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PARTICULATE MATTERS EFFECT ON MAIZE POLLINATION, FOOD SECURITY AND HUMAN HEALTH

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ABSTRACT

Maize (*Zea mays* L.) is a short photoperiodic C_4 crop. It affects atmospheric carbon dioxide level and en-rich O_2 from plant population. Maize crops are more O_3 exposure elevated significantly and decline grain yields due to inactive pollen grains in heavy sunlight. The elevated CO_2 significantly increased the leaf area index, chlorophyll content and photosynthetic capacity. Airborne particulate matters (O_3, CO, NO_2, SO_2, Pb) are a born particle of the atmosphere that inactivates pollen grains of maize crop and affecting maize grain yield from fertilization during *Rabi* season. These particulate matters affecting also food securities and human health along maize crop grain yield. This article is providing a view of maize crop grain yield and food securities from particulate matters under field condition.

Keywords: Airborne particulate matter, Maize, Pollination, Yields and Health.

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Introduction

Particulate matter (PM) is a solid-liquid particle in the air. Solid particle of air having different sizes from 0.7–1 mm that accumulated by coagulation of ultra fine particles. Air particles are more distributed from road, traffics air environment about 58–68% (Wrobel, 2000). Combustion, mining, cooking, smoking, vehicles, and industrial emissions human activities are major causes of air pollution origin. These pollutants are originated to different sources of stationary and automobile industries in urban areas (Mishra et al., 2019). A complex chemical structure is generated to the environmental solid and liquid matter and generated into atmospheric matters like O_3 and NO_2 (Morillas et al., 2016). The atmospheric pollutants deposited onto different flora and fauna of earth by accumulating rain, snow, and fog droplets. Most pollutants are also remaining either in small particles of the soil and water (Liu et al., 2020). Urban road soil or dust are mostly pollutant originate by inorganic particles or heavy metals (Pb, Cd, Cr, Ni, Zn, Cu, etc.) which direct influence on human health as it can easily enter into human bodies from inhalation, dermal contact and dust ingestion. Previous report observed that heavy metals easily deposit in fatty tissues of human and affecting different problems in the body due to endocrinal system disrupting (Duzgoren-Aydin, 2007). Such type creates carcinogenic, terato-genic and mutagenic disease in the body tissues of human. The C, O, Al, Si, K, Ca, Fe and Ni are generated in the troposphere due to human activity and create soil pollution. These carbon particles are more releases to diesel exhaust by vehicular emissions in India (Pachauri et al., 2013) and affected our environment by deposition on surface soil. This PM is following types:

(a) Ozone (O_3)

O_3 is environmental gases create from the joining of two oxygen atom under high electric condition. It is a strong oxidant about 52% stronger than chlorine gas. O_3 is creating in stratosphere by a chain of photochemical smog in the troposphere. It is reform from carbon assimilation and reduces growth of maize crop from act to natural environment in different soil micro flora (Alexopoulos et al., 2017).

(b) Carbon Monoxide (CO)

The incomplete combustion of fossil fuels is more generate carbon monoxide in stratosphere. The contacting of carbon monoxide to human lungs causes headache, dizziness and producing weakness, nausea, vomiting due to losses consciousness in normal people. CO is bind greater from haemoglobin than oxygen and causes poisoning condition. The high levels of CO loss of oxygen from competitive binding of CO and creates hypoxia, ischemia, and cardiovascular disease in long duration. The insufficient amount of CO is produces green houses gases and creates global warming condition in India. The global warming condition is increases soil and water temperatures in any area of weather (Emberson et al., 2017).

(c) Nitrogen Di-oxide (NO_2)

NO_2 is a traffic-related pollutant and created from automobile motor vehicles. NO_2 concentration is increases over 0.2 ppm amount due to T-lymphocytes and Natural Killer cells property change to which it produces adverse effects in human body (Richmont et al., 2017). This condition observed from disturbing immune system of our body. Often first produces eye, throat and nose irritation in men from increasing NO_2 in our environment. It also causes different respiratory diseases, coughing, wheezing, broncho-spasm and produces pulmonary edema from inhalation more amount of NO_2 after binding to lungs alveoli (Chen et al., 2007). It is emerging chronic lung disease after long term exposure of high levels NO_2 and also reduces maize crop leaf growth.

(d) **Sulfur Di-oxide (SO_2)**

SO_2 is generated from incomplete consumption of fossil fuel. It is a harmful gas that releases from industries and affects human, animal, and plant life. SO_2 is produces chronic lung disease in children and old people which living near industrial zone. Men are feeling irritation, bronchitis, mucus production and broncho-spasm after infection in respiratory system. Infected person's skin sowing redness and it damages mucous membranes of eye. SO_2 is annually produces 0.03 ppm. It is pre-existing symptoms of cardiovascular disease (Chen et al., 2007). SO_2 is produces acid rain and causes acidification of the agricultural soils.

(e) Lead (Pb)

Pb is more using industrial heavy metals that generated from petrol engines, batteries, radiators, waste incinerators, and waste waters. Pb pollutants are mostly produces from metals, ore, and piston engine aircraft in Industry. It is enter in body from inhalation, ingestion, and dermal absorption and produces more toxic effects on the foetus and damages nervous system from brain swelling (NIH; 2017). Pb is accumulates in the blood system, soft tissue, liver, lung, bones, reproductive systems, cardiovascular and nervous system and produces chronic muscles and joint pain. Farhat et al (2017) reported children's are mostly suspected from Pb in metro cities. The children's are suffer to learning disabilities, hyperactivity and mental retardation. High amount of leads are showing harmful effect on maize crop growth rate.

The glumes of spikelet of the floret are designed to express anthesis to which a successful promotion create in pollination but also environmental heat stress lightly decreases spikelet tolerance from male gametophyte development. The maize ear is wrapped to multiple layers of husk. The maize husk leaves are control about 2-3 ^{o}C temperature inside from the outside temperature of the ear to which it easily situated in the middle section of the maize crop (Wang et al., 2023). The major objectives of the present article is entitled "Impact of Particulate Matter on Pollination Diversity and Food Security in maize crop" which assesses different pollutants associated with soil surface contamination and losses maize yield due to pollination shock.

Particulate Matters effect on Maize Crop pollination

Maize is popular form of 'cereal queen' name, it is cultivated whole year in India due to higher yield potency and easily grow under different soils and minimum moisture condition. Maize is a field crop and, its pollen grain is highly sensitive to heat during fertilization. Minimum effect of heat stress (About 2 week) is greater affects kernel number in per ear than pre-silking stage of stress during silking stage (Liu et al., 2022). Maize pollen grain is larger from 80-125 μm in diameter which easily spread in any crop environment from wind flow. Silk emerging is an important property of maize crop which occurs only some days in whole plant life of maize; it easily influences to high temperature during flowering time of maize crop to which decreases seed settlement on maize cob. Wang et al (2020) recorded some experiment of maize under control environment and explain 5 days of pre-silking environmental stress (3-4^{0}C) reduced 10% maize seed set (22-32^{o}C), whereas 5-days post-silking environmental stress reduced seed set by 23%.

Biologically a pollen grain is releases active lipids, air pollutants that modify pollen allergens through interaction of other spores. These air pollutants bind to allergens and create allergic disorders in men. Maize pollen grains are showing some protection against some air pollutant but it not fully active in dry environment. D'amato et al (2007) a data recorded

(Table 1) from the polluted field and recover to the control pollutant level. The pollutant is affected more to sample site and flowering of maize crop. Song et al. (2022) observed economic condition of maize crop yields due to climate change. It is grown about 150 m/ha in irrigated soils and contributes 36% global production. Atmospheric CO_2 increases photosynthesis, dry matter production, and yields in maize crop due to transpiration and rate of stomata conductance and increases water-use efficiency.

Waongo et al. (2015) reported that the temperature increase annually about 2°C from CO_2 to which reduces maize crop yield in eastern India. Higher level of CO_2 increases water demand and increases biomass in maize crop production. Several studies also found that higher atmospheric CO_2 is affect maize crop than less nutrient stress crops under high nutrient enrich environment. The impact of change annual temperature on maize crop yield and stem growth is quite sparse. Armentia et al (2017) collected allergens from different samples of maize and recorded morphological condition of pollination. In vitro and in vivo more number of pollens allergens is recorded from urban areas than rural areas. The polluted sites are shows higher number of allergens of pollen that more contribute to conformational transformations than post translational modifications.

Particulate Matters effect on Maize crop grain yield

Global yield of maize crops is down from seasonal increasing temperature during flowering condition from excess releasing CO_2. Therefore, CO_2 carrying crop resilience is not increase O_2 level. Annually increasing CO_2 is maize yield declines about 7.4% in the major cropping systems due to climate change and low rainfall in India (Ainsworth and Long, 2020). Temperature is meteorological determinant of maize crop development; it alters enzyme function in a leaf and triggers changes in developing stage of maize crop that tightly coupled with crop yield. The metabolic function is increases from increasing temperature and catalytic activity increases by Rubisco carboxylation. The Rubisco oxygenation ratio is increasing plant temperature and releases more 2-phosphoglycolate in photo-respiratory system and losses of previously stored carbon. The Rubisco is decreases ratio of carboxylation with the help of oxygen and decreases of flowing plant system temperature (Walker et al., 2016). CO_2 is collected more around Rubisco in C_4 cycle of chloroplast bundle sheath. Now, activation of photorespiration is down from increasing temperatures and maize crop can absorb more temperature than C_3 crop. The aeration and soil condition is also more help in the absorption of environmental temperature. It catalysing oxygenation of RuBP therefore Rubisco is a bi-functional enzyme in capturing environment CO_2 (Bathellier et al., 2020). Thus temperature is a limiting factor for C_4 photosynthesis and inactivation of Rubisco by C_4 bundle sheath enzymes. Maize is multi environmental crop that grow in different temperature and yield is less (0.8- 1.2%) affected during *Kharif* season; but exposure of particulate matter (PM) on maize crop yield is total losses. PM is deposit in maize crop leaf during early vegetative stage of life and yield losses in harvesting stage. Maize crop yield is also decreases to exposure of PM to which stomata blockage, and necrosis create during leaf let stage that decline yields (5-10%). Few studies and extant literatures are exploring intricacies of PM and dust deposition on maize leaf at road side due to contribute in yield losses (Hatami et al., 2018). The PM is more produces from large-scale biomass burning and ammonium emissions with crop residue combustion.

The winter organic carbon is accounting up to 45% of the total PM with 25% contribution of burning biomass. The particulate matter is indirect effect to deposit aerosol matter on leaf and scatters it by photoreceptors that reducing energy and carbon fixing (Wang et al., 2019). Increasing leaf temperature of a crop variety is increase photosynthesis rate or halt photosynthesis. Some maize crop varieties is growing in more temperature and dust polluted area in many region of India but yield is slow such as highway region (Dubey et al., 2020). In this area mostly farmers used maize crop production as fodder purpose. The photosynthesis is slow in maize crop after blockage of adaxial leaf stomata and reduced gas exchange in tissue system. The PM is an insulator for increasing leaf temperature but it also reduces to rainfall and presence of moisture in air.

Particulate Matters (PM) effect of Food securities

PM is a regulatory factor for air pollutant and its effect recently identified in the maize crops. Maize is nourishes about 10% of the world's population, in absence of tryptophan million premature children's suffering from malnutrition (UNICEF, 2021). 98% population of the lower and middle-income person is suffering from malnutrition. Middle and lower latitudes areas are more affected from climate change. Increasing global temperature and air pollutions are facing risk for failure crop production in middle and lower latitudes areas (IPCC, 2022). O_3 is trice oxygen molecule and breaking down as double oxygen (O_2) in the lower atmosphere. The O_2 is easily acted to UV light and include in suns UV radiation. More sunlight is create vital effect in the formation of O_3 in troposphere and reduced actual form of sun light at the earth surface. PM and O_3 interaction is more important for study modification in maize crop physiology. More amount of O_3 is recorded from the state of New Delhi, Panjab, Hariyana, U.P., Bihar and some areas of Bengal. Normally PM is increases O_3 formation rate in the form of NOx. NOx is a type of factor for O_3 formation from photochemical interaction (Sicard et al., 2020). Many records proof that lower rate of NOx is down and compressed MP from light interception by causing O_3 interaction.

Avnery et al (2011) observed that O3 is creating a type of global risk on maize crop yield in the nearest year 2030. Maize crop cob length (cm) and grains number are reduced PM affected areas. Therefore PM will be produce food crisis in future. The exploiting of population was first problems and PM become second problems in food production according to our demand. So it is need for Indian formers to produce resistant Quality Protein maize (QPM) hybrid varieties like HQPM-1. The QPM hybrids are recorded better production in India (Achchhelal et al., 2020).

Particulate Matters effect on Human Health

Airborne PM consistence a heterogeneous mixture of solid and liquid suspension particles in air that chemical concentration is dissolve to moisture contact. PM is heart associated materials that increased or decreased heart-rate function with cardiac arrhythmias. After long time exposure it observed in the form of lung cancer and chronic pulmonary disease in urban area which causes mortality. The lung cancer is increasing (0.5%) as global incidence in a year. Such disease is caused with air pollutant that infects tissues of human lung. The PM is reduces the life span of the population about 8 months from the average duration (Krewski, 2009). Atmospheric air pollutants spread human health problems through ammonia, hydrogen sulphide, pesticides, particulate matter and some agricultural air pollutants.

Agricultural air pollutants distribute to environment and climate change of Indian ecosystem by emission of greenhouse gas and aerosols. Agricultural air pollutants also contact to soil active nitrogen, eutro-phication and acidification of agricultural soil and can endangered biodiversity. Inorganic ammonia is playing dangerous role in environmental crisis through interactions of different compounds in the atmosphere. Chemical constituents of PM are distributed through biological compounds and metals. Fang et al (2013) reported approximately 3% cardiopulmonary and 5% lung cancer deaths are observed from PM. The PM causes more dangerous to human health than ozone and also other common air pollutants (as carbon monoxide).

Conclusion

High quantity of CO_2 increases carbon uptake and yield of maize crop but increased amount of other PM is decline the nutrient content in maize crop due to exposure. The PM is decreases air quality of environment during *Rabi* season. Higher quantity PM is produces from road side soil than the residential soil. The road is produces high anthropogenic elements (Pb, Cd, Zn, Mn, and Ni) due to vehicular diesel and petrol exhaust. Physio-chemical processes of maize crop is reduces to dust coating on leaf and movement of pollen grains. It decreases nutrient quality due to absorption of pollutant. In the recent forming system a responsibility of formers that to be select PM resistant maize crop varieties to which neither loss of grain yield and nor defect human health. Farmers become use to sprinkler irrigation for road side crop irrigation that wash dust particles of maize crop leaf and help in pollen grain transfer from anthers to silk.

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General Mini Review Article

AGRICULTURAL SUSTAINABILITY IN THE FACE OF CLIMATE CHANGE

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Abstract

Agriculture is facing unprecedented challenges due to climate change, with rising temperatures, shifting precipitation patterns, and increased frequency of extreme weather events significantly impacting crop yields, livestock productivity, and overall food security. This paper explores the multifaceted effects of climate change on agriculture and examines potential adaptation and mitigation strategies to ensure agricultural sustainability. Rising global temperatures accelerate crop maturation, reduce yields, and exacerbate heat stress in livestock. Studies indicate that for every 1°C increase in temperature, maize yields decline by approximately 7.4%, while wheat and rice also experience significant productivity losses. Changing rainfall patterns contribute to water scarcity and flooding, disrupting irrigation systems and degrading soil health. Extreme weather events, such as hurricanes, droughts, and wildfires, further threaten agricultural stability, leading to economic losses and displacement of farming communities. Additionally, climate change influences pest and disease distribution, necessitating increased pesticide use and adaptive management strategies. To address these challenges, various adaptation and mitigation approaches are being explored. The development of climate-resilient crop varieties, improved water management techniques, and precision agriculture are crucial in sustaining agricultural productivity. Efficient irrigation systems, rainwater harvesting, and soil moisture conservation techniques can enhance water-use efficiency. Furthermore, technological advancements, including AI-driven climate modeling, early warning systems, and renewable energy solutions, play a pivotal role in building climate resilience in agriculture. This paper underscores the urgency of collaborative efforts among policymakers, scientists, and farmers to develop and implement sustainable agricultural practices. By integrating traditional knowledge with innovative technologies, the agricultural sector can adapt to climate-induced changes and ensure food security for future generations. The findings highlight the need for immediate action to mitigate climate risks and promote resilience in global agricultural systems.

Keywords: Agricultural sustainability, Climate change, Crop yields, Water management, Extreme weather events, Food security, Adaptation strategies, Technological innovations, Water scarcity, Climate resilience.

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Introduction

Climate change is exerting profound and multifaceted impacts on agriculture, a sector integral to human sustenance and economic stability. The intricate interplay of rising temperatures, altered precipitation patterns, and the increasing frequency of extreme weather events is reshaping agricultural practices and outcomes across the globe (IPCC, 2021).

One of the most immediate effects of climate change on agriculture is the alteration of crop yields. Elevated temperatures can accelerate crop maturation, leading to reduced yields. Studies indicate that for every 1°C increase in global temperature, maize yields may decline by approximately 7.4% (Lobell et al., 2011). Additionally, higher temperatures can exacerbate heat stress in livestock, diminishing productivity and increasing susceptibility to diseases (Thornton et al., 2009). Altered precipitation patterns further complicate agricultural productivity. Climate change is disrupting traditional rainfall patterns, resulting in both droughts and excessive rainfall (Trenberth, 2011). These changes can lead to water scarcity, affecting irrigation practices, or cause flooding, which damages crops and degrades soil quality (FAO, 2020). Such variability poses challenges for farmers in planning and sustaining consistent agricultural output.

The increasing frequency of extreme weather events, such as hurricanes, heatwaves, and storms, has direct and devastating effects on agriculture. For example, in 2024, France experienced excessive rainfall leading to a 22% decline in cereal production, highlighting the vulnerability of agricultural systems to climate-induced weather anomalies (OECD, 2024).
Climate change also influences the prevalence and distribution of pests and diseases. Warmer temperatures and changing climates can expand the habitats of pests and pathogens, leading to increased infestations and crop diseases (Bebber et al., 2013). This proliferation necessitates greater use of pesticides, which can have environmental and economic consequences.

Soil health, a cornerstone of productive agriculture, is also at risk. Climate-induced factors such as increased rainfall intensity and prolonged droughts contribute to soil erosion and degradation (Lal, 2004). This degradation reduces soil fertility, affecting crop productivity and necessitating more intensive land management practices.
The cumulative effects of climate change on agriculture threaten global food security. Declining crop yields and livestock productivity can lead to higher food prices and increased hunger, particularly in vulnerable regions (FAO, 2019). For instance, Japan recently released 210,000 tonnes from its emergency rice stockpile to stabilize soaring prices caused by record summer heat and distribution challenges (Japan Ministry of Agriculture, 2024).

In response to these challenges, adaptation and mitigation strategies are being developed and implemented. The development of climate-resilient crop varieties is essential. In India, scientists are focusing on creating rice strains that can withstand extreme weather, require less water, and offer better yields, aiming to ensure agricultural sustainability amidst changing climatic conditions (ICAR, 2023).

I. Rising Temperatures and Crop Yields

Rising global temperatures are exerting significant pressure on agricultural systems, particularly affecting crop yields. The relationship between increased temperatures and crop productivity is complex, involving factors such as accelerated plant development, heat stress, and altered water availability (Lobell et al., 2011).

Impact on Major Crops: Maize (corn) is notably sensitive to temperature increases. Research indicates that for every 1°C rise in global temperature, maize yields may decline by approximately 7.4% (Zhao et al., 2017). This sensitivity is attributed to maize's specific growth requirements and its limited ability to adapt to heat stress. Wheat exhibits a more nuanced response to rising temperatures. While some studies suggest that moderate warming could initially benefit wheat yields in certain regions, further temperature increases are expected to have detrimental effects. A meta-analysis concluded that global wheat yield decreases by about 6% for each 1°C increase in temperature (Asseng et al., 2015). Rice, a staple food for a significant portion of the world's population, is also vulnerable. Elevated temperatures can lead to sterility in rice flowers, reducing grain quality and yield. Studies have shown that temperature increases alone can reduce global rice yields by 3.2% per 1°C rise (Peng et al., 2004). Soybeans face challenges under rising temperatures as well. Higher temperatures can impair photosynthesis and increase respiration rates, leading to lower yields. Research indicates that global soybean yields decrease by approximately 3.1% for each 1°C increase in temperature (Rasmussen et al., 2018).

Mechanisms of Yield Reduction: The decline in crop yields due to rising temperatures can be attributed to several physiological and environmental mechanisms:

Accelerated Phenological Development: Higher temperatures speed up the growth cycle of crops, leading to shorter periods for grain filling and, consequently, reduced yields (Hatfield & Prueger, 2015).

Heat Stress: Elevated temperatures, especially during critical growth stages like flowering, can cause heat stress, leading to reduced fertility and grain quality (Teixeira et al., 2013).

Increased Evapotranspiration: Warmer temperatures enhance water loss from both soil and plants, increasing the risk of drought conditions and water stress, which adversely affect crop growth (Fischer et al., 2014).

Pest and Disease Proliferation: Rising temperatures can expand the habitats of pests and pathogens, leading to increased infestations and crop diseases (Deutsch et al., 2018).

Adaptation Strategies

To mitigate the adverse effects of rising temperatures on crop yields, several adaptation strategies are being explored:

- Breeding and genetically engineering crops to withstand higher temperatures are crucial. For instance, scientists in China are developing heat-tolerant potato varieties to address climate-induced yield reductions (Zhang et al., 2020).
- Implementing efficient irrigation systems and water conservation practices can help alleviate water stress caused by increased evapotranspiration (Döll et al., 2018).
- Altering planting dates to avoid peak temperature periods can reduce heat exposure during sensitive growth stages (Craufurd & Wheeler, 2009).
- Integrating trees into farming systems can provide shade and reduce heat stress on crops (Lobell et al., 2011).

II. Changing Rainfall Patterns and Water Scarcity

Climate change is altering global precipitation patterns, leading to increased variability in rainfall and exacerbating water scarcity issues (IPCC, 2021). Changes in rainfall distribution, frequency, and intensity are affecting agriculture, water supply, and ecosystems worldwide. While some regions experience excessive rainfall and flooding, others face prolonged droughts and declining water availability (Huang et al., 2016). Understanding these changing patterns and their implications is crucial for developing effective water management strategies.

Changing Rainfall Patterns: One of the most significant impacts of climate change is the shift in global rainfall patterns. Many regions have observed an increase in extreme weather events, including both intense storms and prolonged dry periods (Trenberth, 2011). For example, the South Asian monsoon, which provides essential rainfall for agriculture, has become more erratic, leading to both floods and droughts in different years (Singh et al., 2014). Similarly, the Mediterranean region is experiencing declining annual precipitation, increasing the risk of desertification (García-Ruiz et al., 2011). Additionally, changes in rainfall patterns are affecting groundwater recharge rates. In many areas, irregular precipitation prevents adequate replenishment of underground water reserves, leading to long-term declines in water availability (Taylor et al., 2013). This is particularly concerning for arid and semi-arid regions that rely on groundwater as their primary water source.

Water Scarcity and Its Implications: Water scarcity is becoming a critical issue, driven by both changing rainfall patterns and increasing demand for water. More than 2 billion people worldwide already experience high water stress, and this number is expected to rise due to population growth and climate change (WWAP, 2019). Water scarcity can be classified into two types:

1. Physical Water Scarcity – Occurs when natural water sources are insufficient to meet demand, often seen in arid regions (Mekonnen & Hoekstra, 2016).
2. Economic Water Scarcity – Arises when a lack of infrastructure prevents access to available water resources, affecting many developing countries (Rosa et al., 2020).

In agriculture, changing rainfall patterns and water scarcity threaten food production. Crops depend on consistent water supply, and unpredictable precipitation can lead to reduced yields or crop failures (Lobell et al., 2011). For example, persistent droughts in California have severely impacted the agricultural sector, leading to economic losses and water rationing measures (Griffin & Anchukaitis, 2014).

Adaptation and Mitigation Strategies

- To address these challenges, several strategies have been proposed:
- Improved Water Management: Efficient irrigation techniques, such as drip irrigation, can help conserve water and improve agricultural resilience (Jägermeyr et al., 2016).
- Rainwater Harvesting: Collecting and storing rainwater for future use is a viable solution, especially in regions with seasonal rainfall patterns (Kahinda et al., 2007).
- Desalination and Water Recycling: Technologies that convert seawater into freshwater and treat wastewater for reuse are increasingly important in water-scarce regions (Elimelech & Phillip, 2011).
- Policy and Governance: Governments must implement policies to regulate water use, promote conservation, and ensure equitable distribution of water resources (Grafton et al., 2018).

III. Extreme Weather Events and Their Consequences

Extreme weather events have become increasingly frequent and intense due to climate change and other environmental factors (IPCC, 2021). These events include hurricanes, tornadoes, heat waves, droughts, floods, and wildfires, each having severe consequences for human life, infrastructure, and ecosystems (NOAA, 2022).

Types of Extreme Weather Events:

Hurricanes and Cyclones: These powerful storms bring strong winds, heavy rainfall, and storm surges, leading to extensive coastal flooding, destruction of buildings, and loss of lives (Emanuel, 2005).

Tornadoes: Characterized by rotating columns of air, tornadoes can cause massive destruction to homes, vehicles, and power lines in a short span of time (Doswell et al., 1993).

Heat waves: Prolonged periods of excessively high temperatures can lead to heat-related illnesses, wildfires, and severe strain on energy resources (Smith et al., 2013).

Droughts: A prolonged lack of precipitation results in water shortages, reduced agricultural yield, and economic distress for farming communities (Wilhite & Glantz, 1985).

Floods: Heavy rains, melting snow, or dam failures lead to overflowing rivers and water bodies, causing damage to properties, infrastructure, and displacement of communities (Pinter, 2005).

Wildfires: Dry conditions and high temperatures can trigger uncontrollable fires, destroying forests, homes, and air quality (Bowman et al., 2009).

Consequences of Extreme Weather Events:

Human Casualties and Health Impacts: Extreme weather can result in fatalities, injuries, and outbreaks of diseases due to contaminated water and poor sanitation (CDC, 2020).
Economic Losses: Damage to infrastructure, loss of crops, and business disruptions lead to financial instability for communities and governments.

Displacement of Populations: Severe weather events force people to evacuate their homes, leading to an increase in climate refugees and social challenges (UNHCR, 2018).

Environmental Degradation: Deforestation, soil erosion, loss of biodiversity, and pollution often result from extreme weather conditions (Vitousek et al., 1997).

Disruption of Essential Services: Power outages, communication breakdowns, and transportation issues hinder emergency responses and recovery efforts (FEMA, 2019).

Mitigation and Adaptation Strategies:
Improved Forecasting and Early Warning Systems: Enhancing meteorological predictions can help communities prepare better for impending disasters (WMO, 2021).

Infrastructure Resilience: Constructing weather-resistant buildings and flood barriers can reduce destruction (Cutter et al., 2008).

Sustainable Land and Water Management: Preventing deforestation and promoting efficient water use can mitigate the effects of droughts and wildfires (FAO, 2020).

Climate Change Policies: Governments and organizations must implement policies to reduce greenhouse gas emissions and combat global warming (IPCC, 2021).

Community Awareness and Preparedness: Educating the public on emergency plans and disaster preparedness can save lives (Red Cross, 2017).

Extreme weather events pose serious threats, but with proper planning, adaptation, and global cooperation, their impacts can be minimized. It is essential for governments, scientists, and communities to work together in addressing these challenges and ensuring a safer future for all.

IV. Water Management Strategies for Agriculture

Water is a critical resource for agriculture, and efficient water management is essential for sustaining crop production, ensuring food security, and conserving natural resources (FAO, 2020). Various strategies have been developed to optimize water use in agriculture and mitigate the impacts of water scarcity.

Key Water Management Strategies:

Efficient Irrigation Systems: The adoption of advanced irrigation technologies, such as drip irrigation and sprinkler systems, helps to reduce water wastage and improve crop yields (Postel et al., 2001).

Rainwater Harvesting: Collecting and storing rainwater for agricultural use can supplement irrigation and reduce dependency on groundwater sources (Boers & Ben-Asher, 1982).

Soil Moisture Conservation: Techniques such as mulching, cover cropping, and conservation tillage help to retain soil moisture and reduce evaporation losses (Lal, 2004).

Use of Drought-Resistant Crops: Breeding and cultivating crop varieties that require less water can enhance agricultural resilience in arid and semi-arid regions (Blum, 2005).

Water Recycling and Reuse: Treating and reusing wastewater for irrigation can provide an alternative water source and reduce pressure on freshwater supplies (Qadir et al., 2010).

Precision Agriculture: The application of data-driven technologies, such as remote sensing and soil moisture sensors, enables farmers to optimize water use and improve efficiency (Gebbers & Adamchuk, 2010).

Policy and Governance: Implementing regulations and incentives to promote sustainable water use in agriculture can help prevent over-extraction and ensure long-term water availability (Gleick, 1993).

Challenges in Water Management:

1. Climate Change Impacts: Rising temperatures and unpredictable precipitation patterns can exacerbate water scarcity and affect crop yields (IPCC, 2021).
2. Overuse of Groundwater: Excessive reliance on groundwater for irrigation has led to depletion and declining water tables in many regions (Shah et al., 2007).
3. Water Pollution: Agricultural runoff containing pesticides and fertilizers can degrade water quality and limit its usability for irrigation (Pimentel et al., 1995).
4. Economic and Technological Barriers: The high cost of modern irrigation technologies and limited access to resources can hinder their adoption by small-scale farmers (Rosegrant et al., 2002).

V. The Role of Technology in Climate Adaptation

Significant challenges to ecosystems, human societies, and economies worldwide. As extreme weather events become more frequent and unpredictable, technological advancements are playing a crucial role in helping communities adapt to these changes (IPCC, 2021). Climate adaptation refers to the process of adjusting to actual or expected climate impacts to minimize harm and capitalize on potential benefits (UNFCCC, 2019).

Key Technological Innovations in Climate Adaptation:

Early Warning Systems: Advanced meteorological forecasting, satellite imagery, and AI-powered predictive models enable early warning systems for extreme weather events, allowing communities to prepare and mitigate risks (World Meteorological Organization, 2020).

Climate-Resilient Infrastructure: The use of innovative materials and designs, such as flood-resistant buildings and permeable pavements, helps cities withstand climate impacts (Hallegatte et al., 2013).

Precision Agriculture: Technologies like remote sensing, IoT-based soil sensors, and AI-driven analytics optimize water use and improve crop yields in response to changing climatic conditions (Gebbers & Adamchuk, 2010).

Renewable Energy Solutions: Solar, wind, and hydroelectric power contribute to reducing greenhouse gas emissions while ensuring sustainable energy supply in vulnerable regions (IEA, 2021).

Water Management Technologies: Smart irrigation systems, desalination plants, and wastewater recycling improve water efficiency in drought-prone areas (FAO, 2020).

Urban Planning and Smart Cities: The integration of green roofs, urban cooling systems, and data-driven traffic management reduces urban heat islands and enhances climate resilience (Dodman et al., 2019).

Carbon Capture and Storage (CCS): Innovations in CCS technology help reduce atmospheric carbon dioxide levels, mitigating further climate impacts (IPCC, 2018).

Artificial Intelligence and Big Data: AI-driven climate modeling and real-time data analysis support decision-making processes for policymakers and disaster response teams (Rolnick et al., 2019).

Challenges in Implementing Climate Adaptation Technologies:

High Costs and Funding Gaps: Many climate adaptation technologies require substantial investments, which can be challenging for developing nations (OECD, 2020).

1. Technological Accessibility: Limited infrastructure and technical expertise hinder the adoption of climate-resilient technologies in rural and underdeveloped regions (UNDP, 2021).
2. Policy and Regulatory Barriers: The lack of supportive policies and regulations may slow down the deployment of climate adaptation technologies (Eakin et al., 2014).
3. Data Privacy and Security Concerns: The integration of AI and IoT in climate adaptation raises concerns about data security and privacy (Mittelstadt et al., 2016).

Conclusion

Climate change presents multifaceted challenges to agriculture, necessitating comprehensive adaptation and mitigation strategies. Collaborative efforts among governments, researchers, and farming communities are crucial to developing resilient agricultural systems that can withstand the evolving climate landscape. Rising temperatures pose a significant threat to global crop yields, with major staples like maize, wheat, rice, and soybeans experiencing notable declines. Understanding the mechanisms behind these reductions and implementing effective adaptation strategies are essential steps toward ensuring food security in a warming world. Changing rainfall patterns and water scarcity pose significant challenges to global water security, agriculture, and ecosystems. As climate change continues to intensify, proactive water management and adaptive strategies are essential to mitigate the impacts. Investing in sustainable water infrastructure, improving conservation efforts, and promoting international cooperation will be crucial steps toward securing water resources for future generations. Effective water management strategies are essential for ensuring the sustainability of agricultural production and addressing water scarcity challenges. By adopting efficient irrigation methods, conserving soil moisture, and promoting sustainable policies, farmers can optimize water use while maintaining productivity. Governments, researchers, and stakeholders must collaborate to develop innovative solutions that balance agricultural needs with water conservation goals. Technological innovations offer promising solutions to address the impacts of climate change. However, their successful implementation requires collaboration between governments, private sectors, and research institutions. By investing in sustainable technology and integrating it with traditional adaptation strategies, societies can build resilience against climate change and safeguard future generations

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General Article

POST-HARVEST TECHNOLOGIES FOR IMPROVING VEGETABLE SHELF LIFE AND MARKET VALUE

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Abstract

Vegetables are perishable commodities that must be handled properly after harvest to retain quality and shelf life. Numerous postharvest methods have been created to limit financial losses, maintain nutritional content, and lessen spoiling. Important postharvest practices are examined in this research, including temperature control, chemical treatments, controlled atmosphere storage (CAS), modified atmosphere packing (MAP), and physical techniques like coating and irradiation.Vegetable freshness is greatly increased by temperature control, especially chilling, which inhibits microbial development and enzymatic activity. In order to postpone ripening and senescence, MAP and CAS control the levels of carbon dioxide and oxygen. Chemical treatments that aid lower moisture loss and microbiological contamination include the use of natural preservatives, edible coatings, and chlorine washes. Furthermore, sustainable alternatives for conventional postharvest preservation techniques have been made possible by developments in nanotechnology and biodegradable packaging materials. Smart sensor integration in transportation and storage improves environmental condition monitoring and management, guaranteeing maximum freshness.Even if these methods successfully increase shelf life, issues including price, customer acceptance, and environmental impact need to be considered. Future studies should concentrate on economical and environmentally friendly approaches that strike a balance between food safety, environmental sustainability, and quality preservation. Using a variety of postharvest methods designed for certain crops can increase food security, minimize food waste, and maximize shelf life.

Keywords: Postharvest techniques, shelf-life extension, vegetables, temperature management, modified atmosphere packaging, controlled atmosphere storage, chemical treatments, edible coatings, irradiation, food preservation, sustainable storage.

Introduction

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Introduction

Vegetables are necessary for human nutrition, giving vitamins, minerals, and fiber. However, they are extremely perishable due to their high moisture content and metabolic activity, resulting in quick deterioration upon harvest. Postharvest losses make up a large amount of worldwide food waste, affecting food security, economic sustainability, and environmental conservation. To address these problems, appropriate postharvest strategies are required to increase shelf life, maintain quality, and reduce losses due to microbial spoilage, physiological degradation, and mechanical damage. (Palumbo et al., 2022) Postharvest losses can occur at any point, including harvesting, processing, storage, transit, and retail. Temperature variations, incorrect packaging, excessive moisture loss, and microbiological contamination all contribute to spoiling, which causes economic losses for farmers, dealers, and consumers. As a result, optimizing postharvest handling practices is crucial for preserving the nutritional and sensory quality of vegetables while assuring food safety. (Ali et al., 2017)

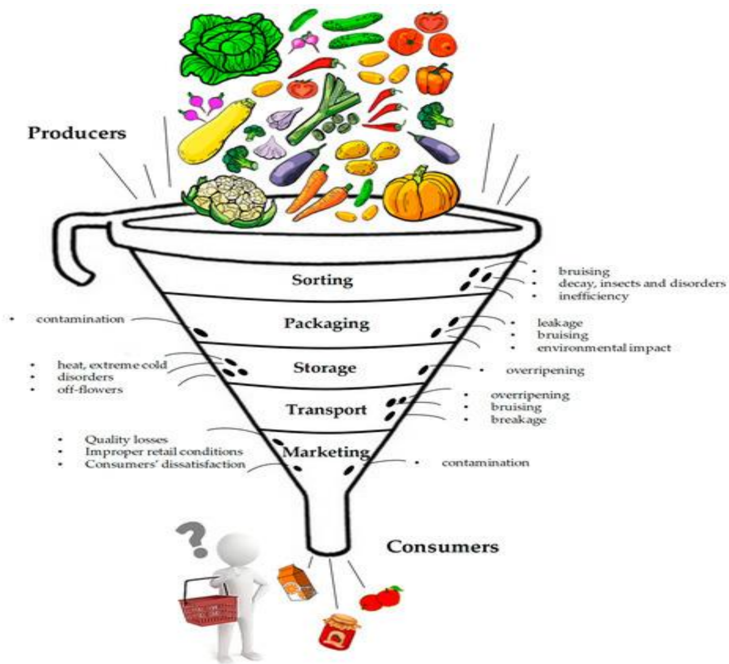

Fig1. Post Harvest Losses during Supply Chain (Palumbo *et al.*, 2022)

Temperature is a crucial postharvest strategy that uses cooling technologies like as refrigeration, hydro-cooling, and vacuum chilling to limit respiration rates and microbial development. Cold storage is commonly used to preserve vegetables for extended periods of time, while the appropriate temperature and humidity levels differ depending on the kind of vegetable. Modified Atmosphere Packaging (MAP) and Controlled Atmosphere Storage (CAS) are cutting-edge strategies for regulating oxygen and carbon dioxide levels, delaying ripening and enzymatic processes. These approaches are especially useful for leafy greens, tomatoes, and root crops, which are extremely sensitive to climatic fluctuations. (Sharma et al., 2024)

Physical preservation approaches, such as ultraviolet (UV-C) irradiation and ozone treatment, have proven to be efficient in suppressing microbial growth while preserving vegetable structural integrity (Mahajan et al., 2014). These approaches are rapidly being investigated because to their low chemical residue and environmental effect. Furthermore, biodegradable and nanotechnology-based packaging has gained popularity as a sustainable alternative to traditional plastic packaging, providing both longer shelf life and a lower environmental impact. (Sharma et al., 2024)

The use of smart technologies, including as sensor-based monitoring systems and blockchain-enabled tracking, has enhanced postharvest management by enabling for real-time monitoring of temperature, humidity, and gas composition throughout transport and storage. These advances enable stakeholders to make data-driven decisions that improve vegetable freshness and decrease waste.While postharvest procedures considerably extend shelf life, problems such as high implementation costs, limited availability in underdeveloped countries, and customer concerns about chemical treatments must be addressed. Future developments should prioritize sustainable, inexpensive, and scalable methods that balance food preservation with environmental and economic concerns. This chapter addresses the numerous postharvest procedures used to extend the shelf life of vegetables, examining their efficacy, limitations, and possible future developments. By implementing effective postharvest procedures, the agriculture and food sectors may improve vegetable quality, minimize food waste, and contribute to a more sustainable global food system.

Postharvest Methods for Extending the Shelf-Life of Vegetables

1. Temperature Management

The regulation of temperatures is one of the most crucial factors in increasing the shelf life of vegetables. The rate of respiration and microbial growth rises with temperature, resulting in rapid degradation. Rapid cooling of vegetables right after harvest reduces respiration rates and microbiological development. Precooling technologies, such as hydrocooling and vacuum cooling, are excellent in swiftly lowering the temperature of product, extending its shelf life. For example, hydrocooling involves immersing plants in cold water to quickly remove field heat, which is particularly good for crops like broccoli and leafy greens. (Farmers, 2024)

Refrigeration: Storing vegetables at appropriate temperatures (often 0°C to 10°C, depending on the kind) reduces enzyme activity and microbial development. Leafy greens, for example, thrive at temperatures near 0°C, but tropical crops such as tomatoes and peppers need slightly warmer storage (10°C-13°C) to avoid chilling harm.

Pre-cooling Methods: Hydro-cooling involves immersing veggies in cold water to immediately remove their heat. This approach works particularly well for crops like broccoli, lettuce, and carrots.

Vacuum Cooling: Used for leafy greens, this process quickly eliminates moisture and heat via evaporation, preserving crispness.

Forced Air Cooling: This method uses cold air circulation to evenly cool huge amounts of product, and is commonly used for berries and packaged vegetables.

2. Edible Coatings

Applying edible coatings to the surface of vegetables forms a semi-permeable barrier, limiting moisture loss and delaying ripening. These coatings can be created from natural ingredients such polysaccharides, proteins, and lipids. For example, chitosan-based coatings have been found to successfully improve tomato shelf life by preventing microbial growth and lowering respiration rates. (Zdulski et al., 2024)

These coatings are made from natural materials such as:

- Polysaccharides (e.g., chitosan, alginate, starch): These provide a semi-permeable barrier that controls gas exchange and reduces dehydration. Chitosan coatings have been found to be effective in preserving tomatoes by inhibiting bacterial and fungal growth.
- Proteins (e.g., whey protein, soy protein): These improve the mechanical properties of coatings, making them more resistant to damage.
- Lipids (e.g., beeswax, carnauba wax): These create a hydrophobic layer that prevents water loss, commonly used for cucumbers and citrus fruits.

3. Irradiation

Irradiation is a postharvest method that relies on ionizing radiation (gamma rays, X-rays, or electron beams) to kill pathogens, minimize spoiling, and slow ripening.Gamma Irradiation is effective in controlling bacteria and fungus, extending shelf life without affecting flavor, texture, or nutrition.Electron Beam Irradiation: A non-thermal approach for reducing microbial load and inhibiting sprouting in root plants such as potatoes and onions.X-ray Irradiation: A safer alternative to food irradiation that has no effect on sensory qualities.The efficiency of irradiation is dependent on the dosage, which must be carefully controlled to avoid undesired changes in the texture or nutritional profile of vegetables. Low doses of irradiation have been used to inhibit sprouting in tubers and delay senescence in various vegetables, thereby extending their shelf life without compromising nutritional quality. (Mahajan *et al.*, 2014)

4. Modified Atmosphere Packaging (MAP)

Changing the composition of gases in packaging might slow down the metabolic processes in vegetables. To postpone ripening and senescence, MAP generally entails decreasing oxygen levels while raising carbon dioxide concentrations. This approach has been used successfully to increase the shelf life of several crops, including leafy greens and cruciferous vegetables. (Palumbo et al., 2022)MAP includes changing the gas composition of packaging to decrease respiration and microbiological development. This is often accomplished by:Reducing oxygen (O_2) slows respiration and enzyme activity, which delays ripening and senescence.Increasing carbon dioxide (CO_2) inhibits microbial development and lowers ethylene production (a natural ripening hormone).Humidity Control: Prevents dehydration and preserves freshness. For example, MAP is commonly used for leafy greens, which require a balance of 3-5% oxygen and 5-10% carbon dioxide. Packaging materials like polyethylene and polypropylene are frequently utilized to produce a controlled environment.

5. UV-C Light Treatments

UV-C light has germicidal capabilities that can lower the number of microbes on the surface of plants. The proper use of UV-C light has been found to increase product shelf life by suppressing the growth of bacteria and other diseases. However, the dose and exposure duration must be carefully monitored to avoid harming the crop. (Davis, 2024)The following are some of the main advantages of using ultraviolet-C (UV-C) light (wavelength 200–280 nm) to sterilize vegetables by destroying microbial DNA and preventing spoiling: Microbial Reduction: UV-C light effectively reduces bacteria, molds, and fungi on the surface of vegetables, extending shelf life; Delay in Ripening: Inhibits ethylene production in certain vegetables, slowing down the ripening process; Non-Thermal Preservation: Unlike heat treatments, UV-C does not significantly change the texture or flavor of vegetables; however, proper dosage calibration is required to prevent damage to the outer layers of delicate vegetables, such as spinach and lettuce.

6. Curing

For root vegetables (such as potatoes, sweet potatoes, and onions), curing is a postharvest procedure that strengthens the outer skin, heals wounds, and guards against microbial infection. The following are part of the curing process:Controlled Temperature Promotes the healing of wounds and bruises (20–30°C).High Humidity (85–95%) Promotes skin thickening while reducing moisture loss.Ventilation Guarantees the elimination of surplus ethylene and inhibits the development of mold. (Farmers, 2024)Curing vegetables increases their resistance to deterioration and dehydration over time, extending their shelf life.

Conclusion

Effective postharvest practices have a key role in increasing the shelf life of vegetables, preserving their quality, and avoiding food waste. Essential techniques for reducing spoilage, preventing microbial development, and preserving freshness include temperature control, edible coatings, irradiation, modified environment packaging, UV-C light treatments, and curing. Furthermore, real-time monitoring is improved by intelligent storage and transportation technology, guaranteeing ideal conditions across the supply chain. Farmers, distributors, and retailers may greatly lower postharvest losses, increase market value, and improve food security by combining these strategies. To guarantee widespread adoption, however, issues like cost, accessibility, and environmental effect must be resolved. To increase the accessibility of these technologies, future research should concentrate on economical, environmentally beneficial, and sustainable solutions. Postharvest innovations can help create a more resilient, sustainable, and effective global food system if they are properly integrated and advanced.

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General Article

ROLES AND CONTRIBUTION OF COMMUNITY SEED BANKS IN CLIMATE CHANGE ADAPTION

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Abstract

Community seed banks are repositories of local genetic diversity that is often adapted to prevailing climate conditions, including biotic stresses. They may be useful to contribute to community based strategies for adaptation to climate change. However, to date community seed banks have received little attention in the literature related to climate change adaptation. This comes as a surprise given that community-based seed-saving initiatives have been around for about 30 years. Different names are used for these initiatives: community gene bank, farmer seed house, seed hut, seed wealth centre, seed savers group, association, or network, community seed reserve, seed library, and community seed bank.

Key words: Community Seed Banks, Climate Change Adaptation, Agro-biodiversity, Seed Sovereignty, Traditional Varieties, Farmer Resilience

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Introduction

Climate change is affecting agricultural productivity and food security globally. Global warming resulting in increased temperatures, erratic rainfall, and leading to severe droughts and floods could pose a serious threat to food production (IPCC 2014). One common strategy for adapting to climate change is to exploit genetic sources of resistance to the abiotic and biotic stresses that result from climate changes. Both inter- and intra-crop genetic diversity can be utilised for this strategy. Farmers can use inter-crop diversity by switching to crops that are more resilient. Or they can use better adapted varieties of the same crop developed through their own on-farm selection, a formal sector crop/tree improvement programme, or a collaborative effort such as participatory plant/tree breeding.

In recent years, scientists around the world have come up with concrete suggestions to strengthen the roles that plant genetic resources can play in coping with climate change. Jarvis et al. (2015) identify several of these concrete actions in the Food and Agricultural Organization of the United Nations (FAO) publication "Coping with climate change ─ the roles of genetic resources for food and agriculture". They include diversification at species and variety levels; revalorization of plant species that have been or have become underutilized and neglected; broadening and intensifying the collection, characterization, and utilization of crop wild relatives; better targeted plant breeding; and forging better linkages between in situ and ex situ conservation activities. In addition, the authors argue for more policy support to improve access to improved seeds and to allow farmers to produce, save, exchange, and sell seeds (Yadav et al. 2011).

Linn (2011) elaborates on the multiple benefits of crop diversification practices such as using varietal diversity in monocultures, mixing crops with non-crop vegetation, crop rotations, polycultures (including wild varieties), agroforestry and mixed landscapes. Benefits derived from these strategies include pest and disease reduction, increased production, increased production stability, and climate stress buffering. Evidence from field trials underway in various countries offers strong support for the use of intraspecific crop diversity within the production system to reduce disease incidence and risks related to climate change (Jarvis et al. 2011a). Such practices will likely also reduce the vulnerability to pest and disease infestations in the future caused by changing climate conditions.

Bellon and van Etten (2014) identify other types of interventions that can support on-farm crop conservation as an effective way to respond to climate change. These interventions include the establishment of a global information system that reports changes in adaptation and evolution processes and enables the localisation of new crop genes and genotypes that can be used in adaptation efforts. They also make the practical suggestion to improve community-based seed saving and storage practices, with particular attention to safeguarding seeds of plants that survive under extreme weather conditions. Sthapit et.al (2010) reinforce these suggestions by highlighting the need for more policy support given to the various forms of in situ and on-farm conservation in which farmers and their local forms of organization should play key roles. The multiple suggestions put forward by all these authors have been brought together in a comprehensive decision-making frame work (Jarvis et al. 2011) that links constraints with action options. The framework also identifies which kind of farmer organization could be the most effective for implementing each action. A community seed bank is one of the organizational forms included.

Community seed banks are repositories of local genetic diversity that is often adapted to prevailing climate conditions, including biotic stresses. They may be useful to contribute to community based strategies for adaptation to climate change. However, to date community seed banks have received little attention in the literature related to climate change adaptation. This comes as a surprise given that community-based seed-saving initiatives have been around for about 30 years. Different names are used for these initiatives: community gene bank, farmer seed house, seed hut, seed wealth centre, seed savers group, association, or network, community seed reserve, seed library, and community seed bank (Vernooy et. al. 2015). The latter seems the most common. These article illustrate two important ways in which more effective management of plant genetic resources can strengthen farmers' capacity to adapt to climate change: (1) securing improved access to, and availability of diverse, locally adapted crops and varieties through the use of multiple germplasm sources;

and (2) enhancement of related local knowledge and skills in plant management, including seed selection, treatment, storage, multiplication, and distribution. As such, community seed banks can enhance or revive traditional social seed networks that have existed for decades or centuries based on combinations of seed saving, seed exchanges, seed giving, seed bartering, and seed purchase. What is needed now is a growing recognition among policymakers that community seed banks can be a very effective form of farmer organization toward more climate smart agriculture.

What is Community Seed Banks (CSBs)?

Community seed banks are collections of seeds of local landraces that are maintained and administered by the communities themselves, with the following criteria:

1. Community seed banks had birth from the necessity of local people, importance has assigned after that.
2. CSBs serve local farmers to form an informal seed distribution system prevailing in villages since ancient time at no or very low cost.
3. CSB system is maintained and promoted by farmers and conserves landraces; in addition to that it may also include improved varieties of farmers/farmers group interest, farmer selected varieties etc.
4. Seeds stored in CSBs in order ensure planting material for farmer himself or group in large quantities for the season or to ensure conservation genetic material of rare and endangered varieties for the posterity due to their importance.
5. Establishment and management community seed banks form an important part of informal seed distribution system in villages and they have no established guideline for the same.
6. Community seed banks serve as focal point in maintaining indigenous genetic diversity and associated traditional knowledge involving farmers' community.
7. The main aim of community seed conservation is to ensure/increase local seed security and to help prolonged utilization of locally important genetic diversity.
8. Community seed banks play a vital role in improving farmers' access to seeds, conserving agricultural biodiversity for seed security and the associated traditional knowledge, providing options for adapting to climate change, as well as can contribute to the realization of Farmers' Rights.
9. Farmers need relatively little skill to access the community seed banks and on-farm conservation efforts can be linked easily.
10. Specific objectives, include:
    - Maintain diversity and sustainable conservation of farmer landraces.
    - Link community seed banks and Farmers' Rights.
    - Link community seed banks with Farmers' Rights and sustainable agricultural production.
11. Motivation is necessary for the community farmers in order to participate in conservation and seed management programme for the posterity.
12. Assessing the quality and quantity of seed at the time of distribution and while taking it back from the farmers for storage.

13. Linking CSBs with FPOs and seed marketing companies in order to market for the surplus/extra seeds available with the seeds banks and extend the support to farmers as well as CSBs.
14. Conditions leading to success of CSBs

- Willingness of farmers to participate in community seed bank interventions.
- Large scale cultivation of local landraces as component of subsistence farming.

Majority of local landraces have an important incentive of fetching premium prices in markets after some add-value interventions particularly through processing or packaging.

Functions and Activities of Community Seed Banks that Contribute to Climate Change Adaptation

A community seed bank is defined as a locally governed and managed, mostly informal, institution whose core function is to maintain seeds for local use (Development Fund 2011). Beyond this core conservation function, community seed banks have a broad range of additional purposes and vary significantly in scope, size, governance and management models, infrastructure and technical aspects. There is considerable variability in the performance of community seed banks in terms of technical and operational capacities (e.g. technical rigor in monitoring germination and ensuring viability of stored seed), governance, and operational management. Technical and operational challenges are often compounded by lack of legal recognition and scarce financial resources. Past experience has shown that community seed bank initiatives are usually quite effective during their initial years, but with withdrawal of external support, many cut back on activities or stop altogether. As in other organizational efforts, when community seed banks are established without proper foundations, long-term survival is difficult. Nonetheless, in many countries one can find well-functioning community seed banks (Vernooy et al. 2015). In recent years, the number of newly established community seed banks has been on the rise partly due to the growing support of national and state or provincial governments.

Based on a global review of the mostly grey literature about community seed banks (CSBs)and a collection of comparative case studies from various parts of the world published in 2015 (Vernooy et al. 2015), we developed a framework to identify and organise key functions and activities of community seed banks. The three key functions are: (i) conservation of plant genetic resources; (ii) access and availability of diverse seeds and planting materials according to farmers' needs and interests; and (iii) seed and food sovereignty (Vernooy et al. 2014). Some community seed banks are strictly focused on conservation of agricultural biodiversity including reviving lost local varieties, while others give priority to both conservation, and access and availability of diverse types of seeds and planting materials suitable to various agro-ecological domains. Very few community seed banks explicitly present their efforts as promoting seed and food sovereignty.

Here we expand this framework by identifying activities that are particularly relevant with regard to climate change adaptation. Under conservation these are: conservation of a portfolio of diverse seeds of crops and crop varieties; conservation of seeds from plants that have high capacity to survive under extreme weather conditions; restoration of "lost" varieties, particularly those with good adaption potential. Under access and availability, they are: platform for multiple channels of access and availability of seeds at the community level;

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accessing novel diversity not conserved locally; accessing seeds from areas where plants have adapted to extreme weather conditions; pro vision of adapted seed to marginal communities not served by commercial seed dissemination efforts. Under seed and food sovereignty there are no activities that deal explicitly with climate change adaptation. However, the approach known as community based biodiversity management (de Boef et al. 2013) encourages the search for, use of and control over portfolios of locally adapted germplasm that could be sourced from diverse sources and locations. In the next sections we present a number of community seed banks that put one or more of these climate change adaptation activities in practice.

Roles of CSBs in Addressing Climate Change

Many researchers have emphasized the importance of crops and seed diversity for climate change adaptation. Over-reliance on limited crop species has increased global food insecurity (Sthapit 2013). There are many common strategies being practised by communities with or without the support of development agencies. One common strategy is to exploit and effectively use resistant and diverse seeds to adapt to climate change (Vernooy et al. 2017). Furthermore, CSBs improve the accessibility and availability of diverse and Indigenous tree, locally adapted crops, seeds, and varieties and also enhance the adaptive capacities, development, and exchange of tolerant and resistant varieties and crops. Livelihood diversification through onsite or on-farm conservation of crops is an additional strategy that has been practiced by farmers (Table 1).

Table 1. The climate adaptation-related functions of CSBs

Climate adaptation-related functions	Main functions of CSBs
On-farm management of crop diversity to address climate adversity	Conservation of diverse seeds and crop genetic resources
Enhance climate resilience and stress-tolerant seeds	Restoration of rare and lost seeds and varieties
Maintenance of locally adapted seeds at low cost	Enhance farmers' accessibility and availability of diverse seeds and crop genetic resources
Provision of adapted seeds to poor and marginalized communities	Maintenance of local control over seed conservation, community based management of seed
Enhance capacity of farmers to respond to local crisis, disasters, and shortages	Income generation through conservation and sales of seeds
Sources of resources for participatory crop enhancement and seed exchange	Contribution to ecological agriculture and food sovereignty Linkage between in-situ and ex-situ conservation and sharing of knowledge through farmers' seed network

Source: Sthapit (2013)

(1) On-farm management of crops for addressing climate adversity:

Maintenance of crop diversity and pool of genetic resources and variability has a significant role in sustainable agricultural practices and also support farmers in adapting to changes in weather and climatic patterns. However, modern agriculture has shrunk that pool of crop genetic resources and increased the dependency of farmers towards external sources. Although traditional and local landraces are resistant to both biotic and abiotic stresses, farmers have to depend on the modern and hybrid varieties because of lack of access to local landraces and also easily available hybrid seeds in the markets. That has led to dependency on external sources of seeds and loss of traditional landraces, and loss of agrobiodiversity, associated knowledge, practices, and the whole evolutionary process of farming (Shrestha et al. 2006).

CSBs have emerged as a reliable option for maintaining the pool of resources and variability through on-farm conservation that provides seed and food security to farmers against biotic and abiotic stresses such as diseases, pests, droughts, and floods (Shrestha et al. 2012). Vernooy et al. (2014) further confirmed CSBs as on-farm management of local crop diversity for natural and human selection in agricultural production systems, in which farmers are the custodians and managers in handling the crop diversity and processes (Subedi et al. 2006). CSBs have also empowered farmers in managing and continuing on-farm practices such as diversity blocks, community biodiversity registers (CBRs), community-based seed productions (CBSPs), community-based management fund (CBM fund), and participatory landrace enhancement such as participatory plant breeding, among others (Sthapit et al. 2006). All of these on-farm practices have strengthened socio-economic, cultural, and environmental relationships and benefits among the community.

(2) Farmers' accessibility and adaptive capacities enhancement:

CSBs have enhanced seed availability and accessibility to the poor and needy farmers based on a cash or loan basis. Borrowers need to return 50 to 100% more seeds than they borrowed as seed loans, which will be stored and distributed to other farmers or replicated in diversity blocks to maintain viability (Vernooy et al. 2015). Thus, CSBs have become a successful and reliable local institution that enhances the farmers' accessibility and capacities to locally adaptable and improved seeds through the process of collection, conservation, distribution and sustainable use of seeds and its diversity, to ultimately support on local food security.

CSBs have mostly conserved and distributed rare and tolerant seeds to the farmers that have made them more common, ensuring seed and food security in the local context (Maharjan et al. 2011b). The availability of quality seeds is very important for the production of enough food (Progressio 2009). Shrestha et al. (2012) also reported that the CSBs have increased abundance and accessibility of landraces and overall diversity. Maharjan et al. 2011a and Pokhrel et al. 2012 further confirmed that CSBs have enhanced the easy availability of seeds, conservation of landraces, and associated knowledge and livelihood security.

Furthermore, Progressio (2009) claimed that conservation of diverse seeds has enhanced the adaptive capacities of farmers to adapt to climate change. Farmers' capacities on seed conservation, distribution, multiplication, marketing, seed/diversity fairs, and diversity blocks become more sustainable due to CSBs, which also strengthened the seed networks among farmers. Likewise, farmers have gained skills in conservation farming, home gardens, sloping agriculture land technologies (SALT), and participatory seed exchange to address seed shortages and climate change issues. Some CSBs have also focused on empowering farmers, promoting ecological agriculture, establishing farmers' rights over seeds, and developing mechanisms for fair and equitable benefits (Vernooy et al. 2015).

(3) Increased access to climate resilient and stress-tolerant seeds:

Climate change and climate-induced disasters such as flood and drought have further intensified the vulnerability of poor and marginalised farmers in India. Many crop genetic resources are extinct because of rapid erosion due to climate change and induced disasters. CSBs have played a crucial role in preserving and reviving such important genetic resources through a collection of resources and associated knowledge, storage, regeneration, multiplication, and distribution of resilient seeds to farmers and their networks, fulfilling their seed demands (Maharjan et al. 2011a; Vernooy et al. 2015). CSBs have developed a healthy and stable seed system since seeds are distributed to the wider communities and rare seeds become more common. Some drought- and flood-resistant varieties have become more broadly available to the public through CSBs, therefore enhancing the resilience of the community and agroecosystems (Maharjan et al. 2011b; Shrestha et al. 2012) that support farmers to prepare for erratic weather events (Zofeen 2014). FAO (2010) revealed that conservation and use of crop diversity help farmers to respond to climate change issues. Therefore, CSBs have enhanced farmers' resilience both at the household and the community levels through securing improved access to diverse and locally adapted crops and enhancement of related knowledge and skills (Maharjan et al. 2011b; Vernooy et al. 2015).

Shrestha et al. (2012) claimed that CSBs are a viable and reliable opportunity for farmers living in marginal and disaster-prone areas. Vernooy et al. (2017) emphasized that the establishment of CSBs in climate vulnerable communities help them to respond quickly to environmental stresses and contribute to the restoration of local food security.

Progressio (2009) also found CSB as "safe deposits" of farmers' valued seeds, especially during total crop failure caused by drought, floods, or fire. In such crises, CSBs have provided seeds saved by the farmers. Furthermore, farmers have diverse options to utilise the full range of highly varied microclimates and diverse seeds since they saved seeds by themselves in CSBs, which is suitable for different soil types, temperature, altitude, slopes, water availability, and overall fertility. In these areas, CSBs have provided viable traditional landraces, which are better adapted to such stressful conditions. Both farmers and geneticists preferred and valued traditional landraces because of its diversity and heterogeneity, unique traits and adaptability to the local and harsh climate (Gyawali et al. 2006). Diverse seeds in the field and CSBs act as insurance against losing seeds and crops under adverse climatic conditions, and some of these seeds can withstand extreme climatic conditions (Regmi et al. 2009).

(4) Participatory landrace enhancement and participatory plant breeding (PPB):

Local landraces are important bio-resources for sustainable production and livelihood improvement of the community, providing the foundation for the development of new varieties (Gyawali et al. 2006) through participatory crop improvement to conserve genetically pure, healthy, and quality seeds at the grassroots level (Vernooy et al. 2014). Farmers have been selecting varieties that would perform better under the changing climate conditions, which has triggered discussion among researchers about the participatory variety selection to select good quality seeds for upcoming growing seasons (Vernooy et al. 2017). One important focus of CSBs and participatory crop improvement is to train farmers on the procedures and requirements of participatory breeding (Sthapit et al. 2006). Participatory crop improvement and PPB, selection of farmers' preferred seeds, and community-based seed production are ways to improve the access and availability of improved seeds (Vernooy et al. 2015).

(5) Participatory seed exchange among farmers during climate hardships:

For generations, farmers have been managing the local crop diversities and maintaining informal seed networks and seed systems through bartering or exchanging with their neighbours, relatives, and friends within and outside the community, which is crucial for the maintenance of local crop diversity (Maharjan et al. 2011a; Subedi et al. 2006). It is estimated that globally 80% of seeds are farm-saved through informal networks and exchange (Vernooy et al. 2015). Informal networks and systems include CSBs as they have been playing significant roles in maintenance and seed exchange. They also enhance social cohesion and inclusion among farmers since it is a collective effort of farmers to manage landraces and exchange (Subedi et al. 2006).

Furthermore, CSBs have prioritised seed access to women, poor and marginalised farmers, who are facing seed shortages since they cannot save and purchase seeds in the market (Shrestha et al. 2006). It is also found that women have played key roles in farmers' seed systems and active participation in participatory seed exchange by sharing seeds and associated knowledge with their neighbours, relatives, and other farmers in CSBs, although their roles are often ignored by research and development actors, policies, and programmes (Maharjan et al. 2011b; Vernooy et al. 2015).

CSBs have enhanced farmers' seed systems and strengthened social networks for seed exchange, which also help in coping with climate change adversity and impacts. Social seed networks among farmers are a secure source of seeds that are locally adapted to the local climate (Subedi et al. 2006). CSBs have developed a mechanism of participatory seed exchange among farmers within and outside to expand seed exchange and farmers' networks (Maharjanet al. 2011a).

Issues and Key Challenges of CSBs

Despite agriculture intensification and other human pressures, local crop genetic resources are still conserved and maintained by farmers in India, both at household and community levels, to fulfil seed demands and also address local climatic conditions. However, these resources and landraces are significantly disappearing over the years at both levels, although landraces have been developed and adapted to the local environment for generations (Shrestha et al. 2006). The reasons behind mainly the inaccessibility of resource-poor farmers and their control over on these landraces, lack of quality seeds leading to increased farmers' preference on high yielding modern/hybrid varieties, lack of policy and incentives to farmers on conservation and maintenance of landraces, and increased climatic risks and vulnerabilities.

Despite the lack of any incentives to farmers for conservation and management of diversity, CSBs have been conserving and maintaining the landraces. It is difficult to conserve all landraces. Similarly, not all farmers may be interested in conserving the landraces, as it requires resources and commitment of the farmers. Therefore, incentives and motivation play a role in conserving and maintaining such important landraces in the CSBs (Gyawali et al. 2006). Incentives could be created through linking to the market for conservation and exchange of landraces; creating an enabling environment to cultivate and exchange seeds at the local and national levels; and linking CSBs to the private sector for income generation, and/or national gene bank, and government agencies for the expansion of seed exchanges. Incentives can also be created through policy support and reform for the conservation of agro-biodiversity and also for commercialization of high-value products (Gyawali et al. 2006a).

Additional climate change pressures have been observed recently on farmers' seed and food production systems. The roles of CSBs in addressing climate change impacts are often neglected. It is estimated that climatic impacts will be more severe in future, meaning additional challenges to adapt to new weather dynamics. Very few scientific publications are available on CSBs, their history, evolution, experiences, successes, challenges, and prospects, and their importance in maintaining agrobiodiversity and in addressing climate change impacts are continuously ignored. Additionally, the roles and contributions of women in CSBs are often neglected in CSB-related programmes and policies, even though they have played significant roles in seed saving and farmers' seed networks (Vernooy et al. 2015). The main challenge is the commodification and commercialization of seeds by companies and corporate industries. Farmers are aggressively running after agro-vets for improved seeds and agricultural inputs rather than CSBs.

Conclusion

CSBs have multiple functions in farmers' livelihoods and welfare, and have gained considerable recognition in India, with a long history in conservation, distribution, regeneration, and multiplication of seeds, fulfilling farmers' seed demands. CSBs have made rare seeds more widely available, and enhanced social cohesion and relationships among farmers through different on-farm activities. Additionally, both farmers and researchers have realized that landraces are more tolerant to both biotic and abiotic stresses. However, farmers still prefer improved and hybrid seeds found in the agro-vets and markets because of their easy accessibility. CSBs have played crucial roles in increasing awareness among farmers on the importance of landraces, indigenous species and enhancing the accessibility of quality seeds to farmers to improve their livelihood and social relationships. They have further strengthened skills and capacities around on-farm conservation and development activities, including adaptive capacities to climatic risks and stresses. However, there are still many issues and challenges for CSBs' sustainability in India due demographic, socio-economic, political, institutional, biophysical, and environmental factors associated with overall development and sustainability.

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General Article

BENEFICIAL INSECTS AND ITS IMPORTANCE IN AGRICULTURE

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Abstract

Beneficial insects are vital for maintaining agricultural productivity, ecosystem stability, and biodiversity. These insects mainly pollinators, predators, and parasitoidsplay a significant role in food production, pest control, and environmental well-being. Pollinators such as bees, butterflies, and hoverflies assist in the reproduction of over 75% of the world's crop species, which directly influences yield and quality. Predatory insects like lady beetles, lacewings, and ground beetles help to naturally control pest populations, thereby decreasing the need for chemical pesticides. Parasitoid wasps and flies offer precise biological control by parasitizing harmful pests. Furthermore, numerous beneficial insects contribute to nutrient recycling and the enhancement of soil health. Their preservation is crucial for sustainable agriculture and can be accomplished through habitat improvement, integrated pest management (IPM), and minimized pesticide application. Acknowledging and fostering beneficial insects is essential for developing resilient agro-ecosystems and ensuring long-term food security.

Key Words: Beneficial insects, Pollinators, Biological pest control, Sustainable agriculture, Integrated Pest Management (IPM), Agro-ecosystem resilience

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Introduction

The global human population has been increasing at a rapid pace, making food requirements a significant issue in contemporary times. To satisfy this demand, it is necessary to establish new areas for crop cultivation or enhance productivity in existing agricultural zones. Crop yield losses attributed to insects and other arthropods that consume cultivated plants, as well as plant pathogenic fungi, bacteria, and viruses (collectively referred to as 'pests'), are concerning (Oerke, 2006). Globally, pests are responsible for 30–40% of yield loss. Insects are the most successful animals on the planet regarding the number of individuals, species diversity, and habitat range due to various factors such as shorter life spans, higher reproductive rates, and lower body weights. Insects originated over 3 million years ago, and there are nearly 1 million known species of insects, surpassing all other life forms, occupying almost every terrestrial habitat. Most insects found in gardens, yards, or crops do not harm or feed on plants; many are merely "passing through" or exhibit harmless behaviors. Some insects, however, prey on and eliminate pest species. The actions of these beneficial insects help prevent or significantly reduce pest issues in crops. Therefore, recognizing these beneficial insects is crucial for their appreciation and conservation. Beneficial insects are defined as those that fulfill essential roles in ecosystem functions, including dung burial, pollination, and pest control, with examples such as dung beetles and honeybees. Their health can be negatively impacted by pesticides, underscoring the importance of designing pesticides carefully to reduce toxicity. These insects contribute to crop production and the overall health of ecosystems. In fact, only about 1% of all insect species are classified as pests; the vast majority are either harmless or beneficial.

Numerous insects provide vital services, such as pollination by bees (both Apis and non-Apis species), flies (syrphid flies), butterflies, and moths, which fertilize flowers to enable fruit set and seed production.An environmentally sustainable approach to pest management involves introducing predators and parasitoids into agricultural fields or greenhouses, particularly in the cultivation of vegetable crops, soft fruits, and ornamental plants. The most frequently utilized predators for managing herbivorous pests include ladybirds (Coccinellidae), gall midge larvae (Cecidomyiidae), lacewing larvae (Chrysopidae), and hoverfly larvae (Syrphidae). Generalist predators, such as the common green lacewing (*Chrysoperla carnea*), primarily feed on aphids but also consume other small insects and their eggs. In contrast, specific predators like the green lacewing (*Ceraeochrysacubana*) target a single pest species as their natural enemy.

Importance of Beneficial Insects:

Beneficial insects are essential to agriculture and ecosystems. They serve as nature's pest controllers, pollinators, and decomposers, contributing to increased crop yields, decreased pesticide usage, and the preservation of biodiversity and soil health. In contrast to pests, these insects promote sustainable, eco-friendly, and productive farming practices.

Pollination

Function: They transfer pollen from the male to the female parts of flowers, facilitating the production of fruits and seeds.

Benefits:

- Enhances crop yield and quality
- Crucial for the production of fruits, vegetables, oilseeds, and nuts
- Fosters biodiversity among wild plants and ecosystems
- Crops reliant on pollinators include: apple, almond, mango, mustard, tomato, sunflower, cucumber, berries, and many others.

Biological Pest Control

Function: Predators and parasitoids naturally eliminate or suppress harmful insect populations.

Benefits:

- Diminishes pest outbreaks
- Reduces the need for chemical pesticides

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- Averts the development of resistance in pests
- Conserves time, money, and environmental resources.

Soil and Ecosystem Health

Function: Decomposers and detritivores decompose organic matter.

Benefits:

- Enhances soil fertility
- Improves nutrient cycling
- Supports the food web by providing prey for birds, reptiles, and amphibians.

Sustainable Agriculture

- Encourages Integrated Pest Management (IPM) strategies
- Reduces cost of chemical inputs
- Maintains ecological balance
- Promotes biodiversity and resilience of agro ecosystems

Categories of Beneficial Insects

Beneficial insects can be categorized into several important groups, each serving a unique purpose in farms and gardens.

Pollinators (Examples: Bees, Butterflies, and More)

Insects that transfer pollen between flowers are vital for the production of fruits and seeds. Honey bees, bumblebees, and various wild bees rank among the most significant pollinators for food crops. Many flowering vegetables, fruits, nuts, and oilseeds rely on insect pollination: indeed, over 75% of the world's crop species gain from animal pollinators. Other insects also play a role: butterflies, moths, beetles, flies (such as hoverflies or syrphid flies), and even some wasps transport pollen while they feed on nectar. For instance, syrphid ("hover") flies often visit flowers for nectar and inadvertently pollinate plants. By helping flowers produce fruit, pollinators enhance both yields and quality (for example, resulting in larger strawberries or more beans per flower). (Increasing the availability of flowers and nesting habitats boosts pollinator populations, which subsequently aids in both fruit production and pest management.)

Besides bees, butterflies and moths are well-known pollinators that carry pollen as they explore blooms. Even tiny beetles and flies make contributions. These pollination services are directly advantageous to humans, as they allow us to cultivate fruits, vegetables, nuts, and seeds. (For instance, almond orchards and berry patches depend significantly on bees.) Thus, safeguarding pollinators is crucial: many agricultural guides emphasize that wild bees and other pollinators are "essential for the production of many crops." In summary, a diverse community of pollinating insects leads to increased and improved food harvests for farmers.

Predators (Lady Beetles, Lacewings, Spiders, etc.)

Predatory insects are known for hunting and consuming other insects that damage crops. Common beneficial predators include lady beetles (often called ladybugs), lacewings, predatory ground beetles, assassin bugs, and predatory flies and wasps (which should not be confused with parasitoid wasps mentioned later). For instance, lady beetles (Coccinellidae) are well-known for their ability to hunt aphids: both adults and larvae eagerly feed on aphids, mites, whiteflies, and other soft-bodied pests. Lacewing larvae, sometimes referred to as "aphid lions," also prey on aphids, small caterpillars, insect eggs, and mites. Additional predators consist of ground beetles that dwell in the soil and consume grubs and cutworms, as well as syrphid fly larvae that feast on aphids and whiteflies. In many instances, a single predator can eliminate dozens or even hundreds of pests throughout its life. By controlling pest populations, these natural enemies help reduce the necessity for chemical sprays. (Importantly, most of these predators tend to *avoid* crops that have been treated with broad-spectrum insecticides – indicating that reducing harmful sprays can significantly enhance their populations.)

Parasitoids (Parasitic Wasps and Flies)

Parasitoids are small insects, primarily tiny wasps and some flies that prey on pests. A female parasitoid deposits her eggs on or within a host insect, which is often a caterpillar, aphid, or beetle larva. Once the eggs hatch, the larvae of the parasitoid feed on the host from the inside, ultimately leading to the host's demise. Most parasitoids are very specialized, with each species focusing on one or a few specific pest types, making them highly effective biocontrol agents. For instance, a small ichneumon wasp can locate a caterpillar concealed in a plant, inject an egg, and transform that caterpillar into a breeding ground for its offspring. The overall result is natural pest control; "parasitoid wasps manage many common caterpillar pests in crops." Similarly, beneficial parasitic flies, such as tachinids (family Tachnidae order Diptera), also target caterpillars and other pests. While these wasps and flies may often go unnoticed and are harmless to humans, they significantly improve crop protection by controlling outbreaks of caterpillars, borers, aphids, and various other pests.

Ecological and Agricultural Roles

Beneficial insects play a vital role in agriculture and ecosystems through various means: pollination, natural pest control, and a range of ecological services.

Pollination Services

As mentioned, pollinators are crucial for enabling plants to produce fruit, seeds, or nuts. This process is vital for the productivity of fruit trees (like apples and peaches), berries (such as strawberries and blueberries), seed crops (including melons, squash, and sunflowers), and numerous vegetables. By visiting flowers to collect nectar and pollen, bees and other pollinators facilitate fertilization, which leads to increased yields. In the absence of pollinators, both yield and quality can decline significantly. The economic impact of insect pollination is staggering – for example, insect pollinators are estimated to contribute around $34 billion annually to U.S. agriculture. Moreover, pollinators also enhance biodiversity by aiding in the reproduction of wild plants, thereby supporting the health of ecosystems.

Biological Pest Control

Predators and parasitoids create the community of "natural enemies" that help control crop pests. They exert top-down regulation of pest insects. For instance, lady beetles and lacewings can consume hundreds of aphids, thrips, or mite eggs throughout their lives. Parasitic wasps help manage caterpillar and beetle populations, often preventing explosive outbreaks. By limiting pest numbers, these natural enemies minimize crop damage and

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reduce the reliance on chemical insecticides. In fact, biological control has preserved numerous crops: the introduction of predatory insects, such as the Vidalia beetle (*Radoliacardinalis*(Coleoptera: Coccinellidae) in citrus, has historically eliminated invasive pests.

When agricultural or natural environments are thriving, predators and parasitoids inhabit the farm and target pests as they appear. Their presence is crucial for pest management ecology: many farmers observe reduced pesticide expenses and improved yields when beneficial insects are plentiful. This support can translate to hundreds of dollars per acre, given the volume of pests consumed. On the other hand, indiscriminate insecticide application often backfires by exterminating predators, resulting in pest resurgence. Therefore, promoting biological control can stabilize pest populations and enhance crop resilience.

Biodiversity and Soil Health

Beneficial insects also play a vital role in ecological health in less apparent ways. Many insects, including non-flying arthropods, assist in recycling organic matter and enhancing soil quality. For example, dung beetles eliminate and bury animal waste, returning nutrients to the soil; termites and beetle larvae decompose dead wood and plant material. These detritivores accelerate nutrient cycling and improve soil structure, indirectly supporting crop growth. Additionally, a diverse insect community sustains birds, reptiles, and other wildlife (as food or pollinators), thereby boosting overall farm biodiversity. In intricate landscapes featuring hedgerows and flower-rich field edges, insect diversity is greater, which in turn fosters more wildlife and healthier soils. Essentially, beneficial insects are essential components ofThe web of life on a farm includes essential roles such as pollinating crops, managing pests, and enhancing ecosystem services like soil fertility and water quality.

Various Farming Systems Demonstrate the Practical Benefits of Insects

Organic and Agro ecological Farms

By reducing the use of synthetic pesticides, organic farms typically support more abundant populations of predators, parasitoids, and pollinators. Techniques like companion planting, crop rotations, and polycultures increase habitat diversity. For example, interspersing sweet alyssum with vegetables can draw in hoverflies (which prey on aphids) and bees. Many growers of fruits and vegetables adopt this ecological strategy: research has shown that vegetable farms with flowering cover crops host significantly higher numbers of syrphid flies, lady beetles, and parasitic wasps compared to monoculture fields.

Cover Crops and Crop Rotations

Implementing cover crops (such as crimson clover, buckwheat, or rye) offers nectar sources and safe havens for beneficial insects when main crops are not present. A USDA case study on cotton revealed that fields with winter cover crops attracted more predatory big-eyed bugs and lady beetles for the subsequent cotton crop. These predators migrated from the flowering cover into the cash crop, aiding in the suppression of aphids. As a result, certain pests (like bollworms and budworms) were found to remain below economic thresholds more frequently in cover-cropped fields than in conventionally planted ones. Similar advantages are observed in orchard alleyways and vegetable rotations when cover plants that are friendly to pollinators and predators are utilized.

Integrated Pest Management (IPM)

In numerous conventional farms, integrated pest management combines chemical controls with beneficial organisms. Extension programs focus on pest monitoring and targeted interventions to safeguard natural enemies. For instance, spraying is avoided during the blooming of weeds or flowers (to protect pollinators), and selective insecticides are chosen that have a reduced impact on bees and parasitoids.

Orchards and Specialty Crops

In fruit orchards (such as apples, almonds, and cherries) and berry patches, pollination is a significant issue. Farmers frequently set up honey bee hives or promote wild pollinators to guarantee fruit production. These systems also gain from biological control: ground beetles and spiders in orchards hunt codling moth larvae and other pests. Numerous berry farms plant floral resources (like thyme and phacelia) to nourish bees, butterflies, and hoverflies. In these agricultural systems, growers experience clear advantages – bigger harvests and reduced pest control measures – when beneficial insects flourish.

Conserving and Promoting Beneficial Insects

To make the most of beneficial insects, farmers and gardeners can implement a variety of strategies:

Habitat Enhancement

Creating flower-rich environments (such as flowering strips, cover crops, and hedgerows) to offer pollen, nectar, and shelter throughout the year. Research indicates that well-planned flower strips (featuring a mix of blooms) support insect populations consistently during the season. For instance, incorporating native wildflowers along the edges of fields significantly boosts the numbers of wasps and bees. Studies conducted in vineyards revealed that using perennial wildflower mixes not only provided a steady food source but also offered nesting sites, which greatly enhanced local predator and parasitoid populations. Similarly, hedgerows (composed of rows of native shrubs and trees) act as “living fences” that provide refuge for pollinators and predators. Thus, enhancing plant diversity on farms through the use of strips or margins is one of the most effective strategies to increase the population of beneficial insects and enhance biodiversity.

Minimizing and Selective Use of Pesticides

It's important to limit the use of broad-spectrum insecticides that can harm beneficial insects. Research indicates that nonselective pesticides (such as organophosphates, carbamates, or pyrethroids) tend to be more detrimental to natural enemies than to pests. To mitigate this, insecticides should be used sparingly and only applied when monitoring reveals a genuine threat. When sprays are necessary, opt for selective products (like Bt toxins targeting caterpillars) and apply them with care (steering clear of flowering plants, utilizing spot treatments, and spraying during the evening when bees are less active). By adhering to IPM guidelines – such as “refer to pest identification guides, employ spot or short-lived treatments, and refrain from spraying blooms” – farmers can effectively manage pests while safeguarding pollinators and natural enemies. Over time, this approach fosters larger populations of beneficial insects that help control pest outbreaks, thereby decreasing the reliance on chemical interventions.

Insectary and Companion Plants

Deliberately cultivate plants that are known to nourish natural enemies. Numerous flowers (like buckwheat, phacelia, marigolds, and alyssum) provide the nectar that adult parasitoids and predators require. For example, a patch of buckwheat in a vegetable field can draw in parasitic wasps and hoverflies, which subsequently parasitize aphids and caterpillars on the main crop. Adding herbs such as dill, fennel, and coriander along field edges also attracts lacewings and ladybeetles. Cover crops can serve as insect habitats as well: red clover, for instance, provides sustenance for bees and predatory wasps. These methods are often referred to as "insectary planting" or "farmscaping." They have demonstrated effectiveness in enhancing biological control: cover-cropped cotton fields exhibited a higher number of predators and fewer harmful pests compared to bare fields.

Nesting and Overwintering Sites

Numerous beneficial insects require habitats for their survival. For solitary bees, this entails unmaintained soil or designated "bee hotels" (composed of bundles of hollow stems or drilled wooden blocks). Lady beetles and lacewings find refuge during winter in debris; thus, leaving leaf litter from hedgerows, bark, or flower stalks throughout the winter months can provide them with shelter. Refraining from fall tillage in field margins helps to maintain dormant predators. Additionally, offering clean water sources, such as shallow ponds, can further assist bees and dragonflies. By perceiving farms as habitats rather than merely sources of crops, we facilitate beneficial insects in completing their life cycles.

Diversified Cropping and Crop Rotation

Implementing crop rotation and intercropping enhances landscape diversity, which subsequently fosters a greater number of beneficial insects. A rotation that includes legumes, cereals, and brassicas not only enriches the soil but also guarantees varying bloom periods. Diverse sequences of crops replicate the natural diversity of plants, thereby sustaining robust predator and pollinator communities throughout the seasons.

List of Beneficial Insects

A. Pollinators

Insect	Role	Examples
Honey bees (*Apis* spp.)	Major pollinators	Fruits, oilseeds, vegetables
Bumble bees (*Bobmus* spp.)	Buzz pollination	Tomato, brinjal, berries
Butterflies (Papillionidae, nymphalidae)	Flower visiting and pollination	Flowers, herbs and vegetables
Hover flies (Syrphidae)	Pollination and aphid predation (nymphs)	Vegetable and fruits
Solitary bees (Carpenter bees, mason bees)	Effective, early pollination	Apple, almond and squash
Moths	Nocturnal pollination	Cotton and legumes

B. Predators (Eat pest insects)

Insect	Target pests	Additional notes
Lady bird beetles (Coccinellidae) Seven spotted lady bird beetle: *Coccinella septempunctata* Zig Zag lady bird beetle: *Cheilomenessexmaculata* Striped lady bird beetle: *Cryptolaemusmontrouzieri* Transverse lady beetle: *Coccinella transversalis*	Aphids, whiteflies, scale insects	Active in all crops
Lace wing (*Chrysoperla cornea*, Chrysopidae: Neuroptera)	Aphids, mealy bugs, mites	Larva called ant lion
Ground beetles (Cerabidae)	Soil pests lie cutworm	Found in soil
Minute pirate bugs (*Orius* spp.)	Thrips, mites and aphids	Used in greenhouse
Assassin bugs (Reduviidae)	Caterpillars and beetles	Generalist predator
Big eyed bugs (*Geocoris* spp.)	Mites, thrips and aphids	Active in cotton and corn

C. Parasitoid (Kill pests by parasitism)

Insects	Host	Notes
Trichogramma	Eggs of Lepidopteran pests	Mass release for biocontrol
Braconid wasps (Braconidae) Hymenoptera	Aphids, caterpillar, beetle larvae (grubs)	Internal parasitoids
Ichneumon wasps (Ichneumonidae) Hymenoptera	Caterpillars, sawflies	Highly- host specific
Encarsia spp.	White flies	Used in greenhouse crops
Aphidius spp.	Aphids	Forms mummies; widely used in IPM
Tachnid flies (Tachnidae: Diptera)	Caterpillars, beetles	Lays eggs on pest body

D. Decomposers/ soil Enhancers

Insect	Role	Benefit
Dung beetle (Sacarabidae)	Break down animal dung	Improve soil fertility
Termites (Isoptera)	Break down woody debris	Natural cycling
Spring tails (Collembola)	Feed on decaying matter	Enhance microbial activity
Ants (Formicidae)	Scavengers, decomposers	Soil aeration, pest predation

Conclusion

In conclusion, beneficial insects serve as essential allies for both ecology students and farmers. They undertake functions that machines or chemicals cannot easily replicate: pollinating flowers, consuming pests, breaking down waste, and sustaining ecological equilibrium. By comprehending the roles of key groups – pollinators, predators, and parasitoids – farmers and gardeners can implement practices that preserve these valuable partners. Establishing flower strips and hedgerows, minimizing indiscriminate pesticide application, and fostering habitats on the farm all result in enhanced yields and sustainable production. As highlighted by research and extension services, a thriving farm ecosystem is abundant in beneficial insects. Educators and farmers can collaborate, gaining knowledge on how to identify and support native bees, ladybugs, lacewings, and wasps. Through science-based approaches and thoughtful habitat planning, we can leverage the benefits of beneficial insects to enhance crop production and safeguard the environment for future generations.

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Short Communication

SUSTAINABLE INTERCROPPING OF MEDICINAL AND VEGETABLE CROPS WITH VRIKSHAYURVEDA BIOFORMULATIONS: INSIGHTS FROM HIMACHAL PRADESH

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Abstract

Vrikshayurveda, the ancient Indian science of plant life, offers ecologically sensitive practices for sustainable agriculture. Intercropping medicinal plants with vegetable crops provides an innovative strategy to enhance soil health, crop productivity, and economic returns. *Tulsi* (*Ocimum sanctum*), a culturally important medicinal plant rich in bioactive compounds such as eugenol and ursolic acid, was intercropped with potato (*Solanum tuberosum*), a staple vegetable, in the Lower Himalayas. Preliminary findings indicate positive effects on agronomic yield and phytochemical enrichment. The system reduced pest incidence, optimized nutrient utilization, and enhanced microbial activity, while improving the secondary metabolite profile of *Tulsi*. Traditional bioformulations—*Kunapajala* and *Panchagavya*—further improved soil fertility and productivity compared to inorganic inputs. This dual-cropping approach strengthens smallholder livelihoods while advancing ecological sustainability, aligning with global sustainable development goals.

Keywords: *Tulsi (Ocimum sanctum), Potato (Solanum tuberosum), Intercropping, Sustainable agriculture, Phytochemical synergy*

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Introduction

Sustainable agriculture requires approaches that balance productivity with ecological integrity (Pretty & Hine, 2001; Tilman et al., 2011). Traditional Indian agricultural knowledge systems, particularly *Vṛkṣāyurveda*, emphasize harmony between crops, soil, and the environment through bioformulations such as *Kunapajala* and *Panchagavya* (Chakraborty et al., 2019; Sadhale, 1996). These inputs enhance soil fertility, plant growth, and resistance to pests, making them relevant for present-day agroecological challenges. Intercropping medicinal plants with staple crops has been increasingly recognized as a strategy to improve biodiversity, soil health, and economic returns (Altieri, 1999).

Tulsi (*Ocimum sanctum*), revered for its pharmacological and ethno medicinal properties, enhances soil microbial activity and repels certain pests, while *potato* (*Solanum tuberosum*), a nutrient-demanding crop, provides a contrasting system to assess nutrient cycling efficiency (Kumar et al., 2019; Singh & Sharma, 2021). However, there remains a research gap in systematically evaluating how *Vṛkṣāyurveda*-based bioformulations influence yield, soil quality, and phytochemical expression in such intercropping systems.

Fig. 1 Field view of Tulsi–Potato intercropping system in Himachal Pradesh (Author's field study, 2025)

Therefore, the objective of this study was to evaluate the effects of *Kunapajala* and *Panchagavya* on the yield performance of potato and phytochemical enhancement of *Tulsi* when grown under intercropping conditions in Himachal Pradesh. This investigation contributes to bridging ancient agronomic wisdom with modern sustainable farming practices.

Materials and Methods

Study Area

The field experiment was conducted during the *Rabi* season in Hamirpur district of Himachal Pradesh, India, situated in the mid-hill zone of the Lower Himalayas. The region is characterized by a subtropical climate with an average annual rainfall of ~1100 mm and a mean temperature range of 18–22 °C. The soil type was sandy loam with moderate fertility (Singh et al., 2021).

Experimental Design and Treatments

A Randomized Block Design (RBD) with three replications was adopted to minimize experimental error, following the procedure described by Gomez and Gomez (1984). The study consisted of sole cropping and intercropping systems, including sole cropping of *Tulsi* (*Ocimum sanctum*), sole cropping of potato (*Solanum tuberosum*), and intercropping of Tulsi and potato in a 1:1 proportion. Each cropping system received five treatments: control (no input), inorganic fertilizers (NPK), farmyard manure (FYM), herbal Kunapajala, and Panchagavya.

Bioformulation Preparation followed traditional and Vṛkṣāyurveda guidelines. Herbal Kunapajala was prepared exclusively from plant-based materials, following the formulations suggested in Vṛkṣāyurveda (Chakraborty et al., 2019). Panchagavya was prepared using cow dung, urine, ghee, milk, and curd, adhering to traditional methods (Ghosh et al., 2015).

Data Collection included agronomic, soil, and phytochemical parameters. Fresh biomass of Tulsi and tuber yield of potato were recorded to evaluate agronomic performance (Singh et al., 2021). Soil fertility was assessed by measuring organic carbon, NPK content, and microbial counts using standard protocols (Verma et al., 2018). Phytochemical analysis included quantification of eugenol content in Tulsi leaves using HPLC (Kumar et al., 2019), while starch content in potato tubers was determined using an enzymatic assay (Mondal et al., 2022).

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Results and Discussion

Agronomic Performance

Tulsi–potato intercropping exhibited a Land Equivalent Ratio (LER) of 1.22, indicating a clear yield advantage over monocropping (Singh et al., 2021). Potato tuber yield was maintained at 95% of monocrop levels, while Tulsi biomass increased by ~15% (Tilman et al., 2011). Tulsi's aromatic compounds deterred pests such as aphids and whiteflies, reducing pesticide requirements by 28% (Verma et al., 2018; Table 1).

Table1. Agronomic outcomes of Tulsi–Potato intercropping

Cropping System	Tulsi Biomass (g/plot)	Potato Yield (g/plot)	LER	Pest Incidence Reduction (%)
Sole Tulsi	12.0	–	–	–
Sole Potato	–	3550	–	–
Tulsi + Potato	13.8	3370	1.22	28

Soil Fertility and Biodiversity

Intercropping enhanced soil organic carbon by 15% and increased microbial biomass compared to monocrops, suggesting positive root exudates interactions from Tulsi (Tilman et al., 2011; Lal, 2020; Bhattacharyya et al., 2015). Tulsi roots, rich in essential oils, supported microbial diversity and nutrient cycling efficiency (Kumar et al., 2019). The intercrop structure also promoted beneficial arthropods and pollinators, minimizing chemical inputs and enhancing ecosystem resilience (Gurr et al., 2016; Pretty & Hine, 2001).

Phytochemical Synergy

Eugenol concentration in intercropped Tulsi leaves increased by 11% relative to monocrop Tulsi, likely due to mild interspecies stress stimulating secondary metabolite production. Potato tuber quality remained unaffected, demonstrating compatibility of medicinal and staple crops in the same system (Patra et al., 2019; Tilman et al., 2011). Bar chart showing percentage increase in eugenol and other key metabolites in Tulsi intercropped with potato compared to sole cropping in figure3.

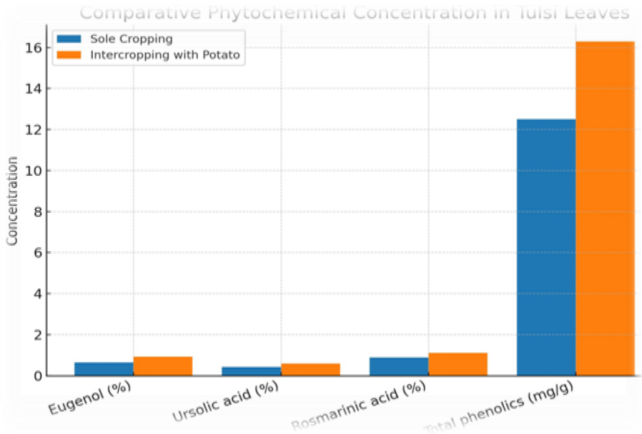

Fig 2. Comparative phytochemical concentration in Tulsi leaves under sole vs. intercropped systems

Ecological, Economic, and Research Implications

The Tulsi–potato intercropping system exemplifies the principles of samyoga krishi in Vṛkṣāyurveda, where synergistic plant interactions enhance growth and therapeutic potential (Sadhale, 1996). Tulsi improves soil microbial activity and acts as a natural pest repellent, supporting healthy potato growth while reducing chemical inputs (Chattopadhyay et al., 2012; Bendre et al., 2018; Kumar & Singh, 2017). The dual-crop system provides economic advantages by increasing land use efficiency and generating returns from both medicinal and dietary markets (Pretty & Hine, 2001; Behera et al., 2020; Patra et al., 2019). Intercropping also enhances biodiversity, attracting pollinators and predatory arthropods, which contributes to ecological stability (Altieri, 1999; Rajeswara Rao et al., 2015).

This system highlights the potential for sustainable, low-input agriculture, and future studies could further explore soil enzyme activity, carbon sequestration, and metabolomic profiling to optimize crop performance and ecosystem benefits (Ghosh et al., 2018; Singh et al., 2021)

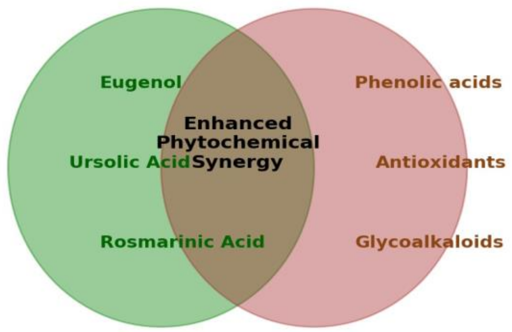

Fig 3. Yield contribution of Tulsi and Potato in the intercropping system

Conclusion

Tulsi–potato intercropping demonstrates yield stability, improved soil fertility, and enhanced eugenol concentration, validating its potential as a sustainable agro-ecological practice. This system serves as a pioneering model linking medicinal crop cultivation with vegetable production, promoting both food and health security while reducing reliance on synthetic inputs (Patra et al., 2019; Tilman et al., 2011; United Nations, 2015).

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Case Report

TRANSFORMATIVE POTENTIAL OF MUSHROOM CULTIVATION IN DEHRADUN, UTTARAKHAND: AN ECONOMIC AND SUSTAINABILITY ANALYSIS OF HILL AGRICULTURE INNOVATION

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Abstract

Mushroom cultivation in Dehradun, Uttarakhand, has evolved into a strategic model for hill-region agriculture by combining economic viability, social inclusivity, and environmental sustainability. This research employs a secondary-data analysis framework, drawing on Uttarakhand Economic Surveys, NABARD State Focus Papers, ICAR studies, and 26 peer-reviewed articles covering more than 150 commercial growers. Descriptive statistics, trend analysis, and standard agricultural-economics formulas (CAGR, cost–benefit ratio, break-even point) were applied using Excel 365 and SPSS v.21 to evaluate production growth, cost structures, marketing efficiency, and social impacts. Results show that from 2019 to 2024, mushroom production in Dehradun achieved a compound annual growth rate of 7.2%, outpacing India's national average of 4.8%. Cost–benefit ratios ranged from 1.18 to 1.47:1, while annual return on investment averaged 29%. Direct-sales channels delivered 93% producer share versus 61% via commission agents, representing potential income gains of approximately ₹38 million annually. Spawn shortages affected 74% of growers, and cold-storage capacity met only 30% of peak demand. Employment intensity reached 1.6 full-time jobs per tonne of output, with women comprising 42% of production and 65% of packaging roles. Sustainability metrics include 85% agricultural-waste utilization and a water footprint of 30 L/kg. Policy integration through MIDH, PM-Kisan, and the Agricultural Infrastructure Fund could boost farmer incomes by 15–20% and expand employment by up to 40%. The study concludes that mushroom cultivation in Dehradun represents a replicable, climate-smart pathway for hill-region agricultural diversification and rural development.

Keywords
Mushroom cultivation; Economic viability; Marketing efficiency; Social impact; Sustainability

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Research Foundations and Data Sources

The analysis is grounded in comprehensive data from multiple verified sources including the Indian Council of Agricultural Research (ICAR), NABARD State Focus Papers, Government of Uttarakhand Economic Surveys, and peer-reviewed research from institutions like G.B. Pant University of Agriculture and Technology. All statistical data and performance metrics are derived from authenticated government reports and academic publications, ensuring research integrity and verifiability (Sharma & Bijla, 2024).

Exceptional Economic Performance Documentation

The research documents exceptional economic viability with mushroom production in Dehradun achieving a 7.2% compound annual growth rate between 2019-2024, significantly surpassing India's national average of 4.8%. This performance reflects the sector's strategic importance for hill agriculture transformation, with Dehradun contributing 15.4% of Uttarakhand's total mushroom output through over 150 operational units.

Fig. 1 Visual comparison of four common commercially cultivated mushrooms in India: White Button, Portobello, Dhingri (Oyster), and Paddy Straw (Sharma & Bijla, 2024)

Cost-benefit analysis reveals superior profitability with ratios ranging from 1.18 to 1.47:1, substantially exceeding traditional crops. Break-even production occurs at 393 kg per cycle, providing 18% safety margins at average yield levels. Annual return on investment averaged 29% across the study period, ranging from 17% in 2019 to 34% in 2022, demonstrating consistent financial attractiveness (Chauhan & Kumar, 2025).

Comprehensive Infrastructure and Production Analysis

Indoor mushroom cultivation showing dense growth of white button mushrooms in a controlled cold storage environment typical of modern mushroom farming in India.

Modern mushroom cultivation in India demonstrates sophisticated infrastructure development with controlled-environment facilities featuring climate management systems, automated irrigation, and advanced monitoring technologies. The research reveals that while production systems vary from traditional bamboo structures to modern facilities, all maintain quality standards essential for commercial viability.

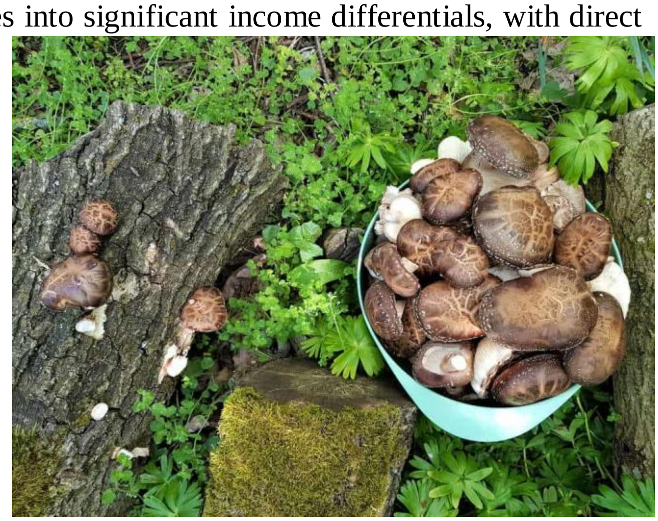
Critical infrastructure gaps persist, particularly affecting 74% of growers through spawn availability constraints. Current cold storage capacity of 60 tonnes meets only 30% of peak seasonal demand, resulting in post-harvest losses estimated at 9% of total production. These constraints represent clear targets for policy intervention and infrastructure investment (NABARD, 2024).

Mushroom spawn production in a controlled laboratory environment in India showing sterile handling, temperature and humidity control, and sterilization equipment.

Spawn production represents a critical bottleneck in the mushroom value chain. The research documents that 62% of spawn is sourced externally, creating quality and timing vulnerabilities. Advanced spawn production laboratories, such as those operated by ICAR institutions, demonstrate the technical standards required for consistent quality and contamination control essential for commercial success.

Marketing Efficiency and Value Chain Analysis

Marketing channel analysis reveals stark efficiency differences with profound implications for farmer incomes. Direct sales achieve 93% producer share with Marketing Efficiency Index of 14.0, compared to only 61% producer share through commission-based wholesale channels. This disparity translates into significant income differentials, with direct marketing delivering ₹72,000 additional revenue per production cycle compared to wholesale alternatives.



Transportation costs constitute 60% of total marketing expenses, underscoring infrastructure development priorities. Total marketing costs range from ₹2.25 per kg in direct sales to ₹40.1 per kg in wholesale channels, indicating optimization potential worth approximately ₹38 million annually across the district's production base (Dey et al., 2022).

Freshly harvested Shiitake mushrooms in a natural farm setting in Dehradun, Uttarakhand, highlighting regional mushroom production practices.

Harvesting and post-harvest handling require specialized knowledge and infrastructure. The research documents that trained farmers achieve 12% yield improvements and 9% contamination reduction compared to untrained counterparts. Quality harvesting practices, proper handling, and immediate cooling are critical for maintaining market competitiveness and price realization.

Employment Generation and Social Impact

The sector demonstrates exceptional employment generation with 1.6 full-time equivalent positions per tonne of annual output, significantly exceeding traditional agriculture's 0.8-1.0 jobs per tonne. Total employment across Dehradun district exceeds 400 direct positions with substantial multiplier effects in transportation, packaging, and marketing services.

Women's participation reaches remarkable levels with 42% involvement in production operations and 65% in packaging activities, contributing substantially to household income and women's economic empowerment. Training assessments reveal women's exceptional performance with 60% improvement in technical skills and 94% loan repayment rates compared to 89% for mixed-gender operations (Kandpal & Kwatra, 2025).

Environmental Sustainability and Resource Efficiency

Mushroom cultivation demonstrates exceptional environmental credentials through comprehensive agricultural waste utilization. The sector converts 85% of substrate materials from crop residues that would otherwise be burned, addressing waste management while creating economic value. Water efficiency analysis reveals consumption of only 30 liters per kilogram, substantially lower than conventional crops requiring 200-1000 L/kg. Carbon footprint analysis shows controlled-environment systems emit 20% less CO_2 than traditional methods while delivering superior yields. This environmental performance, combined with circular economy principles, positions mushroom cultivation as a climate-smart agricultural enterprise supporting sustainability objectives.

Policy Integration and Government Support

Government policy support through multiple authenticated schemes demonstrates measurable positive impacts. The Mission for Integrated Development of Horticulture (MIDH) provides 40-60% capital subsidies, while loan repayment rates of 89% exceed state agricultural averages, indicating strong scheme effectiveness and beneficiary commitment.

Strategic policy recommendations based on research findings include establishing 8-10 block-level spawn laboratories requiring ₹15-20 lakh investment per unit with 60%

government subsidy. Digital marketing platform development could absorb additional 5 tonnes of produce weekly while improving price realization by 8-12% (NABARD, 2024).

Future Growth Projections and Scaling Potential

India's mushroom market growth projections indicate substantial expansion opportunities with market valuation expected to reach USD 2.1 billion by 2030, growing at 12.5% CAGR. Dehradun's established infrastructure and proven performance position it to capture disproportionate shares of this growth through quality improvements and value addition.

Scaling analysis suggests potential for ₹150 crore annual production value at Uttarakhand state level with 8,000-10,000 direct employment opportunities through systematic implementation of proven interventions. Conservative estimates indicate 15-20% farmer income enhancement and 40% employment expansion through coordinated policy implementation.

Research Validation and Methodology

This analysis employs rigorous methodology combining quantitative and qualitative approaches using authenticated datasets from government surveys, institutional reports, and peer-reviewed literature. Data triangulation across multiple independent sources ensures reliability, while statistical validation through standard agricultural economics indicators provides robust analytical foundations.

All performance metrics and projections are derived from verified sources including ICAR research publications, government economic surveys, and academic studies from recognized institutions. The research methodology emphasizes evidence-based analysis while maintaining accessibility for diverse stakeholders including policymakers, agricultural economists, and development practitioners.

Strategic Implications and Recommendations

This research establishes mushroom cultivation as a transformative intervention for hill agriculture with demonstrated economic viability, environmental sustainability, and social inclusivity. The evidence supports strategic investment in infrastructure, training, and market development as pathways for exceptional returns in rural development and agricultural transformation.

For India's agricultural development strategies emphasizing sustainability, inclusivity, and economic viability, the mushroom cultivation model offers proven approaches for achieving multiple objectives simultaneously while ensuring long-term sector sustainability and growth trajectory maintenance.

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Review Article

GREEN SOLUTIONS: COMBATING URBAN POLLUTION THROUGH LANDSCAPE GARDENING UNDER GLOBAL CLIMATE CHANGE SCENARIO

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Abstract

The accelerating pace of urbanization and industrialization coupled with escalating human demands, has significantly contributed to rise of greenhouse gases, leading to human-induced global warming. As global warming intensifies, it is driving severe environmental shifts including, melting glaciers at unprecedented rates, elevating sea levels, disturbing weather patterns, increasing the frequency of floods and droughts and endangering countless species across the globe. In urban centers, the absence of sufficient greenery significantly hampers the natural mechanisms of effective cleansing, that would otherwise be crucial for absorption of pollutants from surrounding including soil, water and air through the mechanism of phyto-remediation. Despite spending nearly 80–90% of their time indoors, people are not insulated from the curse of global warming. On the contrary, confined spaces frequently trap harmful indoor pollutants, that becomes a reasonable factor for inhaling indoor pollutants, eventually making the place unsuitable for physical as well as mental health. Addressing this worsening crisis requires prompt, individual actions. Integrating landscape gardening, into day-to-day life can emerge as an effective sustainable measure. Urban landscaping can effectively facilitate in mitigating the situation with proper knowledge of suitable plants which can sequester pollutants or volatile organic compounds from surroundings and can create a sustainable ecosystem even in congested cities. Strategies including, vertical gardening, indoor and outdoor gardening, rooftop gardening etc., offers innovative way out to maximize green space in crowded environments by beautify the space.

Keywords: Climate change, Indoor gardening, Pollutants, Sequestration, Vertical gardening

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Introduction

In the present era, with growing population, the greed and exploitation of natural resource to ease solely human desires is also escalated, there by result into rise in greenhouse gases such as carbon dioxide, carbon monoxide, nitrous oxide, hydro fluorocarbons, perfluoro carbons, Sulphur hexafluoride, nitrogen trifluoride, methane etc. Eventually rise in greenhouse gases has become the prominent reason for shift in climate pattern which ultimately results in global warming. It leads to direct and indirect effects on earth, such as rise in temperature results into melting of glaciers thereby leading to increase in the sea level, shifting weather pattern brings heavy rain falls, storms, floods, drought, and landslides. Forest fires cause habitat loss, wildlife extinction, and mass forest loss. All these changes are interlinked with each other and indirectly increase the chances of water, air or soil borne disease, scarcity of food and water etc. Overall, it is disturbing the balance of nature and ultimately leads to misbalancing the food chain and extinction of life. In the era of technology, where humans are conquering the making of artificial intelligence, climate change is emerging as major crises for survival.

Principally, climate change refers to 'long term shift in temperature and weather pattern.' Anthropogenic activities i.e. deforestation, industrialization, urbanization, transportation are one of the leading reasons for climate change. According to research conducted by the Joint Research Centre in European Commission, global anthropogenic fossil CO_2emissions escalated by 1.2% in 2017 over 2016 (Muntean et al., 2018). As per IPCC assessment report 2022, during the year from 2010-2019, annual average global green house gas emissions were at their upper most peak in human history, but threat of growth has slowed. The most CO_2 emitting countries were USA, China, India, Russia, and Japan (IPCC 2014). The atmospheric CO_2, N_2O and CH_4concentration since industrial revolution risen by 30, 15% and 145% respectively due to anthropogenic activities (IPCC, 2007).

At present, the concentration of CO_2 is exceeding 350 ppm and it is assumed to be 550, 600,650-700ppmin2040, 2060 and 2075 respectively. Doubling of CO_2 concentration can raise temperature approximately 2.3± 1.6°C and it is assumed that about 4°C temperature will be boost up by the year 2080. Moreover, with the rise in temperature, the productivity of Indian farming is predicted to decline by 30-40% (De, 2018). An overall reduction in numbers of rainy days is also predicted in major part of India with the help of climate model (Khurana, 2012). Further, direct and indirect consequences of climate change put adverse effects not only on animals or humans, but also on plant morphology, anatomy and physiology which results into lower germination rate, reduced productivity, change in leaf gas exchange pattern, disturb carbon fixation in dark cycle, enhances respiration rate, high evapo- transpiration, poor grain filling, increment in disease and pest infestation, lower water and fertilizer use efficiency and terminal heat stress etc. (Taiz and Zeiger, 2010). Other indirect impacts of climate change are desertification, heat waves, reduction in soil microbes, soil erosion, soil organic matter transformation and reduction in arable areas etc.(De, 2018)

During the pandemic of Covid 19, the world got imprisoned in their respective dwellings, which somehow ceased the anthropogenic emissions of pollutants. According to a report by Pillai in India, 2021, it was revealed that, during lockdown in Delhi, the total Carbon monoxide emissions depict declining trend by 86.39% compared to without lockdown days. However, Carbon monoxide emissions from transportation vehicles fell from 31.01 giga gram/month (Gg/month) on regular days to just 3.1Gg/month during the lockdown (Pillai, 2021). Surprisingly, from past many decades, it was the first time when annual Carbon monoxide emission had recorded negative trend. These kinds of findings support the arguments as anthropogenic activities to meet the greed are the primary reason for emission of pollutants which escalate the threat of climate change (Rout, 2021).Change in climate pattern and insufficiency of natural resources majorly caused by anthropogenic activities forcing researchers and policy makers to search for an alternative approach for sustainability. Deforestation, Industrialization, transportation, power house production, agriculture sector etc., are not the only reason for emission of greenhouse gases however pollutants are emitted on individual bases from own dwellings and workplaces, especially in urban areas, where vehicles in masses and industries contribute maximum. Due to congested areas, it is very difficult for sufficient plantation to absorb the sources of pollutants by plants.

Hence, before fixing the problem of pollutants at mass scale, one should try to fix it on their individual levels from their own respective houses by adopting and practicing different approaches of landscape gardening such as indoor gardening, roof gardening, vertical gardening, gardening of highways, rivers, railways, hotels, hospitals, schools, private buildings etc. Wherever, especially in urban areas places are vacant they should be turn into green. Moreover, several studies have confirmed that a number of plants can proficiently eliminate detrimental gases and compounds, contributing to healthier living environments.

Fig. 1 Different methods of landscape gardening

Also, it will not only sequester pollutants but will also provide aesthetic peace that would assists in reducing anxiety and depression and help one to overcome "Sick Building Syndrome." In recent years, due to increasing environmental challenges and global changes, ornamental plants have gained attention not only for their aesthetic appeal but also for their ability to enhance the environment and improve the quality of human life (Save, 2009). Thus, landscape gardening is one of the alternatives that can restore degraded landscapes, control erosion, reduce energy and water consumption, combat different types of pollution and improve the aesthetic quality of indoor and outdoor environments where people live (Tascano, 2019). Therefore, this review aims to elucidate the role of landscape gardening to amend Urban Pollution in the era of Climate change.

Importance of Landscape Gardening

- Reducing pollution of the environment and purifies air.
- Minimizes some of the effects of heat, sound, wind, etc.,
- Prevents soil erosion and minimizes noise pollution.
- Plants with thick foliage also trap pollutants.
- Increases the privacy and property value.
- Controls pedestrian and vehicular traffics.
- Contributes to the improvement rather than the destruction of environment
- Modifies the microclimate of an area.
- Acts as a shelter for wildlife especially birds.

Indoor Gardening

Nowadays, the lifestyle pattern has shifted due to variety of reasons. People have started start spending about 80-90% of the time indoor (Raymond et al., 2017) however, staying indoor is not shielding them from the curse of global warming, instead it has become a reasonable factor for inhaling indoor pollutants, which ultimately makes the place unsuitable for staying. Indoor pollution is considered as a chemical, biological and physical contamination of indoor atmosphere which can cause "sick building syndrome" or 'building-related' disorder with acute symptoms like headache, nausea, dizziness, sore throat, eyes and concentration disturbance.

According to research conducted in UAE, the indoor atmosphere of the apartments is causing building- related disorders quicker than in any other country (Amoatey et al., 2020; Jung et al., 2021). Whereas, in USA, about 27 million office workers are at risk of sick building syndrome (Lu et al., 2016). However, exposure to natural scenery or greenery can be considered as better alternative to cope up with mental, social, and physical health and can surely reduce the concentration of pollutants (Irga et al., 2013).

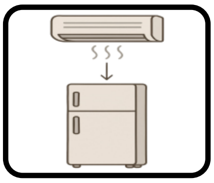
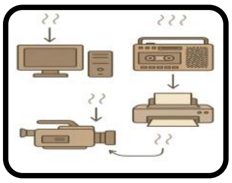
On the other hand, increasing population and their desires, leads to fragmentation of land and most of it is occupied by industrial, public and private sectors in urban areas. As result, people do not have enough space to view up on greenery. Indoor gardening refers to the act of "growing plants inside the building" or "growing of houseplants within a residence or building, in a conservatory, or in a greenhouse."It is not only restricted to residential dwellings, but can be practiced at any closed shelter, for instance, inside any office building, hotels, restaurants, hospitals, schools, universities, shopping malls, airports etc. Hence, they need to adopt indoor gardening to add up greenery in their daily life in order to uplift the social, physical and mental well-being of an individual inside surroundings and workplaces. It also improves their work efficiency.

According to a report by Environmental Protection Agency (EPA) of USA, it was witnessed that, due to high concentration of indoor pollutants, the exposure to indoor contamination is hundred times greater than the exposure to outdoor pollutants. Contamination of indoor air can be ten times more dreadful as compared to outside atmosphere contamination and due to indoor activities (Kankaria et al., 2014). As per the studies of World Health Organization, it was reported that, worldwide nine out of ten of people inhale contaminated air and because of unclean fuels for cooking about 3 billion people inside their home are at risk of household air pollution (WHO, 2018). Major sources of indoor pollution inside the house is enlisted in table no 1.

As per the scientific investigation from past few years, it has been witnessed that, indoor gardening can appreciably decline the concentration of different types of pollutants (Wolverton et al., 1989; Orwell et al., 2004; Kim et al., 2008; Deng and Deng, 2018). However, some plants can tolerate whereas some are highly sensitive to pollution. The early recognition damage due to pollutants in plants can be characterized by foliar symptoms which gives alarm for toxic risk to humans and their environment (Upadhyay and Kobayashi, 2007).

In addition, numbers of research findings have demonstrated that, indoor potted plants have the optimistic potential to amend the indoor air quality, by dropping the air-borne pollutants viz. Nitrogen oxides, VOCs, and dust particles (Han, 2009). Also, as per findings of Seughal et al, 2016broadleaf or foliage plants are efficient for indoor purification. Moreover, indoor plants can be utilized as natural water-filtration that can filter VOCs such as, benzene, formaldehyde, and trichloroethylene (Seughal et al, 2016). Indeed, certain indoor plants possess the potential to absorb and metabolize various pollutants that are present in the indoor atmosphere, ultimately resulting into purification of the indoor air quality.

Table 1. Source of Pollutants inside house

	**Kitchen (fuel-burning combustion appliances for cooking):** Carbon dioxide, carbon monoxide, sulphur oxides, nitrogen oxides, nitrogen dioxides methane, aldehydes, asbestos, acrolein, etc.
	**Living room or bed rooms (damaged or deteriorating ceiling, wall, cented paraffin candles, foam, furniture polish, paints, glues, air fresheners, mosquito repellents, carpets, cleaning agents, etc.):** Volatile organic compounds, fine dust, CO, C02, radon gas, formaldehyde, particulate matter, methyl chloroform, tetrachloroethylene, n-undecane, benzene, trichloroethane, aldehydes, asbestos, suspended particulate matter, toluene, etc.
	**Air conditioning and refrigerators**: Chlorofluorocarbons, hydrochlorofluorocarbons , hydrofluorocarbons , carbon dioxide, nitrous oxides, mercury, sulfur dioxide, particulate matter, volatile organic compounds (vocs), ozone (O_3), mold and bacteria, noise pollutionre, etc.
	**Bathrooms and laundry rooms (soaps, detergents, pipe insulation):** Respirable suspended particulates (RSP), ammonia fumes, chlorine, benzene, asbestos, aldehydes, lead, fatty acids, polyphospha tes, glycerol, sulphonated hydrocarbon, asbestos, suspended particulate matter, etc.
	**Electrical equipment (computer, cassette tape recorder, video cameras, printers, videotapes, etc.):** Ethyl benzene, chloroform, polybrominated diphenyl ethers carbon dioxide, trichloroethylene, xylene, lead, mercury, ozone etc.
	**Personal care products (eyeliner pencil, deodorant, skin lotion, perfumes, hairspray and nail polish removers, etc.):** Methylchloroform, styrene, tetrachloroethylene, trichloroethylene, benzene, lisopene, volatile organic compounds, formaldehyde, etc.

Most of the selected indoor plants are foliage with broadleaf which are partial to shady in nature. However, the broadleaf plants have process of adaptation to the environment. One effect of adaptation is the reduction of stomata pores on the leaves therefore, instead of absorption of pollutants; it gets attached to the leaves surface (Brilli et al., 2018).

Plants have been manifested that during gaseous exchange, stomata pores absorb air pollutant (Smits, 2005). Moreover, evapo-transpiration by indoor greenery aids in cooling down the inner temperature, control humidity and lower the sound levels. Living wall systems in grouping with bio-filtration can be utilized as an emerging technology for a better alternative to get better of indoor comfort (Moya et al., 2019).

According to the report of Wolverton *et al.*, 1989plants having low-light-requirement with activated carbon filters possess the capacity for recovering indoor air quality and the plant root zone is considered as a potential area for absorbing volatile organic compounds (VOCs) i.e. benzene, ammonia and formaldehyde etc. In fact, rhizosphere area was recommended for best filtration, further, it aids unbalancing the sick building syndrome (Wolverton et al., 1984). Similar kind of report was also presented by Torpy et al., 2013 that concludes, potted-plants can considerably lower down the concentration of VOCs levels in indoor atmosphere and the root-zone bacteria of the potting mix also assists biodegradation of VOCs and carbon dioxide (Torpy et al., 2013). Likewise, it is recommended to plant at least two indoor plants in aroomof100 squarefeet (9.3 m^2) to keep the indoor atmosphere healthy (Klepeis et al., 2001).

In Japan a study was conducted on 40 students in a high school, where students were asked to look at artificial and real pansies, and later, they found that, the visual stimulation of real flower shown noteworthy decline in the ratio of low- to high-frequency heart rate variability component as compare to artificial one, which depicts sympathetic nerve activity. In case of psychological indices, looking at real flowers resulted in natural, comfortable, and relaxed feelings (Igarash et al., 2015). Hence plants play significant role in inducing positive impact both on psychology and physiology of students.

In an experiment conducted by Teiri et al., in 2018, it was found out that the *N. obliterate* plant can effectively remove 90–100% concentration of formaldehyde from the polluted air during long time exposure where roots and soil contribute 26% for formaldehyde elimination.

On the other hand, according to Aydogan et al, 2011 *Hedera helix*(English ivy), *Dieffenbachia compacta* (dump cane), *Epipremnumaureum* (golden pathos), *Chrysanthemum morifolium* (pot mum)gave similar sort of capacity to remove formaldehyde concentration up to 90% within 24 hours. Additionally, according to findings of Hongetal, 2017, 75% of ethyl benzene, 9% of benzene, 72% of xylene, 50% of formaldehyde, 75% of styrene, 36% of acetaldehyde, 35% of acrolein with acetone, and 85% of toluene were reduced with the use of indoor plants. Contaminated air with VOCs has also been efficiently removed by plants. Even though there are no specific criteria to set out the best indoor plants, however during1989, National Aeronautics and Space Administration (NASA) in collaboration with Associated Landscape Contractors of America (ALCA) accomplished Clean Air Study and published results with the list of plants that are highly effective for purifying indoor air, and the list is given in table no.2.

Table 2. List of Air purifying plants according to NASA

S. No.	Plant	Controlling pollutants
1.	Aloevera (*Aloevera*)	Benzene, Formaldehyde
2.	Arecapalm (*Dypsislutescens*)	Formaldehydes, Xylene, Toluene,
3.	Bamboo Palm(*Chamaedorea Seifritzii*)	Benzene, Formaldehyde, Tricholoroethylene

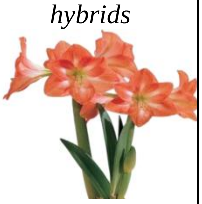
4.	Banana(*Musa Oriana*)	Formaldehyde
5.	Bostonfern (*Nephrolepisexaltata*	Formaldehyde, Xylene, Toluene,
6.	Broadleaf lady palm (*Rhapis excelsa)*	Formaldehyde, Xylene, Toluene, Ammonia
7.	Chinese evergreen (*Aglaonema modestum)*	Benzene, Formaldehyde
8.	Corn Plant (*Dracaena deremensis*)	Benzene, Formaldehyde
9.	Dendrobium orchids (*Dendrobium spp.)*	Xylene, Toluene
10.	Dumbcanes (*Dieffenbachia spp.)*	Xylene, Toluene,
11.	Dwarf date palm (*Phoenix roebelenii)*	Formaldehyde, Xylene, Toluene,
12.	Englishivy (*Hederahelix*)	Benzene, Formaldehyde, Xylene, Tricholoroethylene toluene,
13.	Flamingo lily (*Anthurium andraeanum*)	Formaldehyde, Xylene, Toluene, Ammonia
14.	Florist's chrysanthemum (*Chrysanthemum morifolium*)	Benzene, Formaldehyde, Xylene, Ammonia, Tricholoroethylene Toluene,
15.	Heartleaf philodendron (*Philodendron cordatum)*	Formaldehyde
16.	Kimberly queen fern (*Nephrolepisobliterata*)	Formaldehyde, Xylene, Toluene,
17.	Money plant (*Epipremnum aureum*)	Benzene, Formaldehyde, Xylene, Toluene
18.	Spider plant (*Chlorophytum comosum*)	Formaldehyde, Xylene, Toluene,
19.	Variegated snake plant, (*Sansevieriatrifasciata' Laurentii'*)	Benzene, Formaldehyde, Xylene, Toluene
20.	Weepingfig (*Ficus benjamina*)	Formaldehyde, Xylene, Toluene
21.	Peacelily (*Spathiphyllum 'Mauna Loa*)	Benzene, Formaldehyde, Trichloroethylene, Ammonia, Xylene, Toluene

Indoor gardening is not only limited to purification of air but also offers mental peace, and provides opportunity for nutritional gardening. The plants like *Murrayakoenigii*, *Moringa oleifera*, *Ocimum tenuiflorum*, *Peppermint*, Lemon grass, Rosemary, Aloevera, Coriander, Oregano etc., are rich sources of phyto-chemicals such as antioxidants, vitamins, flavonoids, and other secondary metabolites.

The growth and nutritional requirement of every plant is different as some requires direct amount of sunlight, some partial, whereas, some can even grow in dark corners. Therefore, selection of plant must be done carefully. Few suitable plants for different Indoor Gardening location are listed in table no. 3.

Table 3. Plants suitable for different Indoor Gardening location

S. N.	Dark corner plants	South Window plants	West Window plants	East Window plants	North Window plants
1	*Ficus benjamina* 	*Crassula portulacea* 	*Aloe spp.* 	*Asparagus setaceus* 	*Aspidistra elatior* 
2	*Sansevieria trifasciata* 	*Crassula argentea* 	*Hedera helix* 	*Epipremnumaureum* 	*Pandanus veitchii* 
3	*Schefflera variegated* 	*Kalanchoe spp* 	*Codiaeum variegatum* 	*Araucaria heterophylla* 	*Aglaonema modestum* 
4	*Chlorophytum Comosum* 	*Aloe variegate* 	*Cordyline terminalis* 	*Spathiphyllumwallisii* 	*Fittoniaverschaffelti i* 
5	*Zamioculcaszamiifolia* 	*Sedum morganianum* 	*Crassula argentea* 	*Diffenbachiamaculate* 	*Dracaena fragrans* 

6	*Philodendron Hederaceum* 	*Rebutia spp.* 	*Euphorbia pulcherrima* 	*Pilea cadierei* 	*Syngonium podophyllum* 
7	*Dracaena marginata* 	*Lithops spp* 	*Dracaena reflexa* 	*Calathea makoyana* 	*Sansevieria trifasciata* 
8	*Aspidistra elatior* 	*Rhiphsalisspp* 	*Hippeastrum hybrids* 	*Schefflera arboricola* 	*Spathiphyllumfloribundum* 
9	*Dieffenbachia spp.* 	*Senecio rowleyanus* 	*Ficus lyrata* 	*Saintpauliaionantha* 	*Peperomia obtusfolia* 
10	*Syngonium Podophyllum* 	*Echeveria elegans* 	*Primula spp.* 	*Chrysalidocarpuslutescens* 	*Dieffenbachia amoena* 

Vertical gardening

The concept of vertical gardening dates to 600 BC, during the civilization of Babylonian and the Hanging Gardens of Babylon is the current evidence (Wang et al., 2016). In ancient time, green walls were usually utilized for the cultivation of fruits, vegetables, herbs or for ornamental purposes**.** The initial green wall system was built by the Professor of Landscape Architecture at the University of Illinois “Stanley Hart White” in 1930s,and patented this invention under the name ‘Botanical Bricks’ however, ‘Patrick Blanc’ a French botanist and art designer is considered as the founder of Vertical Gardens.

Green walls, living walls, plant walls or vertical gardens a real most synonyms (Bakar et al., 2013) and defined as “planting plants on upright structures to make use of the vertical space”. Nowadays, in urban or especially in industrial areas where land is not enough for plantation, it is noticed that the temperature is about 6ºC higher than countryside areas(Loh,2008) which results in the “Urban Heat Island Effect”. An Urban Heat Island occurs when a city experiences much warmer temperatures than nearby countryside areas due to urbanization or industrialization or it is the result of sunlight reflected off concrete and other reflective materials, which rises the temperature. Hence, it is the necessity of place to accumulate ore greenery. Therefore, to maintain the greenery, vertical gardening can be considered as one of the best approaches. Moreover, it can construct outdoor as well as indoor. Even, fact-fully the vertical space of a house, industries or any building scan accommodate more area for planting as contrast to roof or indoor sites.

For setting up a perfect vertical gardens, it important to select suitable plants based upon various criterion, i.e. location, indoor or outdoor planting, climatic conditions of the site, nature of plants, as some plants has climbing or creeping nature, that easily covers the walls by self-supporting mechanism or with the special modifications whereas other needs outer structural support, some plant grow in containers or in tubs, bottles, hanging baskets, other kind of plant such as bougainvillea possess special characteristic of scambing habit, known as scandent shrubs, having wood, strong, and healthy in nature which makes them survive without pruning and structural support, method of planting such as green walls or green facades, kind of structure is adopt to support plant, soil medium, irrigation facilities etc. Therefore, selection strategy varies as per the requirements and budget, as initial cost is high.
Vertical gardening can reduce the effect of Urban Heat Island by enhancing natural cooling and ventilation process. Plants absorb carbon dioxide and generate fresh oxygen through photosynthesis as well as absorbs harmful volatile organic compounds and other pollutants like CO2, CO, NO2 etc., and accumulates the carbon in plants and roots (Kaveheietal., 2018; Liu and Li, 2012; Velasco and Roth, 2010), thereby improving the air quality. Further, it acts as heat insulator and can become a barrier to noise pollutions through its sound- absorbing properties (Wang et al., 2018; Bakar et al., 2013). Other important advantages are, green walls provide insulation to buildings from high temperature by the process evapo-transpiration, hence lower the temperature (Raji et al., 2015), control humidity, and provides shade which ultimately reduce the consumption of electricity. In addition, it can convert an empty space into aesthetically pleasurable, fancy and innovatively eye catching, which can uplift the economic value of that concrete structure and also add ecological values by providing habitats and food for insects and birds.

Urban Heat Island effect is one of the prominent concerns of urban zones. During day time, facades of building and hard surfaces absorb radiations from the sun which ultimately causes increase in temperature. As plant can reflect the radiations, hence thermal performance of the buildings can significantly be improved by controlling solar radiation; it reduces temperature, humidity and control microclimatic conditions (Safikhani et al., *2014*), therefore to compensate the urban heat island effect, enhancing greenery vertically can be a suitable substitute, (Mir, 2011). Moreover, as per studies, green walls depict high rate of evaporation rate as compared to green roofs (Malys et al., 2016).Vertical garden enhances the tic value by making walls, grills or trellis more appealing, conserve space and purify air with low maintenance. Additionally, the use of ornamental, flowering and herbal plants is beneficial for dwellings as well as commercial sector. Hence the vertical gardens are ecologically and financially efficient.

In tropical countries, the concept of vertical gardening is gaining huge popularity these days. One of the world's largest recorded vertical gardens is 'Santalaia Building' situated in Bogota, capital of Colombia. It is estimated that it supplies oxygen to 3100 people annually, filter about 2000 tons of harmful gaseous and trap 881 lb of dust (Wilder, 2017). Nowadays the systems of vertical gardening is not restricted to only buildings but have also started adopting on road highways, railway stations, airports, bus stations, hospitals, schools and on other public and private places.

One of the best examples of vertical garden of highway in India is the vertical garden of 'Hosur Road Electronic City Flyover of Bangalore', where about 3,500 plants of 10 different species have been planted with distinctive design from all the sides. It aids in reducing the urban heat island effect, by absorbing greenhouse gases and smog, purifies air, act as a sound-proofing barrier, and make the area healthy and pleasant. According to National Green Building Councils in the world, it is said that, the most effective approach to ensure widespread implementation of vertical garden can be achieved by giving Green Label to the buildings. According to an investigation done by Charoenkit, 2017in tropical climate, it was found that, the living wall in indoor space can lower down the air temperature by 3.6ºC and can enhance the thermal resistance up to 0.05-0.09 m^2 K/W. Plants with dense, medium-sized foliage are appropriate for reducing temperature and recommended for cooling purpose. Further, living walls can sequester carbon in a range of 62.6-118.4 g ·C/m^2/year. In another study done by Rameshkumar in 2018 it was recommended that *Polysciasfruticosa* and *Philodendron erubescens* are suitable ornamental plants for vertical garden system with red soil as growing media.

Additionally, researchers have found that herbaceous flowers can fix 12.16 gm^2 D1 carbon dioxide per unit leaf area in green space (Chu et al., 2022). Moreover, the observations of Coma et al, 2016 revealed that, the green walls represent high energy saving performance than green facades and during summers and winter, energy savings by green wall was up to 58.9% and 4.2% respectively whereas by green facade it was 33.8% and 1.9% respectively. Further, the reduction in wall surfaces temperature by 21.5 °C by green wall and 13.9 °C by green facade (Coma et al., 2016).

Characteristics of plants suitable for vertical garden are (Bharti et al, 2024)

- Plants that can be planted on both sides of the frame.
- Generally dense, compact and low growing plants are selected.
- Dwarf flowering and foliage plants.
- Shallow rooted plants that require very less anchorage
- Sun loving dwarf, trailing or flowering plants. E.g., Allysum, Pansy, Nasturtium
- Shade loving foliage or flowering plant.eg. begonia, African violets, Pepromia, *Zebrina pendula*etc.
- A single vertical garden should not have a mixed planting i.e., combination of both shade loving and sun loving plants.

Plants suitable for vertical garden:

Plants for exterior living walls/ sunny areas

- **Low shrubs:** *Buxus sempervirens, Euonymus japonicus*, etc.
- **Climbers:** *Ficus pumila, Tarlmounia elliptica*, etc.
- **Ground covers**: *Wedelia trilobata*, *Dichondra repens*, etc.
- **Perennial flowers**: *Thunbergia grandiflora*, *Campsis radicans*, etc.
- **Annuals flowers**: *Petunia hybrida*, *Zinnia elegans, etc.*
- **Edible plants***:* *Lactuca sativa*, *Rosmarinus officinalis*, etc.

Plants for interior living wall/shady areas

- ***Philodendron scandens:*** adaptable to low light, low maintenance, air-purifying.
- ***Epipremnum aureum***: hardy, fast-growing, low maintenance, air-purifying.
- ***Peperomia obtusifolia:*** attractive leaves, low maintenance.
- ***Syngonium podophyllum*:** low maintenance, air-purifying.
- ***Sensevieria trifasciata***: low maintenance, hardy, air- purifying
- ***Chlorophytum comosum:*** adaptable to low light, low maintenance, air-purifying

For Living Walls for Green Facades (Green Screens)

Any variety of climbing plants (vines) can be used for making green facades which may include:

- Plants with tendrils e.g., grapes (*Vitis* Spp), Passion flower (*Passiflora*), *Pyrostegiavenusta*.
- Plants with twining stems or leaves -e.g., *Clematisgouriana*, *Adenocalymaalliaceum*, *Jasminum auriculatum*, *J. grandiflorum*
- Hold fasts, plants with aerial roots or stem roots -e.g., *Hedera helix*, *H. hibernica*, *Tecoma radicans*, *Monstera* spp., *Phelodendron*spp.
- Scramblers which have no direct means of attachment e.g., *Bougainvillea* spp., roses (*Rosa* spp.) *Petrea volubilis*, *Vernonia elaegnifolia*,*Quisqualis indica*, *Thunbergia*, *Stigmaphyllonperipocifolium*, *Tristellateia australis* etc.

Rooftop Gardening

Roof gardens are human made green spaces at the uppermost levels of any residential, industrial, public, private or commercial structures. It can be meant for different purposes such as, to produce organic vegetables, create greenery with ornamental plants, provide space for recreational or leisure activities, shade and shelter for humans as well as habits for several birds. It has been suggested that green roofs can be efficiently utilized to enhance sustainability in urban or industrial areas (Kosareo and Ries, 2007), Moreover, green roofs also help in carbon dioxide sequestration through photosynthesis during day time and store the carbon in the form of stems, branches or roots (Rowe and Getter, 2010; Weissert et al., 2014). Further, it can conserve energy through reduced heat transfer and can keep the lower portion cool by evapo-transpiration, reduces noise pollution, turn down heat island effect, and decreased the runoff load on the sewage system. (Gagliano et al., 2016) and ultimately decreases building energy consumption (Sadineni et al., 2011). As roof gardening can sequester carbon and decrease the temperature of roofs and the surrounding hence it adds positive impact on cooling of local climate, and also plants absorb the rain water and reduces overflowing impact on infrastructure. As per the reports, *Sedum acre*, *Frankenia thymifolia*, and *Vinca major* depicts potential capacity to counter carbon emission and can cut down the demand for annual energy consumption of building by 8.5%, 8.0%, and 7.1%, respectively.Moreover, the annual CO2consumption for photosynthesis by these three plants was estimated to be 0.14, 2.07, and 0.61 kg/m^2 respectively (Seyedabadi et al., 2021).

A survey conducted by Thomas and Cherian in 2021, in urban area of city Cochin, India with sample of 102 respondents depicted that, on rooftop, 59% participants were interested in vegetable gardening and 13% were interested in ornamental gardening, whereas 28% were interested in both. On the other hand, the reasons for practicing roof gardening, it was noticed that, 66% responded practiced it to get better family health and 29% respondent started to pursue their hobby, whereas 16% and 14% of them wanted to get rid of pesticides and to become self-sufficient respectively. Discarding practices of garden waste, results out that 75% of the respondents were managing their waste from rooftop through composting, 21% of them burn the waste and 15% were disposing the waste to municipal waste bin.

The phenomenon of roof top gardening has evolved due to disproportion at exploitation of the urban lands. Hence roof gardening is a potential source for urban horticulture. It can efficiently reduce the toxicity around dwellings, improves aesthetic sense, reduces stress and protect environmental pollution.

Table 4. Plants Suitable for Roof Gardening

Flowering plants	Summerannuals -Zinnia, Kochia, Portulaca, Tithonia, Gaillardia, Gomphrena, Sunflower, Daisy, etc.
	Winter annuals - Antirrhinum, China aster, Cornflowers, Larkspur, Sweet Sultan, Phlox, Verbena, Candy tuft, Petunia, etc.
	Rainy season - Balsam, Cock's comb, Celosia, Gaillardia, etc.
	Herbaceous-Periwinkle, Foxglove, Lavender, Aster, Peony etc
Succulents and herbaceous plants	Aloe, Snake plant, Sedums, Jade, *Euphorbiaspp*, Portuluca, Crassula, Kalanchoe, Zebra plant, Agave, Echeveria Echinopsis, Opuntia, Alpinia, Asparagus etc.
Bulbous plants	Amaryllis, Begonia, Canna, Crinum, Fressia, Glorosia, Hedychium, Tuberose, Gladiolus etc.
Groundcovers, vines and climbers	*Setcreasea purpurea*, Vadelia, Gourds, Ficus Pumila, Passion Flower, Bougainvillea, Money Plant, Nasturtium, Curtain Creeper, Blue Moring Glory, etc
Grasses	*Zoysia*and *Bermuda*etc.
Herbs and vegetables	Thyme, Rosemary, *Ocimum Tenuiflorum*, Basil, Coriander, Ginger, Turmeric, etc.
Dwarf trees and shrubs	*Plumeria alba*, Pomegranate, *Acalypha Sp. Codiaeum variegatum*, *Ligustrum ovalifolium*, Duranta, *Ficus benjamina*, Hibiscus etc.

Avenue Planting/ Planting of Tress

Trees (and shrubs) are unique among plants in the way that they have a woody stem and roots that grow annually and these woody parts last for decades or evencenturies. Tree stems and roots are excellent, long-term carbon storage sites because most of the carbon in this wood comes from carbon dioxide. Planting of 44 million more urban trees per year in the U.S. for the next 50 years, for a total of 2.2 billion trees, would replace trees lost to mortality and increase urban tree cover by 5% (Rowntree and Nowak 1991). While trees alone cannot solve the problem of climate change, they can significantly contribute to reducing fossil fuel consumption and carbon dioxide emissions. The influence of forests on the climate is primarily connected to the biochemical processes of trees, particularly photosynthesis, which regulate atmospheric CO_2 levels and play a crucial role in the carbon cycle (Bonan et al., 2008).Through photosynthesis, trees and other plant organisms in forests absorb CO_2 from the atmosphere, aiding in carbon sequestration.The benefits of trees in given in the Fig.2and Fig 3.

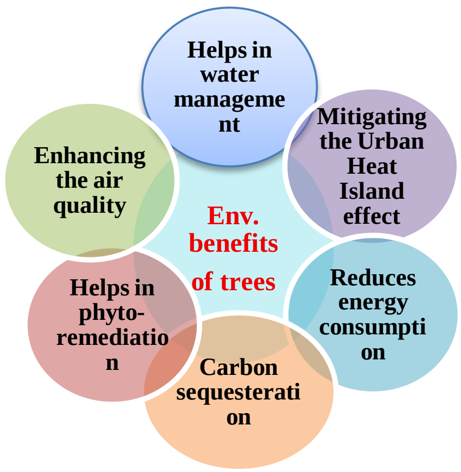


Fig. 2 Environmental benefits of trees (Mylan, 2022)

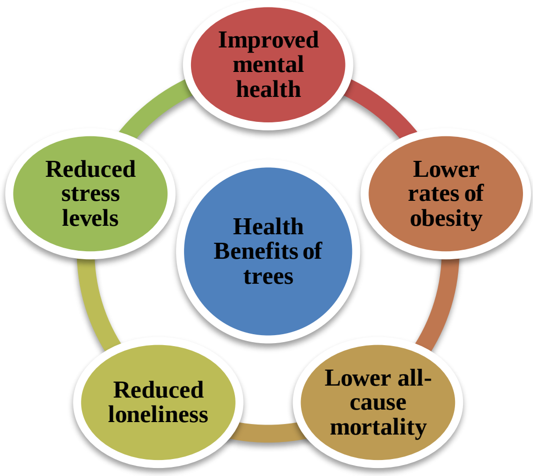


Fig. 3 Health benefits of trees (Feng, Xiaoqi et al., 2022)

Table 5. List of the Trees that Absorbs Pollutants

Tree species	**Pollutants absorbed**	**Other benefits**
English Oak	Nitrogen dioxide, Sulphur dioxide, Particulate matter	Provides habitat for wildlife
Eastern White Pine	Ozone, Nitrogen dioxide, Sulphur dioxide, Particulate matter	Reduces noise pollution
Red Maple	Ozone, Nitrogen dioxide, Particulate matter	Tolerates urban environments
Honey Locust	Particulate matter, Carbon monoxide	Provides shade and reduces energy consumption
Green Ash	Ozone, Particulate matter	Tolerates a wide range of soil types

In a study conducted by Begum and Harikrishna, 2010 at Industrial locations in Bangalore it was found that among various tree species, the most tolerant one with respect to ATPI and heavy metal concentration were *Ficus religiosa*, *Azadirachta indica* and *Pongamia pinnata* (L.). So, these plants can be considered as tolerant species in the industrial areas.

Pragasan and Ganesan, 2022 identified pollution-tolerant tree species for the development of greenbelts for NIA in Kollar district of Karnataka. Air pollutants such as PM10, PM2.5, SO_2, NO_2, Pb, CO, NH_3, and O_3 were detected and their concentrations for the three sites ranged from 21 to 99 μg/m^3, 11 to 67 μg/m^3, 3 to 14 μg/m^3, 5 to 28 μg/m^3, 0.01 to 0.9 μg/m^3, 0.3 to 0.9 mg/m^3, 3 to 17 μg/m^3, 6 to 25 μg/m^3, respectively. Twenty common tree species to NIA were selected and their air pollution tolerance potential was determined by the Air pollution Tolerance Index. It was found that tree species, *Spathodeacampanulata* (9.58 ± 0.33) recorded maximum APTI value followed by *Terminalia catappa, Tabebuia avellanedae, Anthocephalus cadamba,* and *Syzygiumjambos* and were found to be the top air pollution tolerant species.

Landscaping or gardening is not only restricted to sophisticated system but it can be adopted anywhere, i.e. railway stations or railway lines, bus stand and highways, roundabout, airports, banks of rivers or canals, cities and countryside areas, cemeteries and burning ghats, hospitals, schools, universities, offices, market or shopping malls, public or private buildings etc. At every location greenery can be added, each plant can absorb and store the amount of carbon dioxide and prevent soil erosion hence reduces the concentration of pollutants in surroundings.

In Thiruvananthapuram capital of Kerala, a study was conducted by Jyothi and Jaya, 2010 to evaluate the performance of plant species regarding air pollution tolerance index (APTI) along roadsides. Later, it was found that, calculated APTI is maximum for *Polyalthia longifolia*, (Sonner) approx 13.59 followed by Mangifera indica, *L.* (7.56) and *Alstoniascholaris*, (6.84). Whereas in case of shrubs, uppermost APTI value was recorded in the leaves of *Clerodendroninfortunatum L* about 6.23, followed by *Eupatorium odoratum*, L. (5.23) and *Hyptis suaveolens L* (4.39). It was also noticed that, *Polyalthia longifolia*, (Sonner) can tolerate automobile pollutants and different plant species depict significant variation in their susceptibility to air pollution. Hence, plantation can maintain the concentration of greenhouse gases (Jyothi and Jaya, 2010).

Lawn

Lawn is considered as a natural green carpet formed by monocot plants and referred as heart of the garden (Jenkins, 1994). It provides space for leisure activities, professional and personal gatherings, and playgrounds, where it controls dust particles and soil erosion due to crowd (Reynolds and Flint, 2009). Nowadays, in cities, lawns are considered to cover almost, 70- 75%green open spaces i.e. private and public parks, hotels and restaurants, public and private buildings, cemeteries, and playgrounds etc. (Stewart et al., 2009).Lawns or grasses generally store most of the carbon in their roots, as their roots die it gets decomposed in soil; eventually adding the carbon to the soil. Moreover, grasses are very essential for rainwater conservation and drainage. About 60% of rain water ends ups in surface run-off in vegetation-free locality, whereas only 5–15% of the rain water becomes surface run off where lawns are present (Ignatieva et al., 2015).

A model was developed by Zirkle et al., 2011, to find out the potential possibility of carbon sequestration by lawns in dwellings of U.S.A. and, it was estimated that the rate of soil organic carbon sequestration in soil having lawns was approximately 46.0 to 127.1 g /m^2 /year. The excess concentration of carbon dioxide is trapped by deep-rooted penetration more volume, fibrous grasses in deeper soil layer; however, in long run, it partly replenishes the soil organic carbon. Moreover, the undisturbed grasslands can uptake considerable amount of carbon dioxide for photosynthesis in soils (McLauchlan, 2006) and grass can sequester more carbon than leguminous cover crops (Kimble et al., 1998). Further according to study conducted by Townsend and co-workers in Southern California, it was found that high amount of indirect CO^2 emission associated with turf-grass management can sequester organic carbon to mitigate GHG emissions in cities. According to them ornamental lawn can sequester organic carbon ranges from −513 +37 to −513 −73 g CO^2 m−2 yr. Lawns can also help to reduce extremes of temperature in built-up areas by absorbing the heat during the day and releasing it slowly during the evening. According to The Lawn Institute in America, the "cooling properties of turf are so effective that temperatures over turfed surfaces on a sunny summer's day will be 10 – 14 degrees cooler than over concrete or asphalt".

According a study by the University of Maryland (called Maryland Turf grass Survey: An Economic Value Study), a 25-square foot area of healthy lawn produces enough oxygen each day to meet the needs of one adult. That means a 100 square ft lawn will provide sufficient oxygen to supply a family of four.

Terrace garden

Terrace garden is a type of a garden that is built on the terrace of a building. Using planting materials on rooftops offers several ecological and economic advantages. These include effective storm water management, enhanced energy efficiency, reduction of the urban heat island effect, extended lifespan of roofing membranes, decrease in urban air temperature, attracting birds and insects and the creation of a more visually appealing and comfortable living and working environment (Anoop and Saranya, 2021). According to Kalyan et al., 2020 the selection of plant species for terrace garden should be done based on type of terrace, climate, and weather conditions in that particular zone.

Table 6. List of few ornamental plants suitable for terrace garden

1. *Chamaerops humilis* – European Fan Palm Cascade Palm
2. *Chamaedorea elegans* – Parlor Palm Bamboo Palm
3. *Phoenix roebelenii* – Pygmy Date Palm
4. *Dypsislutescens* – Areca Palm
5. *Ravenearivularis* – Majesty Palm
6. *Rhapis excelsa* – Lady Palm
7. *Livistona chinensis* – Chinese Fan Palm
8. *Trachycarpusfortunei* – Windmill Palm
9. *Adonidiamerrillii* – Christmas Palm
10. *Caryota mitis* – Fishtail Palm

The study conducted by Triguero-Mas et al. (2020) highlights the potential benefits of urban rooftop gardening, particularly for individuals with intellectual disabilities and mental health conditions. Similarly, Tuladhar (2019) confirms the interest and enthusiasm among urban residents to grow and harvest fresh, pesticide-free produce on their own rooftops.

A study was on 102 respondents residing in Ernakulam city maintaining rooftop garden was done by Thomas and Cherian in 2021**.** The COVID-19 pandemic highlighted rooftop gardening as a powerful example of self-sufficiency. During this time, urban homemakers were engaged in cultivating a variety of ornamental and vegetable plants using diverse methods.

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Table 6. List of Few Ornamental Plants Suitable for Terrace Garden

			
Annual Flowers: **Summer season:** Zinnia, Portulaca, Cosmos, Balsam, Marigold, Celosia Gomphrena, Gaillardia, etc. **Winter season:** Petunia, Pansy, Phlox, Dianthus, Calendula, Aster, Verbena, Stock, Sweet Pea, etc.	**Shrubs:** **Flowering Shrubs:** Rose, Jasmine, Ixora, Camellia, Barleria, Bougainvillea, Hibiscus, etc. **Non flowering shrubs**: Croton, Thuja, Duranta, Weeping Fig, Jatropha, Aralia, Acalypha, Orange jasmine, etc.	**Climbers:** **Flowering climbers:** Morning Glory, Allamanda, Rangoon Creeper, Garlic vine, Pyrostegia, etc. **Foliage Climbers:** Money Plant, English Ivy, Philodendron, Syngonium Creeping Fig, etc.	**Foliage plants:** Calathea, Dieffenbachia, Aglaonema, Dracaena, Snake Plant, Canna, Calathea, Kochia, Caladium, Coleus, Coral Bells, Hosta, Alocasia, Begonia, Poinsettia, agave, Peperomia, Tradescantia, Pilea, etc.

			
Trees: Plumeria, *Bauhinia*, Juniperus, Yellow olender, Rubber plant, Fiddle leaf fig, *Callistemon*, Japanese Maple, etc. Fruit trees: Citrus, Guava, Papaya, Pomegranate, etc.	**Bulbous plants:** Crinum, Tuberose, Zephyranthes, Oxalis, Gloriosa, Freesia, Alstroemeria, Gladiolus, Amaryllis, Agapanthus, Anemone, Narcissus, Canna, Dahlia, etc.	**Succulents:** Aloe Vera, Echeveria, Sedum, Kalanchoe., Jade Plant, Senecio, Euphorbia, Opuntia, Haworthia, Aeonium, Pachyphytum, Stapelia, Crassula, Mammillaria, etc.	**Palms and Cycades:** Areca Palm, Sago Palm, Chinese Fan Palm, Lady Palm, Parlor Palm, Bamboo Palm, Cascade Palm, Kentia Palm, Metallic Palm, Lipstick Palm, Majesty Palm, etc.

Future thrust

Plants absorb pollutants this is a known fact but every plant and its part absorb different pollutants from different places such as few absorbs from soil few from air and water. Also, the concentration of sequestration is different for all the plants. Therefore, it needs research to find out which plant and which part can be used to sequester pollutant from particular conditions so That accordingly plants would be selected for gardening. Moreover, as Corporate Social Responsibility (CSR) have to invest 2% from their annual net profits if they have market capitalization over five billion Indian Rupees (INR), they can spend it on landscaping of public places i.e. highways, railways, hospitals, rivers, lakes etc. this will surely put huge impact on our surroundings.

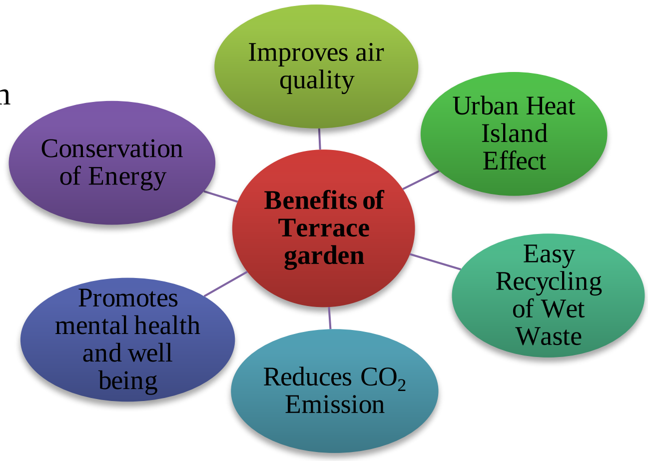

Fig. 3 Benefits of Terrace Garden

Conclusion

From the above literature, it can be concluded that gardening can be proven as one of the best alternative strategies to reduce the concentration of pollutants from our surroundings by using suitable plants. Not only it can sequester pollutants but also beautify the surroundings and bring mental peace. Moreover, it can generate income in floriculture sector and nursery management. For the proper and balanced landscape, it needs skilled landscape designers, therefore, it can provide job. It has dual benefits i.e. protection and generation of money. However, it needs a skilled landscape designer. Also, if the money of CSR would be used for landscaping it will help in improving the condition of rivers, lakes, ponds, railways, bus stands etc. and even can make them better places where tourist can be get attracted.

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General Article

AJWAIN (*TRACHYSPERMUM AMMI*): BRIDGING TRADITIONAL KNOWLEDGE AND MODERN PHARMACOLOGY

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ABSTRACT

Trachyspermumammi (L.) Sprague ex Turrill (Apiaceae) with common name Ajwain is an important medicinal plant, extensively used in Indian Ayurvedaas well as Chinese and Persian medicines. The ethnobotanical significance of the plant is evident from the numerous traditional uses attributed to this plant. It has been widely used in traditional ayurvedic medicine to treat abdominal pains, coughs, headaches, heartburn, asthma, diarrhea, cholera, atonic dyspepsia, bronchial problems, spleen disorders, worm infestation, flatulence, lack of appetite, piles and used to facilitate as a galactagogue and post-partum recovery in women. The present review provides deeper insights into the ethnobotany, geographical distribution, phytochemistry, pharmacological activity and, toxicity of *Trachyspermumammi (TA)*. Phytochemical analyses have identified bioactive compounds within the root bark, stem branches, leaves, and fruits of TA. The comprehensive review of the TAhas provided insights into its ethnopharmacological and therapeutic applications. The main bioactive principles identified are terpenoids, flavonoids, sugars, glycosides, phenylpropanoids, alkaloids, phenols and phenolic glycosides. The plant possesses varied pharmacological effects particularly, antioxidant, anti-inflammatory, anti-proliferative and anti-microbial, antihypertensive, bronchodilator, and anti-hyperlipidemic agent due to its potent bioactive compounds like thymol, p-cymene, phyllandrene. Traditionally, the plant is used to treat and relieve ailments like abdominal pains, abdominal tumors, amenorrhea, asthma, atonic dyspepsia, bronchial problems, flatulence, piles, etc.Extensive literature survey reveals that multiple demographics have leveraged *Trachyspermumammi* globally and the plant possess varied pharmacological activities. Very few studies have been reported on the scientific evidence of the traditional uses of the plant. Delving deeper into its pharmacological effects andfilling existing research gaps regarding its traditional uses are important. Moreover, broader research on safety is needed to support clinical application.

Keywords: *Trachyspermumammi*, phytochemical constituents, Therapeutic potential, Toxicity, pharmacological activities.

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Introduction

Trachyspermumammi (L). family (Apiaceae) is an important medicinal herb, extensively used in Indian Ayurvedic, Chinese, and Persian medicine emphasizing the importance of the plant's versatility in traditional healing practices across different cultural contexts (Vitali et al., 2016). The Ayurvedic text Charak Samhita mentions the Ajwain extract as Admoda Arka, underscoring its efficacy in alleviating colic and pain, enhancing digestive fire, and relieving anorexia (Saraswat et al., 2020). The plant, originally indigenous to Egypt, is extensively grown in Asian countries like India, China, Pakistan, Afghanistan, and Iran, as well as in European countries such as Sweden, and Northern Africa (Modareskia et al., 2022). The plant is known by various vernacular names.In Sanskrit, it is referred to as "Yamani," while in English, it is called Ajwain, Ajowan, and Lovage. In different languages, it goes by names such as Ajmud, Ajmoda, Ajamodhavoma, Bishop's weed, Carom, Ethiopian cumin, Xi Ye Cao Guo Qin, Adiowa, and Agyptischer (Lim, 2012). The Plant List, an online resource developed by the Global Strategy for Plant Conservation and the World Flora Online, documents approximately 29 Latin synonyms for *T. ammi*. Some of these synonyms include *Carom copticum* (L.) Benth & Hook.f. ex Hieren, *Apium ammi* Urb., *Ammi copticum* L., and *Trachyspermumcopticum* Traditionally, the plant has been utilized as a multifunctional ethnomedicine, offering various remedies for a wide range of ailments. These include abdominal pains, coughs, headaches, heartburn, asthma, diarrhea, cholera, atonic dyspepsia, bronchial problems, spleen disorders, worm infestation, flatulence, galactagogue, lack of appetite, piles, etc. The initial utilization of the plant worldwide stemmed from its recognized abilities as purgative and in facilitating the evacuation of kidney stones (Goyal et al., 2022). The seeds of the plant are shown to have carbohydrates, fiber, glycosides, tannins, saponins (Asif et al., 2014). The oil extracted from *T. ammi* leaves and flowers are characterized by significant constituents such as iso-thymol (51.1%), p-cymene (14.1%), thymol (13.0%), limonene (11.8%), and γ-terpinene (6.8%) (Kambouche& El-Abed, 2003a) The aromatic spice is utilized as an important culinary spice because of its high nutritional and medicinal value. Pharmacological studies have reported antioxidant, antibacterial, anti-fungal, anti-cancer, immunomodulatory, antispasmodic, anti-flatulent, anti-diabetic, anti-filarial, antirheumatic, hepatoprotective, and neuroprotective properties (Timalsina et al., 2023). Thymol has been identified as the key monoterpene responsible for the activities (Anusha et al., 2024). Recent research confirmed the utilization of *T. ammi* plant parts in the synthesis of gold and silver nanoparticles for enhanced biological activity. While *T. ammi*is employed in traditional medicine for numerous ailments, its effectiveness must be rigorously assessed. The paper explores the ethnobotanical uses, nutritional properties, isolation and characterization of active phytoconstituents, and pharmacological attributes. There is a pressing need to collect comprehensive information and compile the review which can lead to drug discovery and therapeutics for various diseases.

Botanical Profile of *Trachyspermumammi L.*

T. ammi, an annual herb and mesophyte, grows to a height ranging from 25 to 65 cm. The stems are grooved, glabrous, slender, and striate; the leaves are rather distant, feather-like, and pinnately divided. It features tiny white or pinkish petal flowers in umbels that are borne in terminal or seemingly lateral stalks that develop into small, oval-shaped fruits housing ridged seeds. (The World Flora Online database). The fruits are ovoid, aromatic, greyish brown, 2mm long, and 1.7mm(Bairwa et al., 2012). The fruit's mericarps are compressed, marked by pronounced ridges and a tubercular texture, and they have a distinctly sharp and bitter taste.(Bekhechi et al., 2010). Endospermis made of polygonal cells with oil globules (Bhutya RK, 2011). The striking similarity in aroma between the seeds of *T. ammi* and the leaves of *Plectranthusambonicus* commonly known as Indian Borage, the plant is mistaken in scientific literature as the Coleus ambonicus belonging to the family Lamiaceae. Figure 1 depicts the *Trachyspemumammi* leaves, inflorescence, and seeds.

Origin

Ajwain distributed across the arid and semiarid regions including the Mediterranean Sea and in Southwest Asian countries such as India, China Iran, Afghanistan, Pakistan, and Iraq, Sweden and Northern Africa (Naquvi et al., 2022). Though the plant is indigenous to Egypt, it was spread to other parts of the world during the Greek conquest of central Asia. In India, the plant is widely grown in Madhya Pradesh, Andhra Pradesh, Gujarat, Rajasthan, Uttar Pradesh (Asangi et al., 2023).

Habitat

The growth of the ajwain plant is favored by moist soil conditions and it displays versatility in adapting to different soil types such as loamy, black, and sandy soils, even those with high salt content. Depending on the geographic region, it can be cultivated as a summer crop or a cold-season crop in hilly areas. In India, the cultivation of ajwain is influenced by both natural rainfall and irrigation methods, ensuring its successful growth (Rajeshwari et al., 2011). Native to the Indian subcontinent and the Near East, ajwain is a herbaceous plant with the scientific name *Trachyspermumammi*.

Propagation

Trachyspermumammi is cross pollinated crop, exhibiting a somatic chromosome number of 2n = 18. The plant relies on insects for cross-pollination, as the absence of this process can result in self-fertilization. Optimal sowing time is crucial for maximizing *T. ammi*'s genetic potential, impacting seed and oil productivity (Meena et al., 2018). The experiment using licorice aqueous extract at a concentration of 40 g/L and Moringa ethanol extract with a concentration of 100 g/l (L3 x M2) showed the most favorable essential oil content, L/g and L/area of the oil, and thus the favorable influence of these concentrations on the production of essential oils(El-Ghait et al., 2021). Indian studies affirm that seeding on October 30 th produces much better outcomes than colonizing on October 15 th and November 14 th due to the supporting climatic conditions. The sowing on the 1st of September in the Southern Telangana region of Andhra Pradesh one of the states of India has the highest yield, making it very important to sown at the right time. The best sowing time of Ajwain in different areas depends on various reasons such as weather, suitability of the soil and requirements of the variety. Ajwain is also spreading in Algeria and established itself in the Algerian agricultural setting. Algeria has a benefiting atmosphere to the growth of this aromatic plant since it is a great contribution to local agricultural practices. Hot and dry summer and warm and moist winter climatic conditions characterize the climate, similar to that of its original natural habitat. Realizing the gastronomic and medicinal importance of ajwain, Algerian farmers have devoted themselves to its growing.

Table 1. Ethnobotanical uses of *Trachyspermumammi L.*

Medicinal uses	Part(s) used	Traditional preparation	Region of use	Reference
Digestive aid, relieving stomach discomfort	Seeds	Ground seeds, infused in tea	India, Pakistan	(Siddiquie et al., 2024)
Antispasmodic, stimulant, carminative	Seeds	Fruits mixed with milk or water	Mauritius	(Mahomoodally et al., 2019)
Respiratory ailments	Leaves	Fresh or dried leaves, brewed into tea	Middle East, Egypt	(Chahal et al., 2017)
Relief from indigestion, gas, and bloating	Essential oil	Inhalation, massage oil	Ayurveda (Indian subcontinent), Middle Eastern cuisine	(Moein et al., 2015)
Diuretic	Root	-	India, Pakistan	(Asif & Hashmi, 2021)
Anti-helminthic	Leaves	Infusion	Middle East, Egypt	(Bagherivand et al., 2024)
Epilepsy	Leaves, Roots	-	Middle Eastern cuisine	(Monfared et al., 2020)
To regain strength after delivery	Fruits	Ajwain is mixedwith jaggery and ghee	India	(Johari, 1994)
Piles	Fruits	Seed balls made along with jaggery	India	(Vharamble et al., 2023)
Dipsomania	Leaves	Aqueous leaf extract	India, Egypt	(Mahale et al., 2022)
Tonsillitis	Leaves, Roots	Aqueous Extract of roots and leaves	India	(S. A. Jan et al., 2015)

Ethnobotanical uses

In traditional medicine, every part of the plant is employed to address various health conditions. Using ethnobotanical survey, *T. ammi* L. was found to be a significant culinary herb with exceptional application in the management of primarily colic, and gastrointestinal disorders. It has been reported to act as a galactagogue, uterine tonic, diuretic, and antiemetic, and possesses wound-healing properties (Goyal et al., 2022). Most of the tribes in India have been using this plant for treating various gynecological problems(H. A. Jan et al., 2020)and used to treat boils and epilepsy and acts as a powerful vermifuge (Kaushik et al., 2023). Other nations' ethnomedicine also recognizes the significant contributions *T. ammi*, or ajwain, has made to conventional medical procedures. Ajwain is extensively used in Indian and Pakistani ethnomedicine to treat digestive problems such as gas, bloating, and acidity. Furthermore, due to Ajwain's expectorant qualities, traditional healers in Pakistan frequently suggest it as a treatment for respiratory conditions like bronchitis and coughs (Siddiquie et al., 2024) and is also used in Bangladesh to treat a variety of illnesses, such as irregular menstruation, discomfort following menstrual irregularities, postpartum discomfort, and lactation aid for breastfeeding moms(Das, 2023). Ajwain's alleged antibacterial and antifungal properties are beneficial for treating wounds and various skin ailments. In traditional ethno-veterinary practices, the seeds are employed to relieve diarrhea, indigestion, and constipation. They are given orally to enhance strength and improve milk yield (Sharma et al., 2024).

Nutritional Uses

The nutritional analysis of seed indicated to have energy value of 314.55%, carbohydrates (47.57%), protein content (20.23%), fat content (4.83%), moisture content (11.6%), fiber (4.3%), ash (11.5%) (Javed et al., 2012)].*T. ammi* leaves exhibiting high anti-oxidant activities are consumed by the local people(H. A. Jan et al., 2020). The leaves of the plant are identified as the rich source of phenolic compounds, flavonoids and carotenoids and terpenoids (Saraswat et al., 2020). Seeds of the plant contain Vitamin B and Vitamin C and also include various minerals like cobalt, manganese, and iron.

Phytochemistry

Ajwain seeds comprises carbohydrates (38.6%), fat (18.1%), protein (15.4%), fiber (11.9%), and various phytochemicals such as tannins, glycosides, moisture (8.9%), saponins, flavones, and mineral matter (7.1%). Further, contain important minerals like calcium, phosphorus, iron, cobalt, copper, iodine, manganese, thiamine, riboflavin, and nicotinic acid (Zarshenas et al., 2014). Gas chromatography and mass spectrometry (GC-MS) analysis of hydro distilled volatile oil showed the presence of 17 constituents in the oil of which thymol (39.36%) and γ-terpinene (30.97%) were the major constituents. The total percentage of identified compounds was 99.20%. The GC analysis of distilled volatile oil indicated p-cymene 18.49% - 22.82%, γ-terpinene 22.44%-33.50%, and thymol 37.42%-48.42% as major constituents (Shahrajabian & Sun, 2024). In the study conducted on Ajwain seeds of 23 ecotypes from the gene bank of RIFR, Iran, P-cymene, γ-terpinene, and thymol were found to be in higher concentration (Mirniyam et al., 2022). Flavonoids, terpenoids, and polyphenols are found in various plant extracts and the results revealed how these phytochemicals' abundance changes with the seasons (Saxena, 2015). Interestingly, it has been discovered that one specific phytochemical was seen in large quantities during specific seasons, suggesting seasonal changes in the chemical composition of the plant. In addition, it is found some important compounds that ajwain contained in both its vegetative and flowering stages, suggesting insights into many stages of the plant's growth and development and how they affect the chemical composition of the plant. This study sheds important light on the bioactive elements of ajwain, which may have consequences for both its culinary and medical applications. Hydro-distillation process from the aerial parts of the plant (leaves and Inflorescence) shown to contain isothymol (51.1%), p-cymene (14.1%), thymol (13.0%), limonene (11.8%) and γ-terpinene (6.8%) as major constituents (Kambouche & El-Abed, 2003). Another study by Singh et al., 2004, related to Ajwain essential oil has been found to contain 26 identified components, which collectively account for 96.3% of the total composition. The major component is thymol (39.1%), followed by p-cymene (30.8%) and γ-terpinene (23.2%), along with α-pinene (1.7%) and terpinene-4-ol (0.8%). The highest phenolic content in *T. ammi* was noted with microwave-assisted extraction (MAE), while the highest total phenolic content (TPC) of 1860 ± 31.2 mg GAE 100g DW−1 was achieved using 100% methanol with ultrasonic-assisted extraction (UAE) for 20 minutes. R3Og was subsequently encapsulated within whey protein isolate (WPI) using heat gelation and characterized by FT-IR and SEM. A kinetics study indicated a pH-independent release behavior of R3Og from the WPI matrix, suggesting that the release was controlled by the Pharmacological activities of *T. ammi*

Microbial Inhibitory Effects

The growing worldwide threat of multiple drug resistance (MDR) in bacteria and other pathogens and the occurrence of novel infectious diseases present the greatest challenges in the context of treatment that increases the mortality rates. In such desperate condition, the application of bioactive compounds isolated in medicinal plants has been considered to be a niche in counter-measuring the MDR without causal side effect (Moiketsi et al., 2023) It is in this context that medicinal plants have been effective as anti-microbial agents due to their diverse activity against the broad range of bacteria, fungi and viruses. *T. ammi* seed extract and oil were also discovered to have a potent antimicrobial activity against diverse bacteria, including*; B. subtilis*, *S. aureus*, Bacillus phage CP5, *P. aeruginosa*, *S. dysenteriae*, *E. coli* and S. *aureus(Shin et al., 2018)*. Thymol and Carvacrol are reported as the key active principles with this property (Ardestani et al., 2020). Thymol demonstrates capacity to fight multi-drug-resistant microbial pathogens and demonstrates the prospect of food safeguarding the food stuff against the food spoilage (Hajibonabi et al., 2023). The plant extracts were also more effective against antibiotic-resistant pathogenic bacteria such as two gram-positive bacteria; Bacillus cereus (ATCC 1298), Staphylococcus aureus (ATCC 1189), and four gram-negative bacteria; Pseudomonas aeruginosa (ATCC 27853), Escherichia coli (ATCC 35218), Acinetobacter baumannii (ATCC 1611). Only Thymol and Carvacrol showed good inhibitory effect against the multi-drug-resistant Acinetobacter baumannii isolate with a minimum inhibitive concentration less than 500ug/mL. The hexane fraction in the ethanolic extract and thymol which had a high in vitro and in vivo anti- candidal activity. The lowest concentration of hexanes fraction with an inhibitory effect was identified as 225 mg/mL, which exhibited the same strength as that of the standard drug amphotericin B (200 mg/mL)(Wahab et al., 2021). Thymol, g-terpinene and p-cymene found to be the chemical composition of the *Trachyspermumammi*seed oil. Ajowan volatile oil was sensitive to Streptococcus pneumoniae bacteria with a minimum inhibitory concentration (MIC) of 0.125 to 0.5mg/mL. Synergy was also noticed between thymol and ciprofloxacin, although this was only apparent against P. aeruginosa and the penicillin-resistant Streptococcus pneumoniae clinical isolate.

Digestive Stimulant

The traditional utilization of *T. ammi* in Mexican medicine, Chinese medicine, and Ayurvedic medicine for over a century has predominantly focused on reliving the bloating, indigestion flatulence and abdominal pain. The versatile property and distinctive flavor of

Ajwain contribute to its importance as both a culinary and medicinal ingredient in various cultures(Khan et al., 2010). According to Ayurvedic principles, *T. ammi* has a pungent taste and heating energy, making it valuable for balancing Kapha and Vata doshas(Das, 2023). It is as an effective remedy for Kapha-related digestive concerns, including slow digestion, stomach heaviness, and excessive mucus production. Ayurvedic practitioners commonly prescribe a combination of *T. ammi* with ginger and cumin to synergistically enhance its digestive benefits, and digestive stimulant action, a study on the influence of spices on digestive enzymes like lipase, amylase, and chymotrypsin of rat pancreas and small intestine was conducted. The enzymes enhanced the activity when the ajwain was at the site of action[(Goyal et al., 2022).

Gastroprotective Effects

Gastric hyperacidity and ulceration are characterized by a repetitive cycle of healing and re-exacerbation (Asaad et al., 2024).Traditionally, Ajwain seeds boiled in water have been used to treat indigestion, bloating, and dyspepsia. The mucus neck cells are responsible for the secretion of mucus in the stomach and acts like a first line of defense, protecting the gastric mucosa from physical damage and hydrogen ion back diffusion. Mucopolysaccharides present in the mucus secretion have been enhanced when the TA is given to the animals and may contribute to the ulcer-protective effects of *T. ammi* fruit(Kumar & Singh, 2021)].

Antioxidant effects

T. *ammi* seed extract possessed a high DPPH radical scavenging activity and a moderate H_2O_2 radical scavenging activity (Goswami & Chatterjee, 2014). The presence of various phytochemicals in TA like alkaloids, phenols, phytosterols, and saponins is shown to exhibit free radical scavenging potential and oxidative DNA damage preventive activity (Saxena, 2015). The seed extract of *Trachyspermumammi* is highly regarded for its exceptional antioxidant prowess. Research findings indicate its proficiency in neutralizing hydrogen peroxide (H_2O_2) radicals with moderate efficacy and 2,2-diphenyl-1-picrylhydrazyl (DPPH) radicals with a notably high capacity. This underscores its ability to effectively counteract harmful free radicals within the body, which are notorious for inducing oxidative stress and causing cellular damage. The antioxidant potency of TA is attributed to the presence of various phytochemicals, namely saponins, phenols, alkaloids, and phytosterols. These natural compounds collectively play a pivotal role in safeguarding cells against oxidative DNA damage, thereby upholding cellular integrity and mitigating the risk of debilitating conditions such as cancer and cardiovascular diseases. In light of its remarkable antioxidant properties, TA emerges as a valuable natural remedy for enhancing overall health and well-being. Its ability to combat free radicals effectively positions it as a promising intervention to support bodily health and mitigate the onset of oxidative stress-related ailments. Incorporating TA into one's wellness regimen may prove instrumental in fostering longevity and vitality(Ranjbaran et al., 2019). The effects of oral administration of TA extract in collagen-induced arthritis (CIA) rat models reduced oxidative stress markers and inflammation while enhancing enzymatic antioxidants (Umar et al., 2012). Thymol present in the hexane extracts demonstrated stronger antioxidants from leaves and fruits respectively (Suryawanshi et al., 2015).

Anti hyperlipidemic Properties

Ajwain water is traditionally used in reducing the high amounts of cholesterol(Grover, 2021). An *in vivo* study in the albino rabbit model and in hyperlipidemia rat modelsindicates that ajwain seed powder, methanolic and aqueous extracts of TA is highly effective in improving lipid profiles, leading to reductions in total cholesterol, LDL-cholesterol, triglycerides, and total lipids. Furthermore, the organic extract of the seeds was found to lower the atherogenic index while increasing HDL-cholesterol levels in albino rabbits (Javed et al., 2012) and induced when administered orally at 3g/kg and 5g/kg for 21 days (Saleem et al., 2017). Ajwain intake of hyperlipidemic patients reduced LDL cholesterol by 8.9% and increased HDL cholesterol by 13.1% and was found to be effective for primary hyperlipidemia. T.*ammi* is shown to possess the chemopreventive potential against carcinogenesis. The different concentrations of the seed extract have significantly reduced the DMBA induced skin, B (a) P induced for stomach papillogenesis compared to the control groups.(De La Chapa et al., 2018)

Anti-inflammatory Effect

Research has demonstrated that both the total alcohol and aqueous extracts of ajwain exhibit significant anti-inflammatory effects on carrageenan-induced edema in a rat model. Additionally, the aqueous extract of T. *ammi* seeds was shown to influence inflammatory gene expression in the cartilage tissue of rats with collagen-induced arthritis, resulting in a reduction of Cox-2 mRNA levels. No toxicity was observed in acute and sub-acute toxicity studies, which (El-Ahmady et al., 2021) included assessments of relative weight and histopathological analysis. The fruit extract of T. ammi displayed notable anti-inflammatory potential, with an LD50 exceeding 3000 mg/kg (Saraswat et al., 2020).

Abortifacient and Galactagogue Effect

A survey conducted in Uttar Pradesh, India, indicated that *T. ammi* is among the indigenous medicinal plants traditionally used for abortion, and studies on teratogenicity in rat fetuses suggest it carries a significant risk of fetotoxicity (Balkrishna et al., 2024). Traditionally, ajwain has also been employed as a galactagogue for both dairy cattle and humans. The total phytoestrogen content in dry *T. ammi* seeds was measured at 473 ppm, ranking as the second highest among eight herbs evaluated (Kaur & Arora, 2010)

Hepatoprotective and Antiplatelet- Aggregatory Activities

T. ammi was shown to provide 80% protection in mice against a normally lethal dose of paracetamol (1 g/kg) and successfully normalized elevated serum liver enzyme levels induced by CCl_4-related liver damage in rats (Balkrishna et al., 2024). In antiplatelet aggregation studies conducted *in vitro* using blood from human volunteers, a dried ethereal extract of *T. ammi* seeds inhibited platelet aggregation triggered by arachidonic acid, collagen, and epinephrine. This research aims to support the traditional use of *T. ammi* for women following childbirth (Dubey & Kashyap, 2015).

Nematicidal Activity and Antihelmintic Activity

Ajwain oil constituents, such as camphene, pinene, myrcene, limonene, terpinene, terpinen-4-ol, thymol, and carvacrol, have been demonstrated to have nematicidal activity against pinewood nematode (PWN) *Bursaphelenchusxylophilus* which is known to cause Pine wilt disease. It has been postulated that amino and hydroxyl groups are target sites of methyl isothiocyanate in nematodes. Moreover, certain essential oils are also reported to alter the action of the neuromodulator octopamine or GABA-gated chloride channels in insect pests. Of these constituents, thymol and carvacrol are the most useful against PWN. These investigations show that the nematocidal properties of the ajwain oil are mainly triggered by the influence of thymol and carvacrol (Karvandi et al., 2023). The *T. ammi*antihelminthic has been proven to be active against certain helminths, including Ascaris lumbricoides in humans and *Haemonchuscontortus* in sheep. Such an anthelmintic action is thought to be the result of an inhibition of the energy metabolism of the parasites, an increase in ATPase activity, and a depletion of the energy stores of the parasites. Also, the plant has been reported to possess cholinergic effects, known to stimulate gut peristaltics and thus, help to expel intestinal parasites. This increased gut motility can also add to its total anthelmintic effects (Akhade& Jadhav, 2015).

Neuroprotective Effects

Medicinal plants have a long history of clinical use due to their increased tolerance and better therapeutic potential. Thymol, a major component of T. *ammi* seed extract, has neuroprotective effects. Oral administration of T.*ammi* seed extract (250 and 500 mg/kg), thymol (50 and 100 mg/kg), vehicle, and positive controls was given to pregnant mice. The supplementation markedly increased the expression of early neurogenesis markers and brain-derived neurotrophic factor (BDNF) in the postnatal day 1 in the pups' brains. Similarly, the P12 pups' brains had significantly higher levels of BDNF. Additionally, the P12 pups' brains had noticeably enhanced levels of BDNF. Further, in primary hippocampal cultures, TASE (75 and 100 µg/mL) and thymol (10 and 20 µM) increased the neuronal polarity, early neurite arborization, and maturation of hippocampal neurons in a dose-dependent manner. This reduction of TASE and thymol stimulation of neurite extension by the selective Tropomyosin receptor kinase B (TrkB) inhibitor ANA-12 (5 mM) suggested that the TrkBsignaling was involved (Timalsina et al., 2023). The bioactive principles within the TA offered neuroprotection to the cells by regulating pathways of oxidative stress, mitochondrial membrane potential, and it was also reported to be strong inhibitors of acetylcholine esterase enzymes by being competitive/mixed-type of inhibitors. The experiment had demonstrated to decrease the ROS and recovery of MMP (Mitochondrial Membrane Potential) in induced oxidatively stressed neuroblastoma cell lines.Furthermore, the extracts exhibited anti-acetylcholinesterase (AChE), anti-oligomerization, and anti-fibrilization activities. When comparing the two pure compounds, both demonstrated comparable effects in inhibiting Aβ-fibrilization, reducing reactive oxygen species (ROS), and providing neuroprotection. However, carvacrol was identified as a more potent inhibitor of AChE, being approximately ten times stronger than thymol. Carvacrol inhibited the enzyme through mixed-type inhibition, whereas thymol acted through competitive inhibition (Asangi et al., 2020).

Immunomodulatory Activity

T. *ammi* seed extracts possess immune stimulant and immune modulatory effects in altering skin thickness in rats. Additionally, studies have highlighted the presence of immunomodulatory components in T.*ammi*, such as ajowan glycoprotein (Agp), which induces proliferation of B-cell enriched murine splenocytes and activates macrophages to release nitric oxide and promote phagocytosis, showcasing its immunomodulatory properties(Razzak, 2020).

Toxicological effects

T.*ammi* is usually regarded as safe to consume in moderation. However, certain toxicological effects could result from overindulgence or allergic reactions. The side effects include gastrointestinal distress, which includes diarrhea, vomiting, and nausea - especially in people with sensitive stomachs. Ajwain can occasionally trigger allergic responses, including skin rashes or respiratory problems, particularly in people who already have allergies to related plants or spices. Furthermore, because ajwain seeds contain oxalate, taking significant amounts of them may result in severe issues like kidney damage. Overall, while ajwain offers various health benefits, it is essential to consume it in moderation and be mindful of any adverse reactions.

Conclusion

The purpose of the review was to bring into the limelight the research performed on the plant, and also to establish scientific loop holes. Interestingly, the research has been done on the nutritional and bioactive profiling of its different components very few times. Phytochemical screening of T. ammi has indicated that the plant contains a large number of monoterpenoid-based bioactive compounds such as thymol, g-terpinene, and p-cymene, and carvacrol which lead to the observed pharmacological properties. The *T. ammi* has been traditionally used in different systems of medicine (Ayurveda and Unani systems) and thus they have been well documented and have been among those used to treat digestive disorders, respiratory problems and even cancer related illnesses. Ethnopharmacological data about the plant has given a good platform to the study and the identification of its therapeutic properties. Studies, including in vivo and in vitro, have substantially shown the anti-inflammatory, analgesic, antitumor and antiviral effects. The pharmacological studies have demonstrated encouraging findings and the T. ammi could be used in the treatment of many conditions, such as stroke, rheumatoid arthritis, and cancer. Notwithstanding the achievements in the sphere of researching the therapeutic potential of the plant, there are certain aspects that should be explored further. Future studies ought to concentrate on the discovery of the active phytochemical constituents which impart the observed bioactivities. The interest in the new drug delivery systems of *T. ammi* (nanoparticles, microemulsions, liposomes) is increasing. These are superior formulations that intend to increase the bioavailability and therapeutic response of *T. ammi*. There is still need of further extensive research on the mechanisms of action of some of the bioactive components that are detected in the leaves, fruits, and flowers of the plant in the treatment of different disease conditions. The ability of the plant to reduce blood pressure in humans is one of the noteworthy ethnobotanical applications of the plant leaves. The effects of monoterpenoids were studied on different in vivo models as anticancer agents. Thymol and carvacrol were among the identified phytochemicals with anticancer properties; therefore, the potential therapeutic effects of the plant can be attributed to the synergetic action of these phytochemicals and others in the leaves. The studies have put emphasis on its high essential oil constituents, especially thymol, and many pharmacological effects including diuretic, antibacterial, antitussive, antiplatelet, antihypertensive, bronchodilator, and antihyperlipidemic. Also, Ajwain has been shown to have antiurolithic effect, diuretic effect, preventing aggregation of calcium oxalate crystals, anti-oxidant effect, preserving the renal epithelial cells and also anti-spasmodic. Moreover, research has also investigated cytotoxic action of non-specific lipid transfer protein (nsLTP1) isolated in Ajwain in a range of cancer cell lines, thereby demonstrating its ability to provide anticancer action by inducing apoptosis and its structural stability under high-temperature environments and human serum.

Future Perspectives

Further studies on *Trachyspermumammi* (ajwain) have tremendous potential of extending its medicinal use. *T. ammi* has potential to be a useful natural therapeutic in the clinical scenario due to its antimicrobial, anti-inflammatory as well as anti-cancer effects caused by bioactive compounds that include thymol and carvacrol. Research in the future should be directed to explain the molecular processes of these compounds and do extensive in vivo experiments to ascertain their safety and effectiveness. In addition to that, the synergistic action of *T. ammi* when used with other natural compounds should be studied, which may lead to new formulations. Sustainable production, which would enable the provision of accessible health solutions, which are plant-based, on the global scale, could also be achieved through advances in biotechnology.

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Short Communication

ASSESSMENT OF ALGAL DIVERSITY WITH SPECIFIC REFERENCE TO PHYSICO-CHEMICAL PARAMETERS IN THE PUN STREAM, KANGRA DISTRICT, HIMACHAL PRADESH

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Abstract

The present study evaluates algal diversity with specific reference to physico-chemical parameters of the Pun Stream in Kangra District, Himachal Pradesh, during post-monsoon and winter seasons. A total of 20 algal genera were recorded, representing Bacillariophyceae, Chlorophyceae, Cyanophyceae, and Euglenophyceae. Bacillariophyceae formed the dominant group in both seasons, with *Synedra spp.* and *Fragilaria spp.* showing consistently high abundance in post-monsoon, whereas *Cymbella spp.* appeared exclusively in winter. Physico-chemical analysis revealed a decline in temperature (24.6 °C to 19.8 °C) and a slight rise in pH (7.8 to 8.1) from post-monsoon to winter. TDS and EC increased moderately, indicating higher ion concentration due to reduced flow, while DO (6.9–7.2 mg/L) increased in winter, reflecting enhanced oxygen solubility at lower temperatures. Total hardness, calcium, and magnesium concentrations were relatively high and slightly higher in winter, indicating mineral enrichment. Higher algal diversity during post-monsoon was attributed to favourable temperature, moderate ionic concentration, and nutrient availability, whereas winter showed a shift towards tolerant genera adapted to cooler and more alkaline conditions. The study highlights the strong linkage between water quality parameters and algal community composition and provides baseline data for monitoring the ecological health of Himalayan streams.

Keywords: Algal Diversity, Parameters, Physico-chemical, Seasons.

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Introduction

Algae are among the most diverse groups of all living organisms. According to Rathod et. al.(2008), algae are generally aquatic and can be found in both fresh and salt water. They live in avariety of environments, such as rivers, lakes, ponds, and the ocean (Rathod et al., 2024). The Pun Stream, avital component of the aquatic land scape in the Kangra district of Himachal Pradesh, India, sustains diverse ecosystems and supports numerous forms of life. Among them triad organisms in habiting its waters, algae hold particular significance due to the irpivotal role in nutrient cycling, oxygen production, and overall ecosystem functioning (Arora et al., 2018). Understanding the intricate relationship between algal diversity and physicochemical parameter sis essential for comprehensively assessing the ecological health of the Pun stream and formulating effective management strategies (Diwate et al., 2025). Algae, encompassing abroad spectrum of photosynthetic organisms ranging from microscopic di-atomstomacroscopic sea weeds, exhibit remarkable adaptability to various environmental conditions (Papadopoulou et al., 2025). Their distribution, abundance, and community composition are influenced by a multitude of factors, including water temperature, pH, dissolved oxygen (DO) levels, nutrient availability, light intensity, and sedimentation rates (Vajravelu et al., 2018). Consequently, alterations in the sephysico-chemical parameters can significantly impact algal populations, leading to shifts in community structure and ecosystem dynamics (Kumar & Thomas, 2019). Anthropogenic pressures such as agricultural runoff, industrial discharge, urbanisation, and deforestation can introduce pollutants and disrupt natural hydrological processes in the Pun stream, as they do in many other freshwater bodies (Akhtar et al., 2021). These disturbances may alter physico-chemical conditions within the stream, potentially exerting profound effects on algal diversity and overall ecosystem health (Chakraborty & Chakraborty, 2021; Siddiqui et al., 2025). Research focusing on algal diversity in the Pun stream provides valuable insights into the ecological status of this aquatic habitat and aids in identifying potential stress or sand pollution sources (Machuca-Sepúlveda et al., 2023; Wu et al., 2017). By conducting comprehensive surveys and analyses, researchers can discern patterns of algal distribution, assess water quality parameters, and evaluate ecosystem responses to environmental perturbations (Devi et al., 2016; Stevenson & Rollins, 2017). By advancing our understanding of algal diversity dynamics and their interactions with physico-chemical parameters, this study seeks to contribute to evidence-based decision-making processes for the protection and restoration of fresh water ecosystems in the Kangra district and beyond (Vajravelu et al., 2018). A perusal of the literature has revealed that very little information is available on the algal flora of the Kangra district of Himachal Pradesh.

Materials and Methods

Study Area

It is located between longitude 77°34'16.2012" East and latitude32°5'3. 1416" North. The state is situated in India's Himalayan region. It contains 12 districts and a total size of 55,673 square Kilometres, or around 1.69% of all of India. Kangra district lies between 31˚ 21′ to 32˚ 59′ N latitude and 75˚ 47′ 55″ to 77˚ 45′ E longitude. The district spans a diverse range of altitudes, extending from the Shivalik hills through the Dhauladhar range to the Himalayas, running from northwest to southeast.

Pun Stream

Pun Stream is Binnu Khad's right bank tributary. It is located between latitude 32.044682° North and longitude76.62223° East.

Algal Sample Collection

In the Kangra district, algae samples were taken from the Pun stream. Forceps and needles were used to gather samples. To prevent contamination, allalgal samples were stored in poly carbonate bottles containing a 4% formalin solution (Kaushik, 1987). Thre was less chance of contamination because fresh samples were used. After being transferred to the lab, fresh algae samples were obtained and put in petri plates. Apply one or two drops of glycerol to a glass slide. Next, use a forceps and needle to transfer a little amount of sample on to the glycerol. Finally, cover the glycerol with a cover slip. Under a microscope, the samples were inspected and identified using accepted references.

Water Sample Analysis

Standard procedures were used to conduct physico-chemical examinations on water samples (Association, 1926)(Kaushik, 1987). Water samples from the Pun stream were collected for physico-chemical examination. Using a water testing meter, temperature, pH, TDS, and electrical conductivity were recorded immediately (Singhet al.2013).Titration was used to quantify the samples' total hardness, hardness resulting from Ca^{2+}, and hardness resulting from Mg^{2+}following (Association,1926). Titration of water sampling was done with the help of the Indian Standard method of water testing.

Results and Discussion

Algal Diversity in the Pun Stream

A total of 20 algal genera were identified, belonging to four major classes: Bacillariophyceae, Chlorophyceae, Cyanophyceae, and Euglenophyceae. Bacillariophyceae (diatoms) formed the dominant group in both seasons, with Synedra spp. and Fragilaria spp. showing consistently high (++ abundance) during post-monsoon, whereas Cymbella spp. appeared exclusively in winter. The reduction of Gomphonema spp. in winter suggests a preference for higher temperatures and nutrient availability, which are typically found during the post-monsoon period. Diatoms are well-known indicators of water quality, and their sustained presence reflects the good ecological status of the stream(Rana et al., 2022).

Chlorophyceae displayed a marked seasonal shift. *Chlamydomonas spp.*, *Oedogonium spp.*, and *Stigeoclonium spp.* were abundant in the post-monsoon but absent in winter, indicating their preference for warmer temperatures and higher light availability. In contrast, *Chlorella spp.*, *Scenedesmus spp.*, and *Oedogonium spp.* showed higher abundance in winter, suggesting that certain green algae can tolerate low temperatures and thrive under relatively stable physicochemical conditions(Kumar et al., 2022; Kumari & Sharma, 2018).

Cyanophyceae (blue-green algae) were represented by five genera. *Anabaena* and *Merismopedia spp.* were abundant during post-monsoon, coinciding with higher nutrient concentrations that may promote nitrogen-fixing cyanobacteria (Li et al., 2022). *Chroococcus spp.* and *Calothrix spp.* were more prominent in winter, which could be linked to their ability to survive in low-light and cooler conditions(Minor et al., 2019). *Microcystis spp.* maintained a high presence in both seasons, indicating its adaptability and potential to form blooms under suitable conditions(Narasimha & Benarjee, 2013).

Euglenophyceae were relatively less diverse but exhibited a significant seasonal shift. Euglena spp. and Phacus spp. showed higher abundance in winter, possibly benefiting from increased organic matter accumulation and slightly alkaline conditions observed in the physico-chemical analysis (pH 8.1).

Seasonal Patterns and Ecological Implications

Overall, algal diversity was higher in the post-monsoon season, as indicated by a greater number of genera showing "++" abundance. This trend can be attributed to favourable physico-chemical conditions such as warmer temperature (24.6 °C), lower ionic concentration, and moderate nutrient availability, which collectively support higher primary productivity. In contrast, winter was characterized by a shift towards tolerant genera such as Cymbella, Chlorella, Scenedesmus, Chroococcus, and euglenoids, reflecting adaptation to cooler temperatures (19.8 °C), higher hardness, and slightly alkaline pH.

The observed seasonal turnover highlights the role of temperature, nutrient availability, and light conditions in shaping algal community structure. The dominance of diatoms and the presence of multiple Chlorophyceae and Cyanophyceae genera suggest a well-oxygenated, nutrient-moderate stream ecosystem, indicating relatively healthy water quality.

Table 1. Summarizes the Occurrence and Relative Abundance of Algal Genera Recorded During the Post-Monsoon and Winter Seasons.

Sr.no.	Name of Algal Genera	Post-monsoon	Winter
Class: Bacillariophyceae			
1.	*Amphora spp.*	+	+
2.	*Cymbella spp.*	-	+
3.	*Fragilaria spp.*	++	+
4.	*Gomphonemaspp.*	++	-
5.	*Synedra spp.*	++	++
Class: Chlorophyceae			
6.	*Chlamydomonas spp.*	++	-
7.	*Chlorella spp.*	+	++
8.	*Hydrodictyon spp.*	++	-
9.	*Oedogonium spp.*	++	-
10.	*Scenedesmus spp.*	+	++
11.	*Stigeoclonium spp.*	++	-
12.	*Oedogonium spp.*	-	++
Class: Cyanophyceae			
14.	*Anabaena*	++	+
15.	*Calothrix*	-	+
16.	*Chroococcusspp.*	+	++
17.	*Merismopedia spp.*	++	-
18.	*Microcystisspp.*	++	++
Class: Euglenophyceae			
19.	*Euglena spp.*	+	++
20	*Phacus spp.*	+	++

Table 2 presents the seasonal variation in physico-chemical parameters of the Pun Stream during the post-monsoon and winter seasons. Temperature exhibited a marked seasonal decline from 24.6 °C in the post-monsoon to 19.8 °C in winter, reflecting the influence of low ambient air temperature and reduced solar radiation during the colder months. Similar seasonal patterns have been reported in other Himalayan streams, where temperature is a key determinant of biological activity and nutrient cycling(Ahmad & Hasnain, 2001; Kumar et al., 2022). pH values ranged from 7.8 (post-monsoon) to 8.1 (winter), indicating slightly alkaline conditions throughout the study period. A marginal rise in pH during winter may be attributed to lower rates of organic matter decomposition and reduced carbon dioxide levels due to decreased microbial respiration(Minor et al., 2019).

Table 2. Physico-chemical Parametersof Pun stream

Sr. no.	Parameters	Post-monsoon	Winter
1.	**Temperature**	24.6°C	19.8°C
2.	**pH**	7.8	8.1
3.	**TDS**	72	86
4.	**EC**	136	142
5.	**DO**	6.9	7.2
6.	**Total hardness**	162	172
7.	**Ca2+**	162	172
8.	**Mg2+**	78	82
9.	**Alkalinity**	66	68

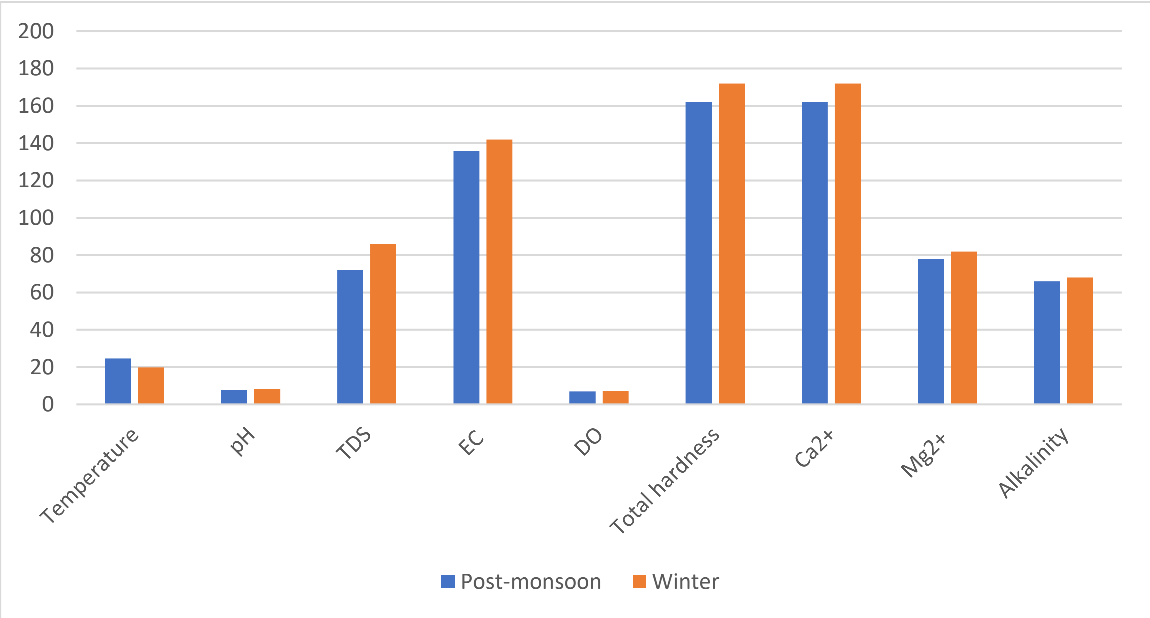

Fig 1. Physico-chemical Parameters of Pun Stream

TDS and EC values showed a moderate increase from 72 mg/L and 136 µS/cm in the post-monsoon to 86 mg/L and 142 µS/cm in winter, respectively. This rise could be linked to lower stream discharge during winter, resulting in higher ion concentration due to reduced dilution(Ahmad & Hasnain, 2001). Similar trends have been reported in streams of the Western Himalaya (Bhat et al., 2016). Dissolved oxygen (DO) levels ranged from 6.9 mg/L in the post-monsoon to 7.2 mg/L in winter. Total hardness, calcium, and magnesium concentrations were found to be relatively high, characteristic of the region's geology, dominated by limestone and other calcium-rich rocks (Parvateesam & Mishra, 1993). Total hardness increased slightly from 162 mg/L in the post-monsoon to 172 mg/L in winter, while calcium and magnesium concentrations increased from 78 mg/L and 84 mg/L to 82 mg/L and 92 mg/L, respectively. These results suggest increased mineral leaching and reduced water flow, leading to higher ion accumulation during the winter months (Patil et al., 2012; Sharma & Kumar, 2017).Alkalinity showed minimal seasonal variation (66–68 mg/L), reflecting the stable bicarbonate buffering capacity of the stream water. This stability is essential for maintaining pH within a narrow range, which is favourable for algal growth and other aquatic biota (Pokhrel et al., 2021).Overall, the physico-chemical profile of the Pun Stream indicates good water quality with slightly alkaline, moderately hard water and adequate oxygenation. The observed seasonal variations are consistent with typical lotic ecosystems, where temperature and discharge play major roles in modulating water chemistry and, consequently, algal diversity and productivity (Patil et al., 2012).

Conclusion

The present study highlights the seasonal variation in algal diversity and its close relationship with the physico-chemical characteristics of the Pun Stream in Kangra District, Himachal Pradesh. A total of 20 algal genera, representing four major classes, were recorded, with Bacillariophyceae emerging as the dominant group across both seasons. Post-monsoon season supported higher algal richness and abundance, which can be attributed to warmer temperatures, moderate nutrient levels, and favorable light conditions that enhance primary productivity. In contrast, winter was characterized by a shift towards tolerant genera such as Cymbella, Chlorella, Scenedesmus, Chroococcus, and euglenoids, reflecting their adaptability to lower temperatures, slightly alkaline pH, and increased ionic concentration. The physico-chemical analysis revealed that temperature, pH, hardness, and dissolved oxygen are key drivers influencing algal community structure. The overall water quality of the Pun Stream was found to be good, with slightly alkaline, moderately hard water and sufficient oxygenation, supporting a diverse algal community. These findings provide baseline data for understanding the ecological status of the Pun Stream and can be used for future biomonitoring programs and conservation planning in Himalayan freshwater ecosystems. Continuous monitoring is recommended to track changes caused by anthropogenic pressure or climate variability.

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General Article

MORPHOLOGICAL DIVERSITY AND ETHNOMEDICINAL USES OF LICHENS IN NORTHWESTERN HIMALAYAN REGION OF HIMACHAL PRADESH

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Abstract

This paper aims to critically examine existing literature concerning the morphological diversity and ethnomedicinal applications of lichens in the Northwestern Himalayan region. Lichens are one of the most important components of the flora of Northwestern Himalayan regions. The region's extensive topographical and climatic variability has contributed to its abundant and diverse lichen flora. Lichens are symbiotic organisms resulting from a mutualistic association between a fungal component (mycobiont) and a photosynthetic partner (photobiont), which may be an alga, a cyanobacterium, or both, responsible for carrying out photosynthesis. Due to the absence of specialized defensive and protective tissues, lichens readily absorb water, nutrients, various compounds, and gases directly from the atmosphere. These physiological characteristics render them highly sensitive to anthropogenic disturbances, including atmospheric pollution, climate change, and particularly sulfur dioxide (SO_2) pollution.Lichens exhibit remarkable diversity in terms of morphology, ecology, and symbiotic complexity. With over 20,000 described species globally, they occupy a wide range of habitats—from arid deserts and alpine tundra to tropical forests and urban environments.Based on thallus structure, they are generally categorized into crustose (crust-like and tightly attached to the substrate), foliose (leaf-like with distinct upper and lower surfaces), and fruticose (shrubby or hair-like and often branched) forms. The thallus may show various surface textures—smooth, lobed, granular, or powdery—and may possess specialized asexual reproductive structures such as isidia and soredia.Lichens have been an integral part of traditional medicine and natural healing practices across various cultures for centuries due to their ethnomedicinal values. Lichens synthesize unique chemicals that have antimicrobial, anti-inflammatory, antioxidant, and wound-healing properties. Traditional healers have evenevaluated lichens for treating respiratory issues, skin conditions, digestive problems, and infections. In this documentation, seven research papers and some article are reviewed for the conclusions and analysis that are brought out.

Keywords: lichens, ethnomedicinal, anthropogenic interruptions, antioxidants & climatic diversity.

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Introduction

Lichens are a fusion of organisms, possessing dual nature, and these are formed bythe mutualistic association of two or more different types of organisms - the fungal partner (mycobiont) and the algal partner (phycobiont).This unique symbiotic association is believed to have evolved as an adaptive strategy to survive in diverse microhabitats characterized by extreme microclimatic conditions, which would be inhospitable for fungi and algae if existing independently (Negi & Upreti, 2000). The word lichen is Greek originated and it grows on a variety of substrata like thick barks and twigs of trees, rocks, soil and leaves in almost every suitable climatic conditions (provided little or no SO_2 pollution) starting from tropical to alpine regions and polar regions of Antarctica including the area under concern i.e., the Northwestern Himalayan regions. The father of botany, Theophrastus, was the one to first time introduce the term 'lichen'.Lichens are regarded as pioneer colonizers of terrestrial ecosystems, exhibiting a widespread global distribution. Globally, approximately 19,387 lichen species have been documented (Lücking et al., 2017). According to Mao et al. (2021), India is home to 2,961 lichen species, accounting for roughly 14% of the known global lichen diversity and representing about 5.41% of the country's total plant diversity. Lichen species are collectively referred to by various vernacular names across different regions and languages of India: 'stone flower' in English, 'Kalachu' in Kannada (Karnataka), 'Patthar ka phool' in Hindi, 'Kalpasi' in Tamil, 'Shilapushpa' in Sanskrit, 'Dagadphool' in Marathi, and 'Richamkamari' in Urdu (Shukla et al., 2014).

In the lichen symbiosis, the fungal component constitutes the majority of the lichen thallus, with its hyphae forming a dense, reticulate network that closely envelops and integrates with the algal cells, creating a mesh-like structure. Fungi acquire nutrients either saprophytically, by decomposing dead organic matter, or through a parasitic mode of nutrition, extracting resources from the living tissues of host organisms (Ahmadjian et al., 1993). Lichens absorb the majority of their mineral nutrients directly from the air and rainfall, as they lack true roots for nutrient uptake. This physiological trait renders them particularly vulnerable to atmospheric pollution, as they can retain and accumulate harmful concentrations of heavy metals, sulfur compounds, radioactive elements, nitrogen oxides, and ozone. Sulfur dioxide (SO_2) is particularly harmful to lichens as it lowers the pH within their tissues and degrades photosynthetic pigments, ultimately disrupting the photosynthetic process and causing it to cease. The chemical substances present in lichen are Depsides, Depsidones and Dibenzofuran (Asahina & Shibata, 1954) and many of such chemicals are not known in other organisms. The first record for the utilizations of a lichen as medicine is 'Shiphal' that is mentioned in Atharveda (around 1500 BCE). In Ayurveda, the vernacular term 'Charilla' is commonly applied to various diseases and disorders, including headache, skin ailments, urinary problems, boils, vomiting, diarrhea, dysentery, heart conditions, cough, fever, leprosy, and is also regarded as a blood purifier, reflecting its use within this ancient Indian medicinal system (Kumar et al., 2001). Synonyms from Sanskrit like '*Shailaya*' ("rock-lichen"), '*Shila Pushp'*("rock-flower") have also been mentioned in our Vedic findings. In the Western Himalayan regions (e.g. Uttarakhand, Tehri Garhwal, Himachal pradesh), local inhabitants use lichens therapeutically and pharmaceutically. For example, *Hypotrachynacirrhata* is one of the most extensively used lichens in Tehri Garhwal for medicinal purposes due to its ethnomedicinal importance.*Usnea barbata* is utilized as an ingredient in deodorants produced by Earth Science Naturals (California, USA). Additionally, powdered extracts of lichens such as *Xanthoparmeliascrabosa*, *Usnea barbata*,

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and *Cetraria islandica* are commercially available online through NutriCargo, LLC. (Wholesale Botanical, Clifton, USA). Furthermore, thallus extracts from *Cetraria islandica, Cladoniarangiferina*, various Usnea species (including *U. barbata, U. subfloridana*, and *U. filipendula*), and *Lobaria pulmonaria* are incorporated into a syrup marketed under the brand name Melato di Licheni (Weleda, UK), which is intended to support the body's natural defense mechanisms and upper respiratory health (Sutar et al., 2021). In present time, numerous research and expeditions have been carried out to explore the vast flora of lichens, still there remains a lot to explore.

The northwestern Himalayan regions including – Himachal Pradesh, Jammu and Kashmir, Uttarakhand, are bestowed with the extraordinary lichen diversity contributing to its significance worldwide.Their wide altitudinal range from about 300m in the foothills to about 6000m in the alpine zones supports a wide range of microclimates ensuring different lichen growth forms. The northwestern Himalayan regions possess a wide range of climatic variations receiving both monsoonal and western disturbance precipitation i.e., snow and rain, ensuring moisture availability which is critical for lichen survival. The diverse topography of these regions creates numerous microclimatic niches like rock crevices, fissured tree barks, exposed cliffs, etc. allowing unique species of lichens to thrive. Additionally, the rich forest varieties e.g., oaks, pines, deodars, rhododendrons, etc. provides barks for the corticolous lichens whereas exposed rocky slopes of high altitudes homes saxicolous lichens. Terricolous lichens are supported by the soil crusts in alpine pastures and meadows. Recent data indicate that 192 lichen species have been recorded in the Great Himalayan National Park (GHNP), encompassing 31 families and 65 genera. This represents over 10% of the lichen species documented in India and 50% of those found in the central Himalayan region. Within GHNP, Tirthan Valley hosts 101 species, Jiwa Valley 100 species, and Sainj Valley 67 species. Notably, 78% of these species are corticolous (bark-inhabiting), while the remainder are classified as saxicolous (rock-inhabiting), terricolous (ground-inhabiting), or foliicolous (leaf-inhabiting).A total of 70 lichen species, representing 29 genera and 15 families, were documented across eight different localities in the Mandi district of Himachal Pradesh, India (Thakur et al., 2020). The lichen genus *Lecanora*, comprising 11 species, demonstrates predominance in the area (Thakur et al., 2020). Among the various localities within the district, Sikandra Dhar exhibited the highest lichen diversity with 19 species, followed by Balh Valley (18 species), Barot (17 species), and Mandi City (16 species) (Thakur et al., 2020). The temperate region of the district, characterized by abundant growth of *Quercus leucotrichophora* trees, supports the prolific growth of lichen species such as *Parmotremanilgherrense*, *Ramalina conduplicans*, *Ramalina sinensis*, *Heterodermiadiademata*, and various *Usnea* species (Thakur et al., 2020). Among the various localities within the district, Sikandra Dhar exhibited the highest lichen diversity with 19 species, followed by Balh Valley (18 species), Barot (17 species), and Mandi City (16 species) (Thakur et al., 2020). The temperate region of the district, characterized by abundant growth of *Quercus leucotrichophora* trees, supports the prolific growth of lichen species such as *Parmotremanilgherrense*, *Ramalina conduplicans*, *Ramalina sinensis*, *Heterodermiadiademata*, and various *Usnea* species (Thakur et al., 2020).

Lichens of the northwestern Himalayan regions serves as an essential ingredient in the traditional medicines and their sensitivity towards the SO_2 makes then an essential indicator for SO_2 pollution. Furthermore, time to time discovery of new lichen species indicates progressing speciation and high endemism. On the whole, the northwestern Himalayan regions serve as a vital center for lichen diversity, conservation and scientific research.

Morphological Features and Growth Forms

Lichens possess a thalloid plant body without any distinct differentiation between true root, stem and leaves. Based on the different growth forms, habit and attachment to the substratum, three major forms have been recognized.

Crustose Lichens

These are thin, flat and crust-like in appearance and tightly adhere to the substratum like rock, bark, soil, etc. These are so tightly attached to the substratum that they cannot be removed without damage. These are mostly corticolous and saxicolous. For example,*Melasphilealentiginosa:* These were found on the bark of *Quercus leucotrichophora*at around 1700 m in Shimla, Himachal Pradesh, these species has a thin, immersed, rough thallus and carbonaceous apothecia (Prasher& Sushma, 2017). *Physconia pulverulenta*: Occurs on bark at 2680 m in Sangla, Himachal Pradesh. It has a foliose-like appearance near apothecia but is considered microlichen due to small, closely attached thalli (Prasher& Sushma, 2017).

Foliose Lichens

These appears leaf-like with lobes and possessing a slightly flattened body. Unlike crustose lichens, these are quite loosely bound to the substratum usually through root-like structures called rhizines. For example, *Hyperphysciaadglutinata*– This lichen hassmall orbicular foliose thalli, greenish-grey to brownish in color, collected in forested areas of Uttarakhand, including Bajpurand Khatima (Awasthi, 1960).*Parmotrema tinctorum* and *Parmotrema austrosinense*: These corticolous lichens are with broad round lobes, soralia present, found in Sikander Dhar, Himachal Pradesh (Thakur & Chander, 2018). *Leptogiumpapillosum*: These saxicolous lichens are loosely attached with flat to ascending lobes, bluish-grey to dark-grey in appearance; found in Himachal Pradesh and reported new to India (Prasher& Sushma, 2017).

Fruticose Lichens

Visually these are shrub-like or hair-like, often found branched with 3-dimensional appearance. These may be erect or pendant, attached to substratum at a single point. For example, *Cladoniasubsquamosa* – A podetiate fruticose lichen growing on soil over rocks in alpine zones, height ranges from 10–20 mm, with secondary thallus podetia exhibiting soredia and microsquamules and this species has also been reported from Nilgiri hills in southern India, highlighting its pantropical distribution as well as Himalayan occurrence (Bhoria et al., 2019). Ramalinaceae and Parmeliaceae representatives – Fruticose members like *Evernia, Everniastrum, and Parmotrema* genera are reported in temperate forests of Himachal Pradesh, Uttarakhand, and J&K, growing on the trunks of evergreen trees (Nayaka et al., 2010).

Ethnomedicinal and Traditional Uses

Ethnobiology has experienced significant growth, with scientific knowledge derived from research expeditions and traditional data on organisms increasingly utilized for medicinal applications. This has heightened researchers’ awareness of bioactive substances present in organisms, facilitating the development of novel pharmaceuticals (Posey, 1992). In this context, lichens have been extensively investigated, particularly focusing on their pharmacological potential and ethno-lichenological aspects, based on survey-based studies (Sharma et al., 2021).Traditional knowledge points towards the knowledge acquired over the years that has been handed down generation after generation over time. Traditionally, lichens are of utmost importance in the ethnomedicinal field. It was observed that 39% of lichen species possess both documented traditional uses and reported biological activities; 12% hold traditional significance but have yet to be investigated for biological activity; while approximately 49% have documented biological activities with no known traditional uses to date (Sutar et al., 2021). Apparently far more percentage of lichens have been overlooked and still remain to be disclosed. Lichens play a major role in our lives.Local communities utilize lichens in preparing numerous traditional medicines. These medicines are used to treat multiple ailments like skin disorders, wound healing, digestive issues, etc.Cultural and medical value of lichens from Himalayan regions are far more superior to synthetic drugs. These numerous properties of lichens are due to the presence of a variety of chemical compounds within them. Basic chemical composition of lichens consist of carbohydrates (like glucans, heteropolysaccharides, cellulose-like wall materials, etc.), polyols (sugar alcohols) such as ribitol, mannitol and sorbitol (which mainly serves as carbon storage and transfer compound), proteins and amino acids from both the algal and fungal partners, lipids (fats, fatty acids, sterols), pigments such as carotenoids, chlorophyll a (in algae), phycobiliproteins (in cyanobacteria). Lichens absorb minerals directly from the air, rainwater, and their substrate, including essential macro-elements such as carbon, hydrogen, oxygen, nitrogen, phosphorus, sulfur, potassium, calcium, magnesium, and sodium. They also take up micro-elements like iron, copper, zinc, manganese, molybdenum, and boron, as well as heavy metals such as lead, cadmium, and mercury, which can accumulate within their tissues. Consequently, lichens serve as effective bioindicators of air pollution. In some regions, lichens are often boiled to make tea out of it. Lichens are especially known to produce several unique secondary metabolites, most of these are phenolic compounds synthesized by the mycobiont the fungal partnerwhich forms around 20 % of the dry weight of lichens. These include- depsides & depsidones (e.g., atranorin, salazinic acid, norstictic acid), usnic acid which are yellow-green pigments having antibiotic, antiviral, and antifungal activity, pulvinic acid derivatives which provides orange, yellow or red pigmentation, anthraquinones (found in a few lichens and imparts red/orange hues) and in very small quantities there are also present terpenes & sterols. Lichen metabolites play a crucial role in metal homeostasis and contribute significantly to the pollution tolerance observed in lichens (Bhattacharyya et al., 2016).

Thus, lichens are used as antimicrobial and antioxidant agents (Elkhateeb et al., 2021) also as antiviral agent (Bhattacharyya et al., 2016).Atranorin exhibits potent antioxidant and antitumor properties, demonstrating one of the highest free radical scavenging activities among lichen-derived compounds tested to date, along with exceptional reducing power and superoxide radical scavenging efficacy (Goga et al., 2020). Currently, lichens are employed to treat a variety of human illnesses because of their anti-cancer, antigenotoxic, anti-inflammatory, analgesic and antipyretic activity (Nugraha et al., 2019; Šeklić et al., 2022). *Usnea* is considered to be the most widely used genus of lichens in traditional medicine. Due to its broad range of biological and ecological activities, atranorin is utilized in various industries, including cosmetics, deodorants, perfumery, toothpaste formulations, and medicinal ointments. Larvae of *Cleorodeslichenaria* exhibited impaired growth, increased mortality rates, and elevated concentrations of usnic acid within their tissues (Goga et al., 2020). In lichens, secondary metabolite production is determined by the environmental factors including UV-exposure, temperature fluctuations, seasonal variations, etc. Due to the diverse topography in the northwestern Himalayan regions, a large variety of lichen species are thriving there, some of which has been mentioned in the table below with their few ethnomedicinal uses;

S. no.	Lichen species	Family	Substratum	Altitude(in m)	Morphologicalcharacters	Traditionaluses	References
1.	*Alectoria sarmentosaAch.*	Parmeliaceae	Tree branches	1500-3500	Fruticose thallus with pendulous and hair-like strands, highly branched, can form tangled mats, surface is smooth and slightly shiny, no soredia or isidia present, loosely attached to branches by basal holdfasts, mostly reproduce via fragmentation.	Lichens have been traditionally used for wound dressing, treating open sores, and incorporated into sanitary napkins and baby diapers due to their absorbent and antimicrobial properties. Additionally, they have been employed in the treatment of asthma, arthritis, and conditions involving excessive mucus discharge from the nose or throat.	(Jain 2016);(Rankovic 2007);(Gollapudi 1994).
2.	*Bryoria bicolor* (Hoffm.) Brodo& D. Hawksw	Parmeliaceae	Bark	1500-3500	Fruticose thallus which is hair-like, pendulous or loosely attached to branches, branches (slender, cylindrical and slightly dichotomous), no soredia or isidia, cortex is well developed, primarily reproduces through fragmentation.	It is commonly indicated for the management of general weakness, vertigo, cardiac palpitations, spontaneous ejaculation, nocturnal hyperhidrosis, urinary retention or difficulty, infectious dermatological conditions, and purulent discharge.	(Wang & Qian, 2013)

3.	*Buelliasubsoriroides*S. Singh & D.D. Awasthi	Buellaceae	Rocks	1500-3500	Crustose lichen, tightly attached to rock surface, smooth to slightly cracked surface, reproduce through spores, apothecia present, compact medulla, well developed cortex.	A paste derived from the thalli is traditionally applied for decorative purposes, such as creating henna-like tattoos on the palms and lips.	(Jain, 2016)
4.	*Bulbothrixsetschwanensis* (Zahlbr.) Hale	Parmeliaceae	Barks	500-2000	Foliose thallus, closely attached to substratum with narrow lobes and smooth texture, bulbate cilia are present along the lobe margin, reproduction primarily vegetative.	It is utilized as a culinary spice in Northern India and also serves as a source of natural dye.	(Behera BC 2002);(Fernandez 2016);(Tiwari 2011);(Maurya 2018).
5.	*Cetraria islandica* (L) Ach.	Parmeliaceae	Rocks and soil	2000-3800	Foliose thallus, forms cushion-like mats, lobes are broad, flattened, often with a wrinkled surface, thick medulla.	It is employed as a tonic in the treatment of pulmonary tuberculosis, hemoptysis, asthma, chronic respiratory congestion, and also functions as a laxative. Additionally, it is used to manage indigestion, dysentery, uterine cysts, nephrolithiasis, and urinary tract infections. Furthermore, it serves as a winter forage for reindeer.	(Crawford, 2015);(Ingolfsdottir, 2000); (Turk et al., 2003); (Gülçin, 2002);(Ogbaji, 2014); (Haraldsdottir et al., 2004).
6.	*Cladoniafruticulosa*Kremp.	Cladoniaceae	Wood	1990	Fruticose thallus forming shrub-like structures, primary thallus is squamulose, dichotomous	It is traditionally used in the treatment of bacterial skin infections,	(Wang & Qian, 2013).

					branching.	vertigo, epistaxis, infectious dermatological conditions, and conjunctivitis.	
7.	*Everniastrumnepalense*(Taylor) Hale ex Sipman	Parmeliaceae	Barks and branches	1800-3400	Foliose thallus, loosely attached to substratum, lobes are broad, flat and dichotomously branched, well developed upper cortex protecting the photobiont layer.	The thalli are consumed as a vegetable after boiling or frying and are also utilized in the traditional treatment of toothache and sore throat.	(Shah, 2014);(Maharjan, 2013);(Tiwari, 2011);(Sinha, 2005).
8.	*Lobariapindarensis*Räsänen	Peltigeraceae	Tress and shrubs in subalpine forests	~2000-4150	Foliose thallus, reproduce by both sexual spores (disk shaped fruiting body called apothecia) and vegetative propagules (isidia, lobules, thallus fragments).	Used as spices in some regions	(Yang et al.,2022); (Yang et al.,2021).
9.	*Lobariaisidiosa*(Müll. Arg.) Vainio	Peltigeraceae	Bark, Mosses & Rock	~1500-3500	Foliose and leathery thallus, broad flattened lobes usually overlapping, isidiate thallus surface, with whitish & loose medulla.	Utilized in the management of dyspepsia, the alleviation of inflammation and pain, the treatment of burns and scalds, as well as the reduction of oedema associated with renal inflammation.	(Crawford, 2015).
10.	*Parmelia saxatilis(L.) Ach*	Parmeliaceae	bark	1200-3000	Foliose thallus tightly attached to substratum, lobes are slightly lobulate or crenate, upper surface is smooth and slightly wrinkled with pseudocyphellae scattered on	Employed in the treatment of visual disturbances, uterine hemorrhage, external bleeding due to injury, chronic dermatitis, as well as	(Wang & Qian, 2013);(Thadhani& Karunaratne, 2017);(Kosanić et al., 2012a);(Ćilerdžić,2016);(Huang, 2014);(Wei et al., 2008);(Karagöz,2009).

					upper surface, lower cortex are with simple rhizines for attachment.	persistent sores and inflammatory swelling.	
11.	*Parmotremahababianum*(Gyeln.) Hale	Parmeliaceae	Barks and rocks	1500-3200	Foliose thallus, broad, rounded, often overlapping lobes, lower surface is black with simple or branched rhizines for attachment, loosely packed medulla.	Traditionally used as a culinary spice and in the management of renal disorders, venereal diseases, and various dermatological conditions. The fresh plant is burned, and the resulting ash is combined with mustard or linseed oil to prepare a topical remedy for ringworm and similar skin infections	(Upreti et al., 2005);(Ganesan, 2016).
12.	*Usnea orientalis*Motyka	Parmeliaceae	Bark, wood, rarely on rocks	2000-3200	Fruticose thallus which is pendulous, hair-like to stringy, extensively dichotomously branched, central cord is visible when thallus is broken, sensitive to air pollution.	Traditionally utilized as a culinary spice in the regional cuisines of Uttaranchal, Uttar Pradesh, and Himachal Pradesh.	(Upreti et al., 2005);(Pathak, 2016b); (Wei et al., 2008).
13.	*Usnea aciculiferaVain.*	Parmeliaceae	Branches and twigs of trees	2000-3500	Fruticose thallus, central axis is elastic, basal holdfasts present, lacks soredia or isidia.	It is employed in the treatment of bladder infections, dysuria, urinary retention, and edema associated with cardiac and renal conditions. Additionally, it is used to manage external	(Jain,2016); (Nayaka et al. 2002B); (Srivastava et al., 2004B).

						hemorrhage, relieve pain, and treat hematochezia. Furthermore, it is utilized as a traditional remedy for pulmonary disorders, internal bleeding, and asthma.	
14.	*Xanthoparmeliac onspersa*(Ach.) Hale	Parmeli aceae	Expose d rocky surface	1200-3000	Foliose thallus, tightly attached to rocks, broad, flat, often overlapping lobes, well developed protectives upper cortex with white and dense medulla.	Traditionally, it is applied topically as a therapeutic intervention for snake bites and utilized in the treatment of syphilis	(Nayaka, 2010);(Karaah met et al., 2019);(Sokmen , 2018).

Discussion

From the data documented in the table above, it can be concluded that there is predominance of foliose lichens in ethnomedicinal practices which may be ascribed to their relatively larger surface area that aids collection and large number of unique secondary metabolites production. It can be also drafted that mostly the lichens found at higher altitudes are being used in ethnomedicinal fields which may be due to the great topographical and climatic variations. Moreover, different tribal communities reside in the landscapes of northwestern Himalayan regions like Gaddi, Gujjars, etc. From generations they have used lichens for the treatment of various diseases. For example, *Usnea*, as believed to have antibacterial properties is often used to treat wound and cuts. *Parmelia* is used to treat various skin diseases and coughs. Our study recorded 70 lichen species, encompassing 29 genera and 15 families, across eight different localities in the Mandi district of Himachal Pradesh, as reported in the referenced research paper "An Assessment of Lichens Diversity from Mandi District,Himachal Pradesh, India"by (Thakur et al.,2020). Their documentation reported that among the primary localities in Mandi district, Himachal Pradesh, the Sikandra Dhar area exhibited the highest lichen diversity with 19 species. Other localities, including Balh Valley, Barot, and Mandi city, recorded 18, 17, and 16 species, respectively. They also noted that lichen species belonging to the genera *Ramalina*, *Parmotrema*, and *Caloplaca* were exclusively found in the pollution-free zones of the inner reserve forest.The study conducted by Bajpai et al., (2022) reported 714 lichen species, representing 189 genera and 49 families, across 12 representative districts of Himachal Pradesh. In their research it was found that among the 12 districts studied only Kullu and Shimla were characterized by a large number of species (425 and 304 species respectively) as both had almost similar habitats. Their study further revealed that the districts of Una, Hamirpur, and Bilaspur exhibited the lowest lichen species diversity, with 10, 39, and 66 species recorded respectively. According to their findings,lichens belonging to Parmeliaceae family were reported in dominance. The study by Chander et al., (2019) reported the collection of sixty lichen species from Balh Valley in the

Mandi district of Himachal Pradesh. Their documentation recorded *Usnea longissima* for the first time from the Mandi district of Himachal Pradesh.

Conclusion

Based on the findings of these studies, it can be concluded that the Northwestern Himalayan region possess remarkable lichen diversity, with a wide range of growth forms and species adapted to different habitat and environmental conditions. These lichens are not only recognized ecologically important but also play an impactful role in the traditional medicine practices of local communities. For generations, indigenous people including tribal communities have used various lichen species to treat several medical urgencies like wounds, skin diseases, coughs, and other common illnesses. Some of these traditional uses are now being supported by modern scientific research, especially for species like *Usnea* and *Parmelia*. However, even though they are so much important, lichens are encountering severe threats from overharvesting, pollution, and climate change. At the same time, the traditional knowledhge related to their medicinal use is gradually vanishing form existence as younger generations are moving away from these practices. Thus, there is an urgent need to document this knowledge, so that lichen habitats can be protected, to carry out even more scientific practices to bring out their full potential in medicinal fields. By combining traditional wisdom with modern research, new and fascinating world of lichens can be brought into light and help to conserve both biodiversity and cultural heritage for future generations.

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