic shifts, sometimes reducing the medicinal quality of plant species or altering their chemical profiles in ways that may be harmful or less effective.

Endangered and high-value medicinal plants are particularly vulnerable. Shifts in climate zones, habitat fragmentation, overharvesting, and the disruption of ecological relationships like pollination are accelerating the risk of extinction for many species. With over 600 plant species lost in the last 250 years and many more projected to decline, the urgency to act has never been greater.

To safeguard these natural assets, the following steps are recommended:

- **Expand field-based and long-term climate impact studies** to better understand how stress conditions influence plant adaptation, productivity, and secondary metabolite profiles across diverse ecosystems.
- **Investigate the full spectrum of phytochemical changes** in response to environmental stress, not just the target compounds, to avoid overlooking the emergence of harmful or ineffective constituents.
- **Promote sustainable cultivation and harvesting practices** by involving local communities and integrating indigenous knowledge systems that have historically ensured plant conservation and responsible use.
- **Develop conservation strategies for threatened species**, including in-situ preservation, habitat restoration, and the use of predictive models to anticipate shifts in plant distributions under different climate scenarios.
- **Encourage interdisciplinary research** into plant-soil feedbacks, pollinator interactions, and stress physiology, which will be vital in building a holistic understanding of climate impacts.

Ultimately, preserving the efficacy, availability, and biodiversity of medicinal plants requires both scientific innovation and ecological responsibility. As the climate continues to change, so must our strategies for protecting the plants that have sustained humanity's health for generations.

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