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OSTRICH FARMING IN INDIA

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ABSTRACT

Ostrich farming is a relatively new and niche industry in India. As the country looks for alternative livestock farming options to meet the growing demand for protein and exotic meats, ostrich farming is gaining traction, though it is still limited compared to traditional poultry or livestock farming. Ostriches are native to Africa but can adapt to various climates, making India a suitable location, especially in regions with dry or semi-arid climates. Indian states like Maharashtra, Tamil Nadu, and Andhra Pradesh have shown interest in ostrich farming due to the suitable environment and demand for alternative meats. Ostrich meat is lean, low in cholesterol, and high in protein, making it an attractive choice for health-conscious consumers. It's often marketed as a healthier alternative to red meats like beef and mutton. With an increasing demand for exotic meats, especially in urban areas, ostrich farming in India could expand. Industry experts suggest that partnerships with food-processing companies and targeted marketing could help make ostrich products more mainstream. There is also potential for export to meet global demand for exotic meats and leather. Ostrich farming in India remains an emerging industry with substantial potential, especially in niche and export markets. While it faces challenges in consumer acceptance, infrastructure, and investment, growing interest in diverse food sources and sustainable farming may boost its prospects in the coming years.

No. of Pages: 11 **References: 37**

Keywords: Ostrich, India, farm, production, meat, eggs.

INTRODUCTION

An ostrich (Fig 1) is the world's largest bird, native to Africa. It belongs to the species *Struthio camelus* Linnaeus, 1758 and is known for its distinctive appearance, long legs, and large size (King and Mclelland, 1984). Ostriches cannot fly, but they are extremely fast runners, capable of reaching speeds up to 70 km/h (43 mph) (Osterhoff, 1979). They are also known for their large, powerful legs, which they use for defence, and their long necks, which help them spot predators from a distance (Synders, 2020). Ostriches have a diet that consists mostly of plants, seeds, and occasionally insects. They lay the largest eggs of any bird species, and these eggs are highly prized for their size (de Mosethal and Harting, 1879; Duerden, 1920). Despite their size, ostriches are very well adapted to survive in hot, arid environments, like savannas and deserts (Osterhoff, 1979).

As of the latest scientific consensus, there are two primary species of ostriches, each with distinct geographical distributions across Africa:

1. Common Ostrich (*Struthio camelus* Linnaeus, 1758): Widely found in Southern African countries such as South Africa, Namibia, Botswana, Zimbabwe,

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and parts of Mozambique; and can also be seen in East African regions of Kenya, Tanzania, and Uganda (Duerden, 1920). They inhabit a variety of environments including savannas, semi-deserts, and open woodlands (Shanawany, 1994a,b). They prefer areas with ample space to roam and access to water sources (Mac Alister, 1964). They are generally classified by IUCN as Least Concern; although certain subspecies may face localized threats (King and Mclelland, 1984).

2. Somali Ostrich (*Struthio molybdophanes* Reichenow, 1883): Primarily located in Somalia, but also found in parts of Ethiopia, Djibouti, and north eastern Kenya. They are adapted to arid and semi-arid regions, including dry savannas and scrublands (Mac Alister, 1964). They thrive in areas with sparse vegetation and limited water availability (Cilliers and Angel, 1999). While both species share common ostrich characteristics-such as large size, flightlessness, and long legs-the Somali ostrich typically has a lighter plumage and may exhibit slight variations in size and coloration compared to the common ostrich (King and Mclelland, 1984). Listed by IUCN as Least Concern; but, due to habitat degradation and hunting pressures local populations can be impacted (Shanawany, 1994a,b).

3. Arabian Ostrich († *Struthio camelus syriacus* Rothschild, 1919): Once native to the Arabian Peninsula, this subspecies is now extinct. Its extinction was primarily due to overhunting and habitat loss (Duerden, 1920; Mac Alister, 1964).

The life cycle of an ostrich consists of several stages, from the egg to adulthood. Here is a breakdown of the main phases: Ostriches lay their eggs in communal nests, called "dump nests," where multiple females may lay their eggs (Shanawany, 1994a). The dominant female usually lays around 7-10 eggs, and other females may add more (Mac Alister, 1964). The eggs are large, weighing about 1.4 kg (3 pounds) each. Both the male and the dominant female take turns incubating the eggs, with the female typically sitting on them during the day and the male taking over at night. This period lasts for about 42 days (Shanawany, 1994b).

Once the eggs hatch, the chicks emerge with a coat of downy feathers. They are well-developed at birth and can walk within hours. The chicks are cared for by both parents and may form larger groups called "creches," where multiple families of ostriches look after the young collectively (Shanawany, 1993). This improves their chances of survival. Ostrich chicks grow rapidly, reaching about half their adult size in six months. They primarily feed on vegetation, insects, and small animals, gradually becoming more independent as they grow (Duerden, 1920). Juvenile ostriches develop adult feathers after about 4-5 months, though they remain smaller and less vibrant than fully grown adults (Osterhoff, 1979). At around 12-18 months, ostriches reach near adult size. Their feathers continue to mature, and their legs and necks grow longer (Mac Alister, 1964). They still rely on their group for protection from predators during this period (Swart and Rahn, 1988).

Ostriches reach sexual maturity between 2 and 4 years old, with females maturing slightly earlier than males. At this stage, the male develops distinctive black and white plumage, while the female remains a more subdued brown (Siegfried, 1984). Once mature, ostriches begin to mate. Males perform elaborate courtship displays to attract females. After mating, the life cycle begins anew with the laying of eggs (Shanawany, 1993). Ostriches in the wild typically live for about 30-40 years, though they can live longer in captivity, sometimes up to 50 years. Throughout their life, they face challenges such as predation, competition for mates, and environmental changes (Van Schalkwyk et al, 1994).

Ecological role played by **ostriches in the nature**

Ostriches play an important ecological role in their habitats, primarily in the savannas and arid regions of Africa. As herbivores, ostriches consume a variety of plants and fruits. The seeds they ingest pass through their digestive systems and are dispersed over wide areas in their droppings. This helps in the regeneration of plant life and promotes biodiversity. Ostriches use their strong legs to scratch and dig into the soil while searching for food. This behaviour helps aerate the soil, improving its structure and promoting water infiltration, which benefits the ecosystem (Samour *et al.*, 1984). Ostriches serve as prey for large African predators such as lions, hyenas, and cheetahs. This makes them a key part of the food web, supporting the survival of predators. Additionally, ostrich eggs and chicks are a food source for smaller predators. Through their feeding and excretion, ostriches contribute to nutrient cycling (Siegfried, 1984). Their droppings return vital nutrients to the soil, enriching the environment for plants and other organisms (Mac Alister, 1964). In some regions, ostriches can be considered a keystone species because their presence and activities can influence the structure of the ecosystem, benefiting other species that share their habitat. These factors make ostriches important contributors to the health and balance of their ecosystems (Saur, 1966).

Economic importance of ostriches

Ostriches have significant economic importance in several sectors. Ostrich meat is considered a healthy alternative to red meat due to its low fat and high protein content (Abbas *et al.*, 1993). It is becoming increasingly popular in health-conscious markets and gourmet cuisine, particularly in regions such as the US, Europe, and parts of Africa (de Mosethal and Harting, 1879). Ostrich leather is a highly sought-after material in the luxury goods market (Levy *et al.*, 1990). It is prized for its durability, softness, and unique pattern (King and Mclelland, 1984). This leather is used to make a wide variety of products, including handbags, shoes, and belts. The feathers are used in the fashion industry, in decorations, and for making feather dusters. They have also been used in traditional costumes and cultural events (Sanawany, 1994a). Ostrich eggs are the largest of any bird species and are used for consumption or in arts and crafts due to their size and sturdy shells. They are popular in gourmet cooking and are also sold as novelty items (Shanawany, 1994b). Ostrich farms attract tourists, and many people visit these farms to see the birds up close, learn about ostrich farming, or even participate in ostrich rides in certain regions (Samour et al., 1984). Ostrich oil, derived from the fat, is sometimes used in cosmetics and skincare products due to its moisturizing properties (Snyders, 2020). The combination of these factors makes ostrich farming a potentially lucrative enterprise, especially in countries with suitable climates such as South Africa, Namibia, and Australia (Yagil *et al.*, 1999).

Figure 1. Top panel: Ostrich farming in India; Second panel: Male ostrich bird highlighted living in their paddock with paired females; Third panel: Ostrich family feeding in a commercial farm India and ostrich eggs in a display gallery; Bottom panel: Close up of ostrich eggs. Location: Hyderabad, Telengana, India. Photo credit: Saikat Kumar Basu.

Ostrich farming practices around the world

Ostrich farming has expanded beyond the African continent (Fig. 2) and is successfully established in various countries around the world. These farms typically focus on producing ostrich meat, leather, feathers, and other by-products (Dubravak, 2003). Here are some notable regions and countries where ostrich farming is thriving outside Africa:

Australia: Predominantly in South Australia, Queensland, and Western Australia. Australia has a well-developed ostrich farming industry. Farmers raise ostriches for their high-quality leather, which is used in fashion and automotive industries, as well as for meat production. The favourable climate and advanced agricultural practices contribute to the success of ostrich farms.

United States: In the U.S., mostly across the states of Texas, California, Florida, and Arizona; ostrich farming is a niche but growing industry. Farms produce ostrich meat, which is marketed as a healthy alternative to traditional red meats due to its low fat and cholesterol content. Additionally, ostrich leather and feathers are utilized in various products.

Spain: The Andalusia and Catalonia in Spain have embraced ostrich farming to diversify its agricultural sector. Spanish ostrich farms supply both domestic and European markets with ostrich meat and leather. The country's Mediterranean climate is conducive to raising ostriches efficiently.

Israel: In Israel, predominantly in the Negev Desert and other arid areas; leverage its desert climate to farm ostriches, utilizing innovative irrigation and farming technologies. The focus is on sustainable meat and leather production, with farms implementing advanced breeding and management practices.

New Zealand: In New Zealand lands across the South Island, particularly in Canterbury and Otago; ostrich farms benefit from the country's extensive pasturelands and favourable climate. The industry produces high-quality ostrich products for both local consumption and export, including meat, leather, and feathers.

Argentina: In the Buenos Aires and Córdoba provinces. has seen growth in ostrich farming as part of its efforts to diversify agriculture. Farms focus on producing ostrich meat and leather, catering to both domestic markets and international exports.

China: Inner Mongolia, Xinjiang, and other northern provinces of China are showing promises to commercial ostrich farming. Although still emerging, ostrich farming in China is expanding due to increasing demand for exotic meats and high-quality leather. Chinese farms are adopting modern farming techniques to improve productivity and product quality.

Brazil: Mato Grosso, São Paulo, and Rio Grande do Sul in Brazil are important centres of ostrich farming. Brazil is investing in ostrich farming as a means to diversify its agricultural outputs. The country's vast land resources and varied climates support ostrich farming, with a focus on meat and leather production for both local use and export.

Mexico: Ostrich farming in Mexico is developing, around Baja California, Sonora, and Chihuahua with farms targeting niche markets for ostrich meat and leather. The country's diverse climates allow for effective ostrich rearing, and there is potential for growth in both domestic and export markets.

United Kingdom: Limited presence, primarily in England and Scotland.While not as widespread as in other countries, ostrich farming exists in the UK on a smaller scale. Farms focus on specialty markets, offering ostrich meat and leather to gourmet restaurants and fashion industries.

Fig. 2: Distribution of ostrich farm outside the continent of Africa.
ND = Natural distribution; ID = Introduced distribution; & NO = Not observed.

Ostrich farming is more favourable

Ostrich farming is generally considered more commercially successful than farming other flightless terrestrial bird species like emus, rheas, or cassowaries (Horbanczukel *et al*., 2008). Several factors contribute to this success. Ostrich meat is lean, low in cholesterol, and considered a delicacy in many markets (Levy *et al*., 1990). There is a growing demand for healthier meat alternatives, which boosts ostrich farming's viability (Douglas, 1995). The skin is highly prized for leather goods, and their feathers are used in fashion and decoration. This adds additional revenue streams beyond just meat production Ostriches are larger than emus and rheas, which means they yield more meat per bird. An adult ostrich can weigh between 220 to 350 pounds, significantly higher than emus (100 to 130 pounds) and rheas (55 to 90 pounds) (Horbanczukel *et al*., 2008). The ostrich farming industry has been established for longer and has more developed market channels compared to emu and rhea farming. There are more resources, support, and market infrastructure for ostrich farmers.

Ostriches typically grow faster than emus and rheas, which can lead to quicker returns on investment. They reach market weight in about 12-14 months. Ostriches can thrive in various climates and conditions, making them suitable for farming in diverse regions. While emu farming can also be profitable, especially for niche markets like oil and feathers, and rhea farming has its advantages in certain areas, the overall commercial success of ostrich farming tends to be higher (Banks and Alexander, 1998). Cassowary farming, on the other hand, is less common and not typically pursued for commercial purposes due to their more specialized care needs and lower market demand (Horbanczukel *et al*., 2008).

Ostrich farming currently stands out as the most commercially successful option among flightless birds around the planet. It can have both positive and negative impacts on the conservation of wild ostrich populations. As farms expand, they can encroach on natural habitats, leading to habitat degradation and loss for wild ostrich populations (Snyders, 2020). Farming can lead to inbreeding or the selection of specific traits that may not be favourable for wild populations, potentially impacting their genetic diversity. Domesticated ostriches can transmit diseases to wild populations, which may have devastating effects on their health and survival (Osterhoff, 1979). Domesticated ostriches may compete for resources (like food and nesting sites) with wild ostrich populations, impacting their survival (Shannawany, 1993).

Profits from ostrich farming can be reinvested into conservation programs aimed at protecting wild ostrich habitats. Farms can serve as educational platforms, raising awareness about the importance of ostrich conservation and the threats they face. If managed sustainably, ostrich farms can provide a means of livelihood for local communities while promoting conservation efforts. The impact of ostrich farming on wild populations largely depends on how the farming practices are managed and integrated into conservation strategies. Sustainable practices that prioritize habitat preservation, genetic diversity, and disease management can help mitigate negative effects while supporting conservation efforts (Rodrigues *et al*., 2008).

Ostrich farming can contribute to the conservation of wild ostriches in several ways:

By providing a sustainable source of meat, feathers, and other products, ostrich farming can reduce the demand for wild-caught ostriches. This alleviates hunting pressure on wild populations, allowing them to recover (Pendian and Selvan, 2018). Farmed ostriches can serve as a genetic reservoir for wild populations, particularly if they are bred with conservation in mind. This could help maintain genetic diversity and assist in breeding programs for endangered species. Profits from ostrich farming can be reinvested into conservation programs aimed at protecting wild habitats and populations. This includes habitat restoration, anti-poaching efforts, and public education campaigns (Saif *et al*., 2003).

Farms can provide opportunities for research on ostrich behaviour, health, and genetics. This research can inform conservation strategies and enhance our understanding of the species. Ostrich farming can raise awareness about the importance of ostriches and their habitats, fostering a conservation ethic among consumers and the public (Horbanczukel *et al*., 2008). Sustainable ostrich farming can provide economic benefits to local communities, promoting livelihoods that are dependent on the conservation of natural resources rather than their exploitation. However, the effectiveness of ostrich farming in contributing to conservation depends on proper management practices, ethical breeding, and ensuring that farming does not negatively impact wild populations or habitats (Rodrigues *et al*., 2008).

The key factors necessary for successful growth of Ostrich farms outside Africa

Successful ostrich farms adapt their practices to suit local climates, whether arid, temperate, or otherwise. High demand for ostrich products, such as lean meat and durable leather, drives the profitability of farms

(Abbas *et al*., 2018). Implementation of modern breeding, feeding, and disease management practices enhance productivity and product quality. In some countries, agricultural policies and subsidies support the establishment and growth of ostrich farms. Ostrich farming outside Africa continues to grow as global demand for its products increases. Countries investing in this sector benefit from the unique advantages ostriches offer, such as sustainable meat production and versatile by-products (Miljkovic *et al*., 2011). Commercial farming of ostriches, known for producing valuable products like meat, leather, feathers, and eggs, has garnered interest globally due to its potential profitability and sustainability. In the context of India, the feasibility and popularity of ostrich farming involve evaluating various factors such as climate suitability, economic viability, infrastructure, and market demand (Nicholas *et al*., 1977).

Current Status of Ostrich Farming in India

Ostrich farming in India is relatively nascent compared to traditional livestock farming. While not widespread, there has been a gradual increase in interest among farmers and entrepreneurs exploring alternative and high-value livestock ventures (Pendian and Selvan, 2018). Several pilot projects and small-scale farms have been established in states like Rajasthan, Maharashtra, and Karnataka, where the climate conditions are more conducive to ostrich farming (Chandrasekhar *et al*., 2021). The Indian government has shown interest in promoting ostrich farming through agricultural extension services and providing information on best practices, though comprehensive policy support is still developing (Selvan *et al*., 2012).

Feasibility under Indian Conditions

Ostriches thrive in semi-arid and arid climates, which align well with regions in India such as Rajasthan and parts of Maharashtra and Karnataka. These areas offer the hot and dry conditions ostriches prefer, reducing the need for intensive climate control. Ostriches require ample space for grazing and exercise (Chandrasekhar *et al*., 2021). India's vast agricultural lands can accommodate ostrich farms, provided that the land is managed properly to prevent overgrazing and ensure sustainability. Adequate water supply is crucial for ostrich farming (Adams and Brian, 2023). While ostriches are more drought-resistant compared to other livestock, ensuring consistent water availability is essential for their health and productivity. Ostriches primarily consume grasses, seeds, and certain grains, which can be cultivated locally in India. However, the cost and availability of supplementary feed must be considered to maintain optimal growth and egg production (Pendian and Selvan, 2018).

Economic Product and Market and Viability

Ostrich meat is lean, high in protein, and has a growing market both domestically and internationally. In India, awareness and demand for ostrich meat are increasing, especially in urban centres (Swart *et al*., 1993). Ostrich leather is prized for its durability and unique texture, making it a lucrative product for the fashion and accessories industry. Feathers are used in decorative items and fashion, while ostrich eggs, although not as widely consumed, can find niche markets (Pendian and Selvan, 2018). Initial investment in ostrich farming can be significant due to the cost of acquiring birds, setting up proper housing, and ensuring adequate feed and healthcare. However, with proper management, the returns from multiple revenue streams can make it a profitable venture in the long run. Skilled labour familiar with ostrich care is limited in India, potentially increasing operational costs. Training and education are essential to ensure efficient farm management (Adams and Brian, 2023).

Challenges

Ostrich farming requires specialized knowledge in breeding, healthcare, and nutrition, which is not widely available in India. Ostriches are susceptible to specific diseases and parasites. Implementing effective health management practices is crucial to prevent outbreaks that can devastate flocks (Saif *et al*., 2003). Developing a robust market for ostrich products requires investment in marketing, establishing supply chains, and educating consumers about the benefits and uses of ostrich products. Navigating the regulatory landscape for livestock farming, including import restrictions on ostrich breeds and compliance with animal welfare standards, can pose challenges (Miljkovic *et al*., 2011).

Opportunities

For farmers looking to diversify beyond traditional livestock, ostrich farming offers a unique opportunity with high-value returns. With increasing global demand for ostrich products, there is significant potential for India to tap into export markets, especially if quality standards are met. Lower environmental footprint compared to other livestock, as they require less water and produce fewer greenhouse gases, aligning with sustainable farming practices (Horbanczukel *et al*., 2008).

Government and Institutional Support

Collaboration with agricultural universities and research institutions can foster innovation and improve farming practices; and potential for government subsidies or incentives to promote ostrich farming, though this area may require more development to support farmers effectively. Establishing training programs and extension services can help disseminate knowledge and best practices among prospective ostrich farmers. While commercial ostrich farming is not yet widespread in India, it holds considerable promise under the right conditions. The suitability of certain regions' climates, coupled with the growing market for high-value ostrich products, makes it a viable venture. However, success depends on overcoming challenges related to clear objectives and expertise, education and training, disease management, market development, appropriate support, investment strategies, market analysis, and risk management plans (Selvan and Pandian, 2018). By exploring available government schemes and support mechanisms that can aid in establishing and expanding ostrich farms; and by building a strong brand and market presence to create demand for ostrich products locally and potentially internationally (Horbanczukel *et al.*, 2008). Ostrich farming can transition from an emerging niche to a significant agricultural enterprise in India by addressing these factors effectively (Chandrasekhar *et al.*, 2021).

Potential of ostrich farming in India

Ostrich farming in India, though offering lucrative potential due to the high value of ostrich meat, leather, and eggs, faces several challenges (Horbanczukel *et al.*, 2008). Ostriches are native to arid African regions, and although they can adapt to various climates, certain parts of India, especially with extreme humidity or rainfall, may not be ideal for their health and productivity (Chandrasekhar *et al.*, 2021). Setting up an ostrich farm requires a significant financial investment in land, infrastructure, and birds, which can be cost-prohibitive for small-scale farmers (Snyders, 2020). Ostrich farming is relatively new in India. There is limited expertise on managing ostrich health, breeding, and feeding. Farmers need specific knowledge on ostrich behaviour and diet, which is not widely available (Van Schalkwyk *et al.*, 1998).

Ostriches require a specialized diet that may be hard to source or expensive in India. Providing a nutritionally balanced feed is essential for their growth and productivity, and deviations can impact their health (Adams and Brain, 2023). Ostrich farming might face regulatory hurdles as exotic species farming regulations are not clearly defined in all Indian states. Farmers might have to navigate complex legal frameworks regarding wildlife and livestock farming (Banks and Alexander, 1998). Ostrich meat and products are not widely consumed or recognized in India, leading to a limited domestic market. Farmers may have to invest in awareness campaigns or focus on export markets, which come with their own challenges like certifications and logistics (Abbas *et al.*, 2018).

Ostriches have specific breeding seasons, and managing the reproduction process is complex. Ensuring a high hatch rate requires expertise in egg incubation, and failure in this process can affect the farm's productivity (Samour *et al.*, 1984). Since ostrich farming is still niche, there is a lack of specialized veterinary care and medicines for ostriches, making it difficult to handle diseases or health issues that may arise (Snyders, 2020). Being large and strong, need secure enclosures to protect them from predators and prevent them from escaping. Setting up such secure environments is another cost and operational challenge (Adams and Brain, 2023). If farmers wish to sell ostrich products (meat, leather, etc.), they need access to proper processing facilities, which may not be widely available in India (Abbas *et al.*, 2018). Additionally, transporting large birds requires specialized vehicles and handling. These challenges mean that ostrich farming in India requires careful planning, knowledge, and resources to succeed (Chandrasekhar *et al.*, 2021).

How to farm ostrich in India

Ostrich farming in India presents a unique and promising agricultural venture with multiple streams of revenue and various benefits. As India continues to diversify its agricultural portfolio, ostrich farming stands out due to its adaptability, profitability, and contribution to sustainable farming practices (Miah *et al.*, 2020). Below is an in-depth exploration of the opportunities, benefits, and considerations for ostrich farming in India. Ostriches are the largest living birds, native to Africa, known for their impressive size, speed, and valuable by-products (Mitrovic *et al.*, 2009). Ostrich farming involves rearing these birds for their meat, leather, feathers, and other products (Siegfried, 1984). Unlike traditional poultry farming, ostriches require specific care, making it a specialized but lucrative venture. While ostrich farming is still in its nascent stages in India compared to countries like South Africa or Australia, interest is growing due to increasing awareness of the benefits and profitability associated with ostrich products (Van Schalkwyk *et* *al.,* 1998). Several farms have been established across states like Rajasthan, Maharashtra, and Karnataka, focusing on different aspects of ostrich production (Chandrasekhar *et al.*, 2021).

Ostrich meat is lean, high in protein, and low in cholesterol, making it a healthier alternative to red meat (King and Mclelland, 1984). With the rising health consciousness among Indian consumers, the demand for such meat is expected to increase. Additionally, ostrich meat has a longer shelf life compared to traditional poultry, reducing wastage (Levy *et al.*, 1990). Ostrich leather is highly prized in the fashion industry for its unique texture and durability. The global market for ostrich leather is robust, with opportunities for exports (Miah *et al.*, 20200. Besides leather, other by-products like oil (used in cosmetics and pharmaceuticals) and fertilizer can add to the revenue streams (Pndian and Selvan, 2018).

Ostrich eggs are large and nutrient-rich, finding applications in both culinary and cosmetic industries. While the primary focus is often on meat and leather, egg production can serve as an additional income sources (Miah *et al.*, 2020). The feathers are sought after for decorative purposes, fashion accessories, and in the event industry. Additionally, ostrich down is used in bedding and insulation materials. Ostrich farms can serve as tourist attractions, offering educational tours and interactive experiences. This not only diversifies income but also promotes awareness and acceptance of ostrich farming (Mac Alister, 1964; Saif *et al.*, 2003). With increasing urbanization and a growing middle class, there is a rising demand for exotic meats and high-quality leather products within India (Pendian and Selvan, 2018). Ostrich products cater to niche markets that are willing to pay a premium for quality and uniqueness. India's strategic location and trade agreements can facilitate the export of ostrich products to international markets. Countries in the Middle East, Southeast Asia, and Europe present viable export destinations (Levy *et al.*, 1990; Saif *et al.*, 2003).

Ostriches can adapt to a range of climatic conditions, making various regions in India suitable for farming (Miah *et al.*, 2020). Ostriches require less land compared to traditional livestock, allowing farmers with limited space to engage in ostrich farming (Yagil *et al.*, 1998). Ostriches have a lower environmental footprint, producing less methane and requiring less water, aligning with sustainable farming practices (Osterhoft, 1984; Cilliers and Angel, 1999; Saif *et al.*, 2003). Setting up an ostrich farm requires significant initial capital for land, housing, fencing, and specialized equipment (Dubravka, 2003). Additionally, ongoing costs for feed, healthcare, and maintenance need to be considered (Miah *et al.*, 2020).

Ostrich farming is specialized, and there is a limited pool of experts in India. Farmers may need to invest in training or consult with international experts to ensure best practices (Levy *et al.*, 1990). Navigating the regulatory landscape for livestock farming, obtaining necessary licenses, and adhering to biosecurity measures can be complex (Abbas *et al.*, 2018). Establishing reliable channels for distributing ostrich products, both domestically and internationally, is crucial for profitability; together with better understanding of the demand, pricing, and competition for ostrich products (Osterhoft, 1984; Douglas, 1995). Outline the goals, investment, operational plan, and financial projections by developing proper business plans and exploring options like loans, grants, or investor funding (Miah *et al.*, 2020; Chandrasekhar *et al.*, 2021).

Selecting a site with suitable climate, access to water, adequate space, appropriate housing, fencing, and facilities for breeding and rearing are important for successful ostrich farming levy et al., 1990; Miah *et al.*, 2020). Sourcing healthy ostrich chicks or adult birds from reputable suppliers, adopting best practices for feeding, healthcare, and breeding is important for farming success (Banks and Alexander, 1998). Creating a brand, establish distribution channels, and promote your products and ensuring all legal requirements are met, including animal welfare standards (Douglas, 1995; Saif *et al.*, 2003). The Indian government has been promoting diversification in agriculture, which includes support for unconventional farming practices (Osterhoft, 1984).

Ostrich farming in India offers a multifaceted opportunity for farmers seeking diversification and higher profitability. With the right planning, investment, and expertise, ostrich farming can tap into various markets, from meat and leather to tourism and beyond (Shannawany, 1993). While challenges exist, especially in terms of initial setup and expertise, the growing demand for high-quality and sustainable products positions ostrich farming as a viable and lucrative venture in the Indian agricultural landscape (Levy et al., 1990; Douglas, 1995). Before embarking on this journey, prospective farmers should conduct thorough research, seek expert advice, and possibly start on a smaller scale to understand the intricacies of ostrich farming (Saif *et al*., 2003). With dedication and strategic planning, ostrich farming can become a rewarding addition to India's diverse agricultural economy (Rodrigues *et al*., 2008; Abbas *et al*., 2018; Chandrasekhar *et al*., 2021).

CONCLUSIONS

Ostrich farming in India is an emerging industry with potential for growth, though it faces unique challenges. The global market for ostrich products-including meat, leather, and feathers is growing due to the bird's efficient meat-to-feed conversion ratio, lean meat, and the high demand for exotic leather. In India, interest in ostrich farming has been on the rise due to these factors and the adaptability of ostriches to semi-arid and arid climates, which are prevalent in many Indian states. The meat is lean and high in protein, fitting well with health-conscious consumers. It can be an alternative to red meats like beef and mutton. Ostrich leather is durable and luxurious, and feathers have uses in fashion, decor, and dusting products. Ostrich oil and other by products are used for their potential medicinal benefits.

Setting up ostrich farms requires significant capital for infrastructure, feeding, and health maintenance. While ostriches are hardy, their health can be affected by India's monsoons and high humidity levels in some regions. The Indian government classifies ostriches under exotic animal categories, which means regulatory frameworks are still evolving. Educating Indian consumers about ostrich meat and by products will be essential for establishing demand. These birds have a lower environmental footprint compared to cattle, appealing to the sustainability-driven. If recognized as a viable agricultural business, it may receive subsidies and policy support similar to livestock farming.

However, due to the novelty of the product, there is still a need for more awareness and demand in the general. Besides meat, ostrich farms also produce other valuable products, such as leather, feathers, and eggs. Ostrich leather is prized for its durability and unique texture, finding a niche market in fashion and accessories. Ostrich eggs, being large and nutrient-dense, also have potential as a specialty item. Initial costs in ostrich farming are relatively high compared to other livestock. The expenses include acquiring land, building specialized enclosures, and managing food and healthcare. In India, the lack of established infrastructure and skilled professionals in ostrich husbandry has created additional challenges for early adopters. Though the demand is gradually increasing, ostrich meat and products remain unfamiliar to most Indian consumers. Price sensitivity, limited availability of processing units, and inadequate marketing are some obstacles that the industry faces. The lack of regulatory standards and limited government support also slow down growth in this sector.

With growing interest in alternative meats and exotic leather, ostrich farming has the potential to become a niche but profitable industry in India. Successful farms in South Africa, Australia, and the U.S. can serve as models for Indian entrepreneurs. The sector could gain momentum with better regulation, R&D, consumer awareness campaigns, and financial support for farmers.

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NUTRIENT-RICH VEGETABLES AND PLANTS: A REVIEW OF THEIR HEALTH BENEFITS AND NUTRITIONAL VALUE

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ABSTRACT

Nutrient-rich vegetables and plants play a crucial role in promoting human health by supplying essential vitamins, minerals, dietary fiber, and a broad array of bioactive compounds. Their consumption is associated with a reduced risk of chronic diseases such as cardiovascular disorders, obesity, type 2 diabetes, and certain types of cancer. This review provides an extensive analysis of the nutritional profiles, phytochemical constituents, and health benefits of commonly consumed nutrient-dense vegetables and plants. It highlights emerging research on their therapeutic roles, sustainable cultivation practices, and future applications in biofortification and food security.

No. of Pages: 5 **References: 45**

Keywords: Nutrient-dense vegetables, phytochemicals, antioxidants, vitamins, minerals, health benefits, dietary fiber.

INTRODUCTION

Vegetables and plants have been central to human diets for centuries, offering a vast reservoir of nutrients vital for health maintenance and disease prevention (Slavin & Lloyd, 2012). With rising incidences of non-communicable diseases, there is renewed interest in nutrient-dense foods. These foods not only supply essential macro- and micronutrients but also include phytochemicals with antioxidative, anti-inflammatory, and therapeutic properties (Liu, 2013; Boeing et al., 2012).

The growing awareness of nutrition's role in combating chronic diseases has prompted researchers, health professionals, and policymakers to emphasize the inclusion of plant-based foods in daily diets. Nutrient-rich vegetables and plants represent a powerful tool in addressing global health challenges such as micronutrient deficiencies, poor dietary diversity, and the rising tide of diet-related illnesses (WHO, 2020; FAO, 2017; Pingali, 2015). Their accessibility, environmental sustainability, and broad spectrum of phytochemicals make them indispensable components of a balanced, health-promoting diet. This review explores the classification, nutritional composition, specific health benefits, and future applications of these critical food sources.

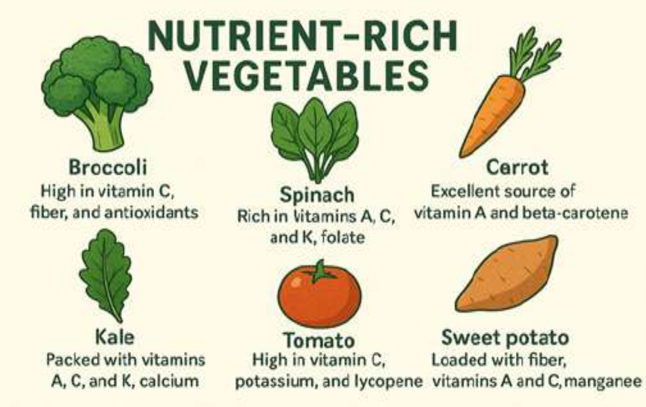

Fig.1: Diagrammatic view of nutrient rich vegetables.

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2. Classification of Nutrient-Rich Plants and Vegetables

Vegetables can be classified into several categories based on their botanical families and nutrient profiles:

- **Leafy greens:** Spinach, kale, Swiss chard, amaranth leaves
- **Cruciferous vegetables:** Broccoli, cabbage, Brussels sprouts, cauliflower
- **Legumes:** Lentils, chickpeas, green peas
- **Root and tuber vegetables:** Sweet potatoes, carrots, beets
- **Herbs and aromatic plants:** Moringa, parsley, cilantro

Each category offers a unique spectrum of nutrients and bioactive compounds beneficial to human health (Boeing et al., 2012; Slavin & Lloyd, 2012).

3. Nutritional Composition of Vegetables and Plants

3.1. Macronutrients Many vegetables, especially legumes, are rich sources of complex carbohydrates and plant-based proteins. They provide dietary fiber, which supports digestive health and modulates blood glucose levels (Anderson et al., 2009; Mudryj et al., 2014).

3.2. Micronutrients Vegetables supply critical micronutrients including:

- **Vitamin A:** Found in carrots and sweet potatoes (van Jaarsveld et al., 2005)
- **Vitamin C:** Abundant in bell peppers and broccoli (Zhang et al., 2006)
- **Vitamin K:** High in kale and spinach (USDA, 2020)
- **Folate:** Present in leafy greens and legumes (Bergman et al., 2021)
- **Iron and calcium:** Prominent in amaranth leaves and moringa (Mbikay, 2012; Shukla et al., 2006)

3.3. Phytochemicals and Antioxidants

Phytochemicals such as flavonoids, glucosinolates, and carotenoids have been shown to reduce oxidative stress and inflammation, playing protective roles against diseases (Liu, 2004; Liu, 2013; Martirosyan & Singh, 2015).

4. Selected Nutrient-Rich Vegetables and Plants

Here is a chart of nutrient-rich vegetables and plants along with their key nutrient values (based on average content per 100g of edible portion):

Plant/Vegetable	**Key Nutrients**	**Nutrient Values (approx.)**
Spinach (Leafy Green)	Iron, Vitamin K, Vitamin A, Folate	Iron: 2.7 mg, Vit K: 483 μg, Vit A: 9377 IU, Folate: 194 μg
Broccoli (Cruciferous)	Vitamin C, Fiber, Vitamin K, Folate	Vit C: 89 mg, Fiber: 2.6 g, Vit K: 101.6 μg, Folate: 63 μg
Carrot (Root Crop)	Beta-carotene, Vitamin A, Fiber	Beta-carotene: 8285 μg, Vit A: 835 μg, Fiber: 2.8 g
Sweet Potato (Tuber)	Vitamin A, Fiber, Manganese, Potassium	Vit A: 14187 IU, Fiber: 3 g, Manganese: 0.5 mg, Potassium: 337 mg
Lentils (Legume)	Protein, Iron, Folate, Fiber	Protein: 9 g, Iron: 3.3 mg, Folate: 181 μg, Fiber: 8 g
Chickpeas (Legume)	Protein, Fiber, Folate, Manganese	Protein: 8.9 g, Fiber: 7.6 g, Folate: 172 μg, Manganese: 1 mg
Moringa Leaves	Vitamin C, Calcium, Iron, Potassium	Vit C: 51.7 mg, Calcium: 185 mg, Iron: 4 mg, Potassium: 337 mg
Parsley (Herb)	Vitamin K, Vitamin C, Iron	Vit K: 1640 μg, Vit C: 133 mg, Iron: 6.2 mg
Kale (Leafy Green)	Vitamin K, Vitamin C, Calcium, Antioxidants	Vit K: 817 μg, Vit C: 120 mg, Calcium: 150 mg
Beetroot (Root Crop)	Folate, Manganese, Nitrates	Folate: 109 μg, Manganese: 0.3 mg, Nitrates: 250 mg

4.1. Kale (Brassica oleracea var. acephala) Kale is packed with vitamins K, A, and C, along with lutein and zeaxanthin, which support eye health (USDA, 2020; Al-Kodmany, 2018).

4.2. Spinach (Spinacia oleracea) Spinach provides iron, magnesium, and folate. It is known for its anti-inflammatory properties due to high flavonoid content (Bergman et al., 2021; Slavin & Lloyd, 2012).

4.3. Broccoli (Brassica oleracea var. italica) Rich in vitamin C, fiber, and sulforaphane, a compound with chemoprotective effects (Zhang et al., 2006; Martirosyan & Singh, 2015).

4.4. Sweet Potato (Ipomoea batatas) High in beta-carotene, fiber, and potassium. It contributes to glycemic control and gut health (van Jaarsveld et al., 2005; Anderson et al., 2009).

4.5. Moringa (Moringa oleifera) Known as a "miracle tree," moringa leaves are exceptionally rich in iron, calcium, vitamin C, and polyphenols (Mbikay, 2012; Padulosi et al., 2013).

4.6. Amaranth Leaves (Amaranthus spp.) Amaranth leaves are high in protein, vitamin C, and calcium, making them valuable in vegetarian diets (Shukla et al., 2006; Padulosi et al., 2013).

4.7. Legumes Legumes like lentils and chickpeas are excellent sources of plant protein, folate, and iron, helping to reduce cardiovascular risk (Mudryj et al., 2014; Bouis & Saltzman, 2017).

5. Role in Combating Malnutrition and Chronic Diseases

Nutrient-rich vegetables are integral to addressing global malnutrition. Their bioavailable nutrients help counteract hidden hunger and support child development (FAO, 2017; WHO, 2020; Pingali, 2015). Additionally, their fiber and antioxidant contents lower the risk of obesity, type 2 diabetes, and hypertension (Slavin & Lloyd, 2012; Liu, 2013).

6. Sustainable Cultivation and Biofortification

Vegetables such as moringa and amaranth thrive in arid climates and require fewer resources, making them suitable for sustainable agriculture (Padulosi et al., 2013; Al-Kodmany, 2018). Biofortified crops like Golden Rice and iron-rich beans have been developed to combat micronutrient deficiencies in vulnerable populations (Bouis & Saltzman, 2017; Zhu et al., 2019).

7. Challenges and Future Prospects

Despite their benefits, access to nutrient-rich vegetables remains limited in some regions. Future strategies must include education, policy support, urban farming, and the integration of these crops into national food security programs (Pingali, 2015; Gelli et al., 2016).

8. Innovative Applications and Future Perspectives

8.1. Functional Foods and Nutraceuticals Functional foods and nutraceuticals derived from plant-based sources are gaining attention for their ability to prevent and manage chronic diseases. Extracts from broccoli (sulforaphane), kale (glucosinolates), and spinach (flavonoids) are now incorporated into dietary supplements and fortified foods aimed at boosting immunity, improving metabolic health, and reducing inflammation (Martirosyan & Singh, 2015).

8.2. Biotechnology and Genetic Engineering Advanced biotechnological tools are facilitating the development of genetically enhanced crops with superior nutrient profiles. Examples include bioengineered crops like Golden Rice, rich in provitamin A, and iron-fortified beans. CRISPR-Cas9 technology has also enabled precision editing of genes responsible for nutrient biosynthesis, enhancing crop quality without compromising yield (Zhu et al., 2019; Bouis & Saltzman, 2017).

8.3. Urban Agriculture and Vertical Farming

With increasing urbanization and land constraints, innovative cultivation methods such as hydroponics, aeroponics, and vertical farming are revolutionizing how nutrient-rich vegetables are grown. These systems offer higher yields, lower water usage, and reduced dependence on pesticides, making them ideal for urban centers and resource-scarce regions (Al-Kodmany, 2018; Pingali, 2015).

8.4. Integration in School Feeding and Public Health Programs Nutrient-rich vegetables are being incorporated into school feeding programs and national nutrition initiatives to tackle childhood malnutrition and improve cognitive development. Programs in countries like India and Brazil highlight the success of integrating indigenous and locally available vegetables into daily meals for children (Gelli et al., 2016; FAO, 2017).

8.5. Future Research Directions Future research should focus on:

- Developing climate-resilient, nutrient-dense crop varieties (Padulosi et al., 2013)

- Exploring synergistic interactions between phytochemicals (Liu, 2013)
- Investigating the gut microbiome's role in mediating the health effects of plant nutrients (Martirosyan & Singh, 2015)
- Enhancing consumer awareness through food labeling and public education campaigns (WHO, 2020; Gelli et al., 2016)

Conclusion

Nutrient-rich vegetables and plants are fundamental to achieving optimal health and addressing nutrition-related challenges globally. From leafy greens to legumes, their rich nutrient profiles, coupled with protective phytochemicals, make them powerful tools in both preventative health and disease management. As we confront the dual burden of malnutrition and chronic disease, these plants offer sustainable, cost-effective, and culturally adaptable solutions (Slavin & Lloyd, 2012; Liu, 2013; Boeing et al., 2012).

The integration of innovative technologies, urban farming systems, and strategic nutrition policies can enhance access and maximize the impact of these crops. Through continued research, education, and policy advocacy, we can harness the full potential of nutrient-rich vegetables and plants to foster a healthier, more resilient global population (Pingali, 2015; Martirosyan & Singh, 2015; Zhu et al., 2019).

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WASTEWATER MANAGEMENT STRATEGIES WITH SPECIAL REFERENCE TO AGRICULTURAL RUNOFF

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ABSTRACT

Agricultural wastewater, which is produced by livestock operations, agro-industrial processes, and irrigation runoff, presents serious environmental problems since it contains pesticides, organic matter, and nutrients. In order to avoid water pollution and guarantee sustainable farming methods, effective treatment is necessary. This essay examines the different approaches used to treat wastewater, paying particular attention to supplies from agriculture. Advanced approaches including membrane filtration, engineered wetlands, anaerobic digestion, and bioremediation are presented alongside more traditional ones like primary sedimentation, secondary biological treatment, and tertiary nutrient removal. The focus is on economical and environmentally friendly solutions that are appropriate for farming and rural areas. A technique to treating agricultural wastewater that shows promise is the combination of natural treatment systems and contemporary technologies. Issues like the necessity for farmer knowledge and the variation in waste content are also covered. According to the study's findings, a mix of suitable treatment techniques can improve water reuse and support sustainable farming.

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Keywords: Agricultural wastewater, constructed wetlands, bioremediation, anaerobic digestion, nutrient removal, sustainable agriculture, membrane filtration,

INTRODUCTION

Water pollution is an escalating global concern that affects both developed and developing nations. Major contributors include urbanization, industrialization, and particularly, agriculture. It is estimated that nearly 80 percent of global municipal wastewater is discharged into water bodies without adequate treatment, and industries contribute millions of tons of heavy metals, solvents, sludge, and other pollutants each year (WWAP, 2024).

In the Indian context, the growing use of veterinary medicines—such as antibiotics, growth hormones, and vaccines—in livestock and aquaculture has emerged as a significant environmental hazard. These substances often enter aquatic ecosystems through surface runoff or leaching, contributing to the rise of antimicrobial resistance (AMR). In response, the Food Safety and Standards Authority of India (FSSAI) in 2024 imposed restrictions on certain antibiotics used in meat, milk, poultry, and aquaculture. This policy reflects increasing awareness of the pathways through which agricultural practices influence waterborne contaminants and subsequently human and ecosystem health.

Globally, agricultural pollution remains a leading cause of deteriorating water quality. Despite improvements in awareness and regulation, agricultural practices continue to contribute disproportionately to water degradation. The widespread use of synthetic fertilizers and pesticides has led to excessive nutrient loading, particularly nitrogen and phosphorus, which are recognized as

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*Corresponding author: *tiwari.anuniit93@gmail.com* major drivers of eutrophication in aquatic ecosystems (Gao et al., 2022; Zhang et al., 2021).

The issue is compounded in developing countries by insufficient wastewater treatment infrastructure. Agricultural runoff often mixes with untreated urban wastewater, creating a complex cocktail of pollutants that contaminate surface and groundwater systems (Kumar et al., 2023). The intensification of livestock and crop production has increased the discharge of nutrient-rich waste into the environment, further contributing to both chemical and microbiological pollution (Singh et al., 2020).

Veterinary pharmaceuticals are now recognized as an emerging class of contaminants. These compounds, particularly antibiotics and hormones, have been found to leach into nearby water bodies, potentially disrupting endocrine systems and fostering resistant bacterial strains (Li et al., 2021). These substances have been detected in alarming concentrations in drinking water sources and groundwater near farms (Chen et al., 2024).

Climate change is exacerbating these effects. Variability in rainfall and rising temperatures are affecting nutrient cycling, leading to sporadic pollution events such as algal blooms that cause oxygen depletion and biodiversity loss (Wang et al., 2022).

To mitigate such effects, researchers have advocated for the adoption of nature-based solutions and precision agriculture technologies. These include controlled fertilizer application using AI and sensors, as well as ecological buffers like constructed wetlands and vegetative strips that help trap nutrients and sediments (Ahmed et al., 2023; Fernández et al., 2020). Such strategies aim to reduce non-point source pollution, which remains difficult to control with conventional regulations.

Wastewater reuse and sustainable treatment methods are gaining traction as essential solutions to the twin challenges of water scarcity and pollution. Alagha et al. (2020) demonstrated that sequencing batch reactors (SBRs) are effective under varied anoxic conditions, supporting their application in water reuse. Villarín and Merel (2020) suggested a shift toward decentralized treatment systems and circular economy models. Tortajada (2020) emphasized that properly treated wastewater can help meet Sustainable Development Goals, particularly clean water and sanitation.

In India, Kamble et al. (2019) conducted life cycle assessments of municipal treatment plants, revealing trade-offs between environmental performance and economic feasibility. Fito and Van Hulle (2021) emphasized the importance of robust treatment in ensuring the safe reuse of wastewater in agriculture. Baskar et al. (2022) highlighted the need to manage spent adsorbents through regeneration and recovery, while Chojnacka et al. (2020) promoted fertigation using reclaimed water as a sustainable but technically challenging practice.

While high-income countries have made strides through stricter regulations and technological innovation, many low- and middle-income countries struggle with enforcement, funding, and infrastructure limitations. This underscores the importance of global knowledge-sharing and collaborative frameworks to address the cross-border nature of agricultural water pollution (UNEP, 2021).

Agriculture accounts for nearly 70 percent of freshwater withdrawals worldwide, making it a significant contributor to water pollution. Farms discharge large volumes of agrochemicals, organic matter, sediment, veterinary residues, and saline runoff into water systems (UNEP, 2016). In many regions, agricultural pollution has overtaken industrial and urban waste as the leading source of inland and coastal water contamination. Nitrate pollution from fertilizers, in particular, is the most widespread groundwater contaminant globally (WWAP, 2013).

Regional data reinforce this trend. In the European Union, 38 percent of water bodies are under significant pressure from agricultural pollution (WWAP, 2015). In the United States, agriculture is the primary pollution source in rivers and streams and ranks second and third in wetlands and lakes, respectively (US EPA, 2016). In China, agriculture is the main contributor to both surface and groundwater nitrogen pollution (FAO, 2013).

The pressures from agriculture stem from cropping, livestock, and aquaculture systems, all of which have expanded rapidly to meet growing food demand. Irrigated farmland has doubled in recent decades (FAO, 2014), and global livestock numbers rose from 7.3 billion units in 1970 to 24.2 billion in 2011 (FAO, 2016a). Aquaculture has increased over twentyfold since the 1980s, particularly in Asia (FAO, 2016b). This growth has been fueled by intensified use of chemical inputs, land expansion, and irrigation—all of which have increased the risk of pollution.

The livestock sector, in particular, poses serious water quality challenges. Manure and urine discharge contribute high loads of nitrogen, phosphorus, and pathogens to water systems (FAO, 2006). In addition, a new class of pollutants—veterinary drugs such as antibiotics and hormones—has emerged, with serious implications for environmental and public health. These contaminants, along with zoonotic pathogens, pose risks to drinking water quality and aquatic ecosystems (WHO, 2012).

The health consequences of agricultural water pollution are well-documented. High nitrate levels in drinking water can cause methemoglobinemia or "blue baby syndrome," which is potentially fatal in infants. Persistent pesticides, such as DDT and organophosphates, though banned in many regions, continue to be used in poorer countries and pose risks of acute and chronic toxicity. Ecosystem damage includes eutrophication, fish kills, and biodiversity loss. The economic cost is substantial—OECD countries alone incur billions of dollars annually in environmental and social damages from agricultural water pollution (OECD, 2012a).

There is a need for comprehensive, region-specific databases on pollutant loads from agriculture, especially in the Global South, to support targeted interventions.

- Limited surveillance of veterinary pharmaceuticals, hormone residues, and AMR pathogens in water sources restricts risk assessments and policy response.
- While advanced treatment and monitoring technologies exist, their implementation is constrained by weak regulatory frameworks, particularly in low-income countries.
- Although shown to be effective, ecological buffers, wetlands, and agroforestry are underutilized due to land and incentive constraints.
- Many smallholder farmers lack access to training in precision farming, waste management, and safe chemical use.
- Strategies to reduce runoff and leaching under changing climate conditions remain inadequately developed and poorly integrated into agricultural planning.

1. Agricultural Pollution

Biological and abiotic results of farming operations that harm people and their financial interests, or contaminate or degrade the environment and nearby ecosystems, are referred to as agricultural pollution. There are several possible sources of the contamination, including more diffuse, landscape-level sources (sometimes referred to as non-point source pollution) and point source water pollution (originating from a single discharge point).

The quantity and effects of these contaminants are greatly influenced by management techniques. Management strategies cover everything from housing and animal care to the application of fertilizers and pesticides in international farming operations.

Table 1: Outlines of various pollutant categories along with representative indicators.

Pollutant Category	**Pollutant Category**	**Pollutant Category**
Nutrients	Animal excrement and chemical and organic fertilizers both contain nitrogen and phosphorus, which are typically found in water as nitrate, ammonia, or phosphate.	Crops, Livestock
Pesticides	Herbicides, insecticides, fungicides, and bactericides, such as carbamates, pyrethroids, organophosphates, and organochlorine pesticides, among others (many, like DDT, are prohibited in most countries but are nonetheless used illegally and persistently; examples include	Crops
Salts	Sodium, chloride, potassium, magnesium, sulfate, calcium, and bicarbonate ions, for instance. This can be measured in water either directly as total dissolved solids or indirectly as electric conductivity.	Crops, Livestock
Sediment	Measured in water as nephelometric turbidity units or total suspended particles, particularly from pond drainage during harvesting	Crops, Livestock

Organic matter	Organic compounds like plant matter and animal feces are examples of chemical or biological oxygen-demanding substances that, during their degradation, deplete the dissolved oxygen in water.	Livestock, Aquaculture
Pathogens	indications of bacteria and pathogens, such as enterococci, fecal coliforms, total coliforms, and Escherichia coli.	Livestock
Metals	e.g., selenium, lead, copper, mercury, arsenic, and manganese	Crops, Livestock, Aquaculture
Emerging pollutants	e.g., drug residues, hormones, and feed additives	Crops, Livestock, Aquaculture

1. Sources of Agricultural Pollution

3.1 Abiotic Sources

fertilizers, pesticides, Fluoride, Cadmium, radioactive substances, additional metals, runoff from leaching and eutrophication, organic pollutants, Metals that are heavy

3.1.1 Pesticides

To manage pests that interfere with crop production, agricultural land is treated with pesticides and herbicides. Pesticides can change microbial processes, boost plant uptake of the chemical, and be poisonous to soil organisms, all of which can lead to soil pollution. The compound's distinct chemistry determines how long the pesticides and herbicides last since it influences sorption dynamics and the subsequent fate and transport in the soil environment. Animals that consume infected bugs and soil organisms may also collect pesticides. Furthermore, natural enemies of pests—that is, insects that feed on or parasitize pests—and helpful insects like pollinators may suffer greater damage from pesticides than the actual pests.

Fig 1: Aerial application of Pesticides.

When pesticides combine with water and permeate the soil, they can contaminate groundwater. This process is known as pesticide leaching. The degree of rainfall and irrigation, as well as the properties of the soil and pesticides, are related to the quantity of leaching. Leaching is more likely to occur when a water-soluble pesticide is used, when the soil has a sandy texture, when extensive watering takes place shortly after the pesticide is applied, or when the pesticide's adsorption capacity to the soil is poor. In addition to treated fields, leaching can also come from places where pesticides are mixed, where equipment used to apply them is washed, or where they are disposed of.

3.1.1 Fertilizers

Produce and other plant matter are produced with a very small percentage of nitrogen-based fertilizers. The rest is lost as runoff or builds up in the soil. The high water solubility of nitrate and the high rates of nitrogen-containing fertilizer application result in increased runoff into surface water and groundwater leaching, which pollutes groundwater. Overuse of nitrogen-containing fertilizers, whether natural or manufactured, is especially harmful because a large portion of the nitrogen that plants cannot absorb is converted to easily leached nitrate.

"Blue baby syndrome" (acquired methemoglobinemia) can be brought on by groundwater containing nitrate levels more than 10 mg/L (10 ppm). If fertilizer nutrients—particularly nitrates—leach through soil into groundwater or are carried off soil into watercourses, they can harm both human health and natural environments. Furthermore, improper fertilizer application resulted in ammonia pollution of the air.

3.1.2 Cadmium

Cadmium levels in fertilizers that contain phosphorus vary widely and can be harmful. For instance, the amount of cadmium in mono-ammonium phosphate fertilizer can range from 0.14 mg/kg to 50.9 mg/kg. This is due to the fact that the phosphate rock that is used to make them can have a cadmium content of up to 188 mg/kg (for instance, deposits in the Christmas islands and Nauru). High-cadmium fertilizer used continuously might contaminate plants and soil. The European Commission has examined limiting the amount of cadmium in phosphate fertilizers. The cadmium level is currently used by manufacturers of fertilizers that contain phosphorus to choose phosphate rock.

3.1.3 Fluoride

Fluoride concentrations in phosphate rocks are high. As a result, soil fluoride concentrations have increased due to the extensive use of phosphate fertilizers. It has been discovered that the likelihood of fluoride toxicity to livestock that consume polluted soils is more concerning than fertilizer-induced food contamination because plants do not acquire much fluoride from the soil. Fluoride's effects on soil microbes may also be a cause for concern.

3.1.4 Radioactive elements

Both the fertilizer production process and the amounts of radioactive elements in the parent material affect the fertilizers' radioactive content, which varies widely. The quantities of uranium-238 in phosphate rock can vary from 7 to 100 pCi/g, while those in phosphate fertilizers can range from 1 to 67 pCi/g. Concentrations of uranium-238 in soils and drainage waters can be many times higher than normal when large annual rates of phosphorus fertilizer are applied. Nevertheless, these increases have very little effect (less than 0.05 mSv/y) on the danger to human health from food contamination by radinuclides.

3.1.5 Other metals

Lead, arsenic, cadmium, chromium, and nickel are among the hazardous metals found in steel industry wastes that are recycled into fertilizers due to their high zinc content, which is necessary for plant growth. Mercury, lead, and arsenic are the most prevalent harmful substances found in this kind of fertilizer. It is possible to eliminate these potentially dangerous contaminants, but doing so comes at a hefty expense. Although there are many highly pure fertilizers on the market, Miracle-Gro and other highly water-soluble fertilizers with blue dyes are probably the most well-known. The plant nursery industry uses these extremely water-soluble fertilizers, which are substantially less expensive in larger packages than in retail settings. Granular garden fertilizers prepared with high-quality ingredients are also available at low-cost retail stores.

3.1.6 Leaching, runoff, and eutrophication

Fig 2: Eutrofication.

Important plant nutrients can be obtained from the nitrogen (N) and phosphorus (P) that are supplied to agricultural land (via synthetic fertilizers, composts, manures, biosolids, etc.). Excess N and P, however, can have detrimental effects on the ecosystem if improperly controlled. Nitrate pollution of groundwater can result from an excess of nitrogen (N) provided by both synthetic fertilizers (as highly soluble nitrate) and organic sources such manures (whose organic N is converted to nitrate by soil microbes). Blue infant syndrome can be brought on by drinking water tainted with nitrate. In addition to surplus P from these same fertilizer sources, eutrophication can happen downstream as a result of an overabundance of nutrients, creating dead zones, which are anoxic places.

3.1.1 Organic contaminants

Numerous minerals included in manures and biosolids are used as food by both humans and animals. Recycling soil nutrients is made possible by the practice of reusing such waste materials on agricultural land. The problem is that in addition to nutrients like carbon, nitrogen, and phosphorus, manures and biosolids may also contain pollutants including personal care products (PPCPs) and medications.

Both people and animals eat a huge diversity of PPCPs, each of which has a distinct chemistry in both terrestrial and aquatic habitats. Because of this, not all have had their influence on the quality of the land, water, and air evaluated. To determine the amounts of different PPCPs present, the US Environmental Protection Agency (EPA) has analyzed sewage sludge from wastewater treatment facilities around the US.

3.1.2 Heavy metals

Fertilizers, organic wastes like manures, and industrial byproduct wastes are the main sources of heavy metals (such as lead, cadmium, arsenic, and mercury) in agricultural systems. Certain farming practices, including irrigation, can cause the naturally occurring selenium (Se) in the soil to build up. This may lead to selenium concentrations in downstream water reservoirs that are harmful to people, animals, and wildlife. Named after the Kesterson Reservoir in the San Joaquin Valley (California, USA), which was designated a toxic waste dump in 1987, this mechanism is called the "Kesterson Effect."

3.1.3 Soil erosion and sedimentation

Due to intense management or ineffective land cover, agriculture significantly contributes to soil erosion and sediment deposition. An estimated 6 million hectares of productive land experience an irreversible decline in fertility annually as a result of agricultural soil degradation. Water quality is impacted by sedimentation, or the buildup of sediments in runoff water, in a number of ways. The transport capacity of rivers, streams, ditches, and navigation channels can all be reduced by sedimentation. Additionally, it may reduce the amount of light that reaches the water, which could have an impact on aquatic biota. Fish eating patterns may be disrupted by the turbidity that results from sedimentation, which could have an impact on population dynamics. Additionally, sedimentation influences the movement and buildup of contaminants, such as phosphorus and other types of pesticides.

3.2 Biotic sources:

Agricultural activities generate both nonpoint and point source pollution, significantly affecting water quality and greenhouse gas emissions. Nonpoint sources such as sediment and nutrient runoff, along with pesticides, enter water bodies diffusely through rainfall or irrigation. Point sources, including animal waste, piggery discharge, and effluents from milking parlours, slaughterhouses, and vegetable washing, release concentrated pollutants. Effective manure management practices like composting, anaerobic digestion, and solid-liquid separation, alongside sustainable methods such as biopesticides and biological control, are essential to mitigate environmental risks and promote circular agriculture.

3.2.1 Greenhouse gases from fecal waste

According to the Food and Agriculture Organization (FAO) of the United Nations, cattle worldwide are directly or indirectly responsible for 18% of anthropogenic greenhouse gas emissions. According to this data, livestock emissions were higher than transportation-related emissions.

3.2.2 Biopesticides

Biopesticides are insecticides made from natural sources, such as plants, animals, microbes, and certain minerals. Because biopesticides are safe to handle, typically have a short residual period, and do not significantly harm beneficial invertebrates or vertebrates, they can be used as an alternative to conventional pesticides to minimize overall agricultural pollution. Although there are some worries that biopesticides can harm non-target species populations, the EPA regulates biopesticides in the US. The government doesn't need as much information to register the use of biopesticides because they are less dangerous and have less of an impact on the environment than other pesticides. According to the United States Department of Agriculture's National Organic Program guidelines for organic crop cultivation, a variety of biopesticides are allowed.

The establishment of these alien species may also be aided by ecological disturbances brought on by farming activities. Weeds may also spread as a result of contaminated equipment, animals, and feed, as well as infected crop or pasture seed.

3.2.3 Manure treatment:

Composting: It is a solid manure management technique that uses either the solids from a liquid manure separator or solid manure from bedded pack pens. Composting can be done in two ways: actively and passively. Active composting involves periodic churning of the manure, while passive composting does not. Because of partial breakdown and reduced gas diffusion rates, passive composting has been shown to have fewer greenhouse gas emissions.

Solid-liquid separation: For simpler management, manure can be mechanically divided into a solid and liquid part. The solid portion (15–30% dry matter) can be composted, exported, or used as stall bedding. The liquids (4–8% dry matter) can be readily dispersed over crops using pump systems.

Biological control:

Organizations like the International Organization for Biological Control of Noxious Plants and Animals, the Commonwealth Institute of Biological Control, the United States Department of Agriculture/Agricultural Research Service (USDA/ARS), and the European Biological Control Laboratory support global search for possible biocontrol agents. Prior to introduction, quarantine and in-depth study of the organism's possible effectiveness and ecological effects are necessary to prevent agricultural pollution. Attempts are made to colonize and spread the biocontrol agent in suitable agricultural environments if authorized. Ongoing assessments of their effectiveness are carried out.

Anaerobic digestionIt involves employing microorganisms to biologically treat liquid animal feces in an air-free environment, which encourages the breakdown of organic materials. The garbage is heated with hot water to speed up the production of biogas. In addition to methane gas that may be burned directly on the biogas stove or in an engine generator to generate heat and electricity, the residual liquid is nutrient-rich and can be applied to fields as fertilizer. Approximately 20 times more potent than carbon dioxide, methane is a greenhouse gas that, if improperly managed, can have serious adverse impacts on the ecosystem. The most effective way to reduce the smell of manure management is to treat waste anaerobically.

Anaerobic digestion is also used in biological treatment lagoons to break down sediments, although it happens considerably more slowly. Unlike the heated digestion tanks, lagoons are maintained at room temperature. Lagoons do not function effectively in many northern U.S. climates because they need broad land expanses and substantial dilution flows. Reduced odor is another advantage of lagoons, and biogas is produced available for electricity and heating.

Studies have shown that aerobic digestion systems lower greenhouse gas emissions. In addition to facilitating producer adoption of environmentally better systems to replace existing anaerobic lagoons, GHG emission reductions and credits can assist offset the higher installation costs of cleaner aerobic technologies.

1. Characteristics of Wastewater

Agrochemical and pesticide wastewater has significant environmental issues because of its high levels of total dissolved solids (12000–13000 mg/L), biochemical and chemical oxygen demands (6000–7000 mg/L, 2000–3000 mg/L), and extremely alkaline pH (12–14). Wastewater from pesticides stands out due to its toxicity and environmental persistence.

2. Evolution of wastewater treatment Technologies

Before wastewater is applied to land, reused, or reintroduced into a body of water, it undergoes a multi-stage process called wastewater treatment. Reducing or eliminating organic debris, sediments, nutrients, pathogens, and other contaminants from wastewater is the aim.

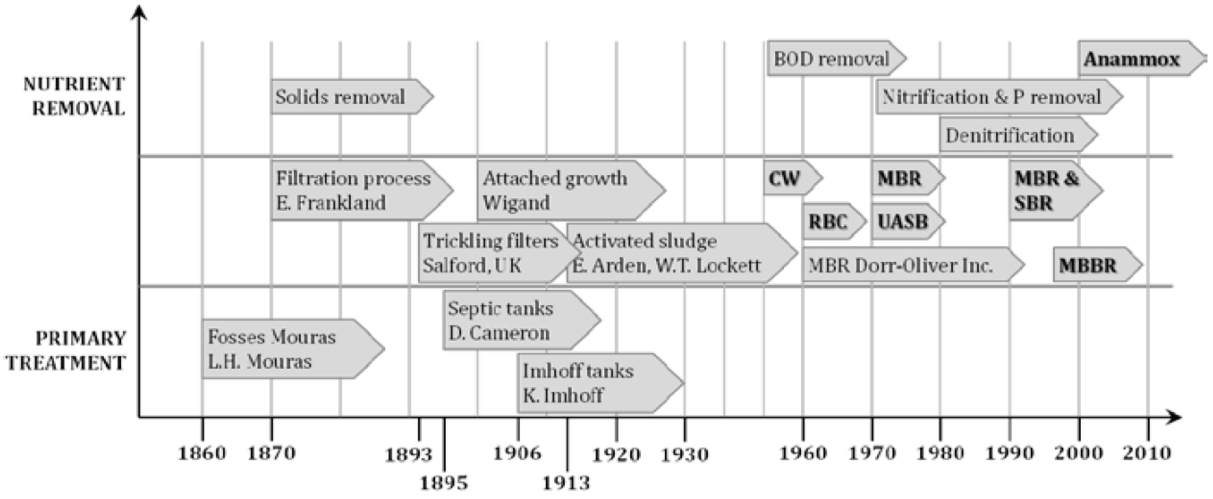

Fig. 3 : Evolution of wastewater treatment (Lofrano & Brown, 2010).

1. Conventional Treatment Technologies:

6.1 Preliminary Treatment:

Initial Care The wastewater is filtered for any particles and separated during the initial treatment. Grit chambers, bar screens, and comminutors are used to filter out debris such as sticks, toys, rags, leaves, sand, food particles, and gravel. The debris that has been separated is subsequently dumped in a landfill.

6.2 Primary Treatment:

Initial Care The wastewater is filtered for any particles and separated during the initial treatment. Grit chambers, bar screens, and comminutors are used to filter out debris such as sticks, toys, rags, leaves, sand, food particles, and gravel. The debris that has been separated is subsequently dumped in a landfill.

6.3 Secondary Treatment:

Aerobic methods are used to remove any leftover organic matter and suspended particles from the first treatment effluent. When aerobic microorganisms are present, organic matter breaks down into inorganic molecules like CO2, NH3, and others as part of aerobic biological treatments. Anaerobic and aerobic treatment technologies are the two categories into which secondary treatment technologies fall, and each is described in detail.

6.3.1 Aerobic Treatment Methods

Although aerobic biological wastewater treatment by itself is ineffective at removing nutrients from wastewater, it usually results in reductions of 20–30% in total phosphorus and total nitrogen (Nieuwstad et al., 1988). Adding a precipitation chemical to the activated sludge process—a procedure known as simultaneous precipitation—is the conventional way to enhance phosphorus removal.

Ferrous and ferric salts (such as ferrous sulfate and ferric chloride) and aluminum salts (such as aluminum sulphate) are the most frequently occurring precipitation chemicals. Rearranging the biological treatment stage (adding anaerobic and anoxic stages) to favor the growth of particular phosphorus-accumulating bacteria can improve biological phosphorus removal. The most common method for removing nitrogen from wastewaters is biological nitrification-denitrification.

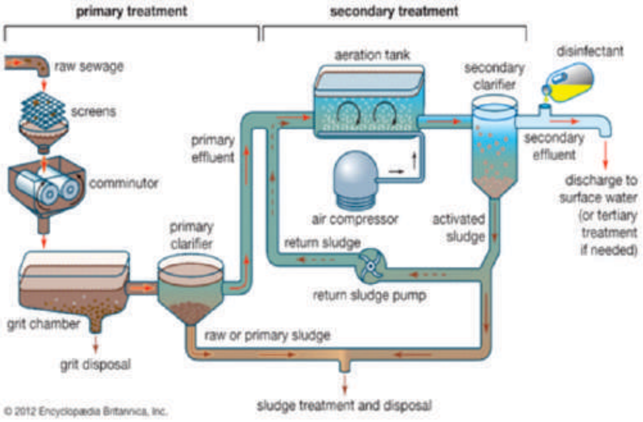

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Fig. 4: Aerobic Treatment Methods (Activated Sludge Process).

6.1.1 Anaerobic Treatment Methods

UASB reactor treatment:

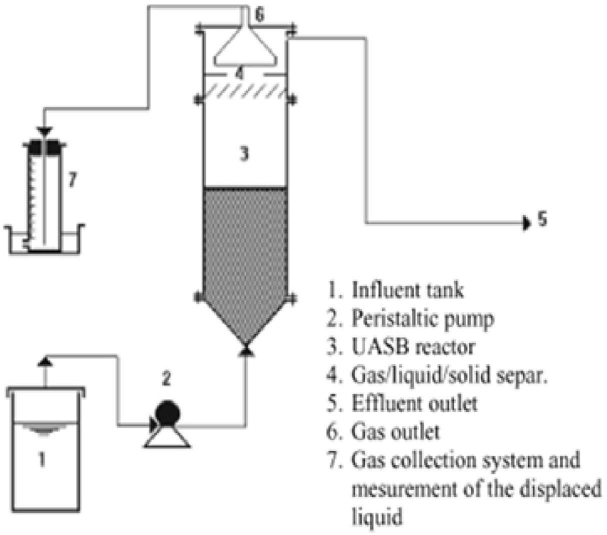

Fig. 5: Schematic diagram of UASB rector in Laboratory scale.

The basic advantages of a UASB reactor treatment unit are:

- It is economically practical,
- requires little land area for building, and uses little energy for operation.
- It is very easy to use, requires little experience, and produces a lot of sludge.
- When the reactor is operating properly, the odor output is controlled.

Anaerobic Attached Film Expanded Bed Reactor:

When there is no air present, wastewater is treated using this procedure. The following principle underlies its operation.

1. Hydrolysis, 2. Acidogenesis, 3. Acetogenesis
   4. Methanogenesis

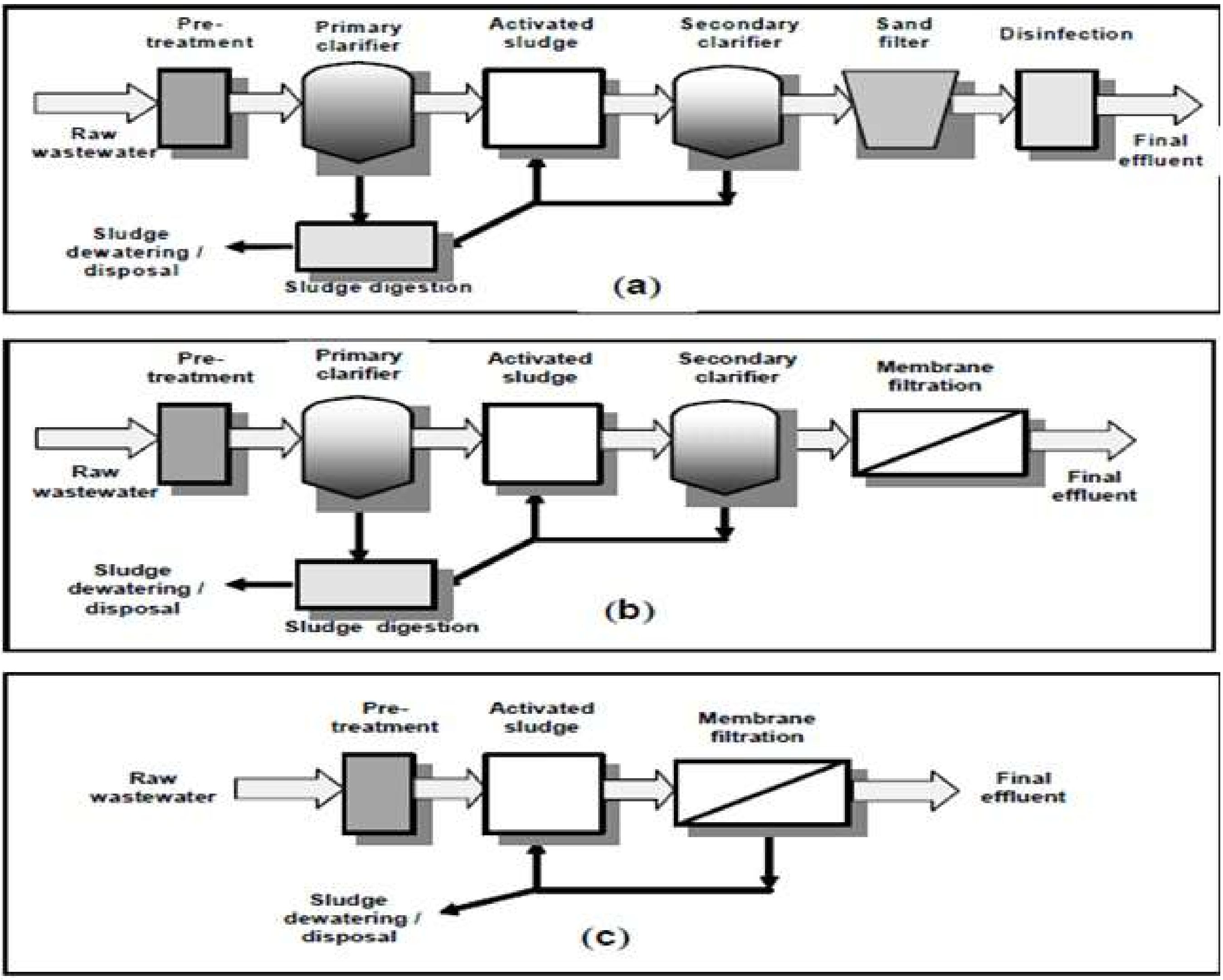

Fig 6: Flowcharts for (a) conventional wastewater treatment; (b) conventional treatment including tertiary membrane filtration; and (c) membrane bioreactors.

6.1.1 Advanced wastewater Treatment Technologies:

Advanced therapeutic technologies include tertiary, physicochemical, and combined biological physical treatment. Following traditional wastewater treatment, tertiary (or advanced) treatment procedures can further enhance the wastewater effluent's quality. Organic particles, suspended particulates, synthetic organic compounds, enteric bacteria, and inorganic ions like phosphate and sulphate are usually eliminated from secondary effluents using tertiary treatment procedures.

For tertiary wastewater treatment, a variety of methods have been employed, such as post-precipitation, rapid sand filtration (RSF), slow sand filtration (SSF), dissolved air flotation (DAF), microfiltration, ultrafiltration, ion exchange, reverse osmosis, chemical oxidation, and carbon adsorption. The goal of treatment, wastewater quality and flow rate, the compatibility of various operations and processes, the ease of operating the process, the space requirements, and the system's economic and environmental viability are some of the factors that influence the applicability and choice of treatment process.

Biological, physicochemical, and hybrid technologies are a few of the more sophisticated wastewater treatment methods. Systems for biologically enhanced phosphorous removal (BEPR) and intermittently decanted extended aeration lagoons (IDEAL) for nitrogen removal are examples of biological treatment technology. These create the groundwork for further treatment procedures but do not create water that may be reused. Deep bed filtration and membrane filtration are examples of physiochemical processes.

Both of these techniques yield reused water and offer the benefits of simplicity and low sludge production, respectively. Membrane reactors, which combine physiochemical and biological processes, are classified as hybrid treatment methods since they offer the aforementioned advantages all at once.

Physicochemical Process of Treatment: Physicochemical treatment appears to be a feasible alternative for treating agricultural wastewater. Alum, poly aluminum chloride (PAC), ferrous sulphate (FeSO4), and polyelectrolyte are a few common coagulates that were chosen for treatment based on the research review. Alum, poly aluminum chloride (PAC), and ferrous sulphate (FeSO4) can be used separately or in conjunction with polyelectrolyte.

Membrane Bioreactor Technology (MBR): Physicochemical treatment appears to be a feasible alternative for treating agricultural wastewater. Alum, poly aluminum chloride (PAC), ferrous sulphate (FeSO4), and polyelectrolyte are a few common coagulates that were chosen for treatment based on the research review. Alum, poly aluminum chloride (PAC), and ferrous sulphate (FeSO4) can be used separately or in conjunction with polyelectrolyte.

Rather, low-pressure membrane filters like reverse osmosis (RO), nanofiltration (NF), and ultrafiltration (UF) or microfiltration (MF) are used to separate the effluent from the activated sludge. Both sidestream and submerged configuration models of MBR are available; however, the submerged design is utilized for treating municipal wastewater. Membrane reactors could be used to eliminate ibuprofen, diclofenac, estrone (E1), and 17α-ethinylestradiol (EE2) (Kruglova et al. 2016).

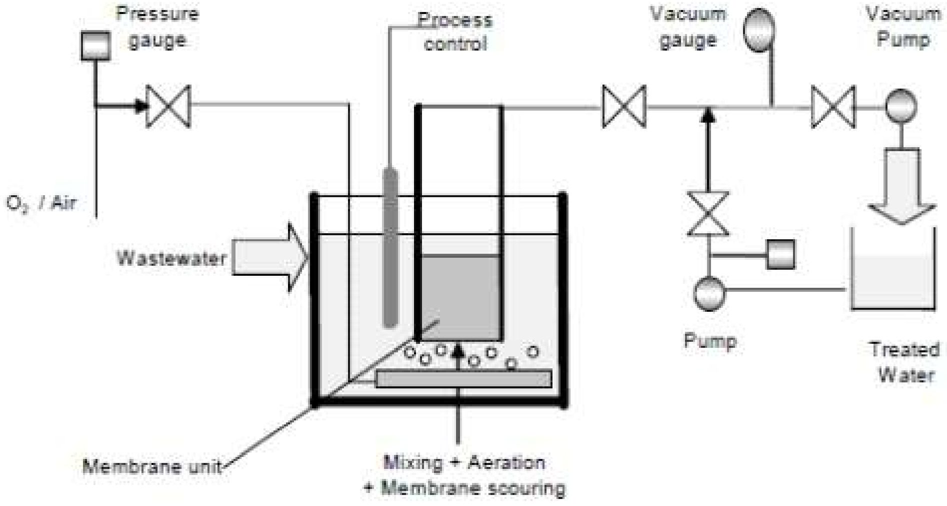

Fig 7: Schematic of integrated (submerged) MBR.

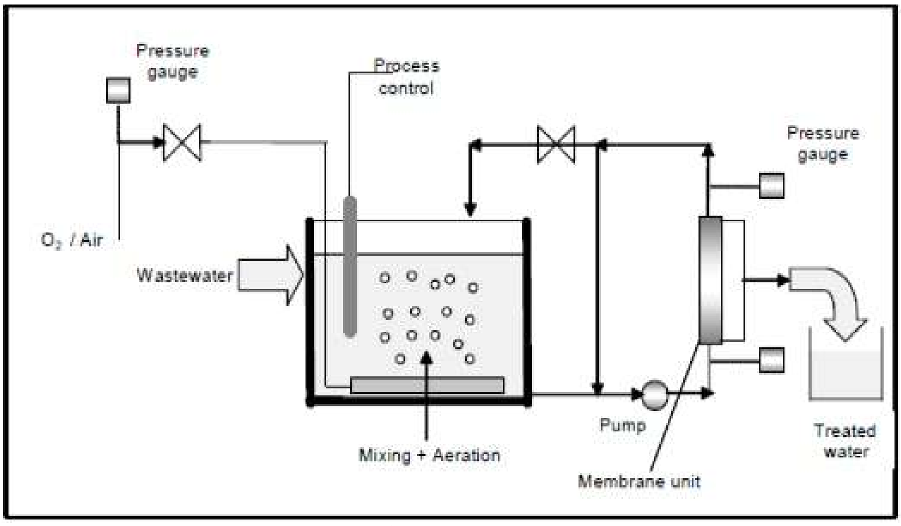

Fig 8 : Schematic of recirculated (external) MBR.

Wastewater disinfection: By putting the water through a different disinfection procedure after secondary or tertiary wastewater treatment, enteric bacteria can be further eliminated from the wastewater effluents. Chemical and physical treatments are the two categories of water disinfection techniques. Chlorine gas (Cl2), hypochlorite (sodium hypochlorite, NaOCl; calcium hypochlorite, Ca(OCl)2), chloramines, chlorine dioxide (ClO2), ozone (O3), and peracetic acid (PAA) are examples of chemical disinfectants. The most crucial physical disinfection technique for water and wastewater is ultraviolet (UV) irradiation, which can dramatically reduce the number of enteric microorganisms in primary, secondary, or tertiary wastewater effluents, hence lowering microbial burdens in receiving natural waterways.

Peracetic acid was shown to be an effective disinfectant against intestinal bacteria in laboratory-scale disinfection tests using a synthetic test media. A 10-minute contact duration and 1.5–3 mg/l of PAA produced roughly 2-3 log (99–99.9%) E. Coli,

Enterococcus faecalis, and Salmonella enteritidis reductions: PAA demonstrated high disinfection efficacy against enterococci and total coliforms in pilot-scale disinfection of municipal secondary and tertiary effluents. The quantities of these indicator bacteria were generally decreased below 500 CFU/100 ml TC and 100 CFU/100 ml EC, and in many cases, to <10-100 CFU/100 ml. PAA doses of 2–7 mg/l and 27 min contact time produced around 3 log reductions of these bacteria.

Previous studies have reported approximately similar PAA disinfection efficiencies against enteric bacteria (Collivignarelli et al., 2000; Stampi et al., 2001; Wagner et al., 2002; Caretti and Lubello, 2003). However, the inactivation of enteric bacteria has been achieved in some studies using slightly higher PAA doses (around 10 mg/l) (Lazarova et al., 1998; Liberti and Notarnicola, 1999). The variations in reactor design, water quality, and operating conditions among the various trials may account for the necessity for larger PAA dosages.

The results also suggest that a combined PAA/UV disinfection treatment may achieve synergistic benefits and improved disinfection efficiency.

1. Nanotechnology in Wastewater Treatment:

One of the best and most cutting-edge methods for treating wastewater is nanotechnology. The success of nanotechnology can be attributed to a number of factors, including the extremely high interacting, absorbing, and reacting capacities of nanoparticles, which result from their small size and enormous surface area. They can even be combined to create colloidal solutions with aqueous suspensions. Because of their small size, nanoparticles are able to conserve energy. Given the strong technological demand for nanoparticle-based water treatment, its cost should be controlled in accordance with market competitiveness (Crane and Scott 2012).

Recent developments in a variety of nanomaterials, including molecularly imprinted polymers (MIPs), bioactive nanoparticles, nanosorbents, biomimetic membranes, nanostructured catalytic membranes, and nanocatalysts, have been applied to the elimination of harmful metal ions, disease-causing microorganisms, and inorganic and organic solutes from water.

7.1 Nanocatalysts

Because of their large surface area, nanocatalysts exhibit great catalytic activity. Because they accelerate the rate of degradation and improve the reactivity of pollutants, nanocatalysts are employed to treat wastewater. Nanocatalysts such as semiconductor materials, zero-valence metals, and bimetallic nanoparticles can degrade environmental contaminants like azo dyes, halogenated aliphatics, polychlorinated biphenyls (PCBs), organ chlorine pesticides, halogenated herbicides, and nitro aromatics (Xin et al. 2011).

Silver (Ag) nanocatalysts, N-doped TiO2 catalysts, and ZrO2 nanoparticles are all highly effective at breaking down microbiological pollutants. The reusability of these nanocatalysts is an added benefit (Shalini et al. 2012). The removal of Cr (IV) from wastewater is accomplished using TiO2-AGs.

The altered TiO2 nanoparticles cause a change in their absorption band from the ultraviolet to the visible spectrum. As a result, TiO2-AGs are highly effective at eliminating Cr (IV) from wastewater. Halogenated organic compounds (HOCs) and other pollutants are difficult to break down and call for sophisticated nanocatalytic processes.

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Consequently, the HOCs undergo biodegradation in the treatment plant after first being treated with Pd nanocatalysts. The reaction's reducing agent might be either hydrogen or formic acid, depending on the degree of contamination. The utilized nanocatalyst is easily removed from the reaction mixture and then reused because of its ferromagnetism (Hildebrand et al. 2008).

Palladium-incorporated ZnO nanoparticles (Khalil et al. 2011) and WO3 nanocatalysts (Khalil et al. 2009) could be used to eliminate E. coli cells. Marcells et al. (2009) used palladium nanoparticles (PdNPs) to investigate the reduction of Cr (IV) to Cr (II). The combination of nanocatalysts with nanosorbents could result in the combined sorption and degradation of the pollutants. By employing tetrahydrofuran treatment to activate the silver and amidoxime fiber nanocatalysts, organic dye remediation can be accomplished (Zhi et al. 2010). ZnO nanoparticles doped with Sm (samarium) could effectively remove the monoazo dye Acid Blue 92 (AB92) (Khataee et al. 2016).

7.2 Nanosorbents

The United States and Asia are the primary markets for the use of nanosorbents in water treatment procedures. Their sorption capability for various pollutants is high and selective. One benefit of the nanosorbents is their ability to be eliminated from the treatment area, which lowers toxicity. Regenerated nanosorbents are also more affordable and widely used in industry.

Nanosorbents are removed from the treatment sites using a variety of techniques, including ion exchangers, magnetic forces, cleaning chemicals, and many more. To create magnetic nanoparticles, particular ligands with particular affinities are placed on top of the particles (Apblett et al. 2001). Nanosorbents, such as poly (aniline-co-5-sulfo-2-anisidine), can be used to extract silver ions as silver nanocrystals (Li et al. 2010).

Nanoclays are used to remove phosphorus and hydrocarbon stains. Magnetic nanosorbents can be used to remove organic pollutants from wastewater (Campos et al. 2012). Excellent mechanical strength, chemical resistance, high specific surface area, and outstanding adsorption capacity are all attributes of carbon-based nanosorbents. According to Lee et al. (2012), they are employed to treat water that contains nickel. Mesoporous silica, chitosan, and dendrimers are employed as nanosorbents to remove heavy metal ions from contaminated water because of their distinct chemical and physical characteristics (Vunain et al. 2016).

7.3 Bioactive Nanoparticles

Chlorine-free biocides known as bioactive nanoparticles are becoming a new tool for wastewater treatment. Gram-positive and gram-negative bacteria as well as bacterial spores can be effectively killed by magnesium oxide nanoparticles and cellulose acetate (CA) fibers that have embedded silver nanoparticles (Nora and Mamadou 2005). Due to their nontoxicity, biological compatibility, and ease of modification with functional groups, mesoporous silica nanoparticles may also find application in wastewater treatment procedures (Gunduz et al. 2015). Both microbial and pathogen detection as well as diagnostics will benefit from current and developing nanotechnology techniques for microbial pathogen detection.

7.4 Molecularly Imprinted Polymers (MIPs)

The process of free radical polymerization to a crosslinker is known as molecular imprinting. One of the best new methods for biological, environmental, and pharmacological applications is molecularly imprinted polymers, or MIPs. According to Hande et al. (2015) and Mattiasson (2015), they are inexpensive, straightforward, durable, selective, and nonbiodegradable. The semi-covalent, covalent, and non-covalent binding of the functional groups of appropriate monomers to the template gives MIPs access to the particular binding sites.

The MIPs are excellent absorbents and have a highly selective nature as a result of this alteration. According to Caro et al. (2006), it is utilized for wastewater treatment and the identification of contaminants, even at extremely low concentrations. The MIPs' ability to be selective gives them a significant edge over other methods. Nano-MIPs are created using the mini-emulsion polymerization process to adsorb micropollutants from hospital effluent.

The nano-MIPs have a particle size range of 50–500 nm. After treatment, nano-MIPs might be coated with magnetic core to be removed from the wastewater (Tino et al. 2009). MIPs encapsulated in nanofibers utilizing the electro-spinning technique are utilized to treat the pollution produced during wastewater treatment. MIPs were used to create a sensor that measures the amount of phosphate in wastewater. Unlike traditional techniques like colorimetry, the proposed sensor was easily portable, had a detection limit of 0.16 mg P/L, and did not require sample filtration for monitoring (Warwick et al. 2014). Cd (II), Pb (II), As (V), Hg (II), Ag, Au, Pt, Pd, acitindes, and lanthanides could all be eliminated using MIPs (Hande et al. 2015).

7.5 Nanostructured Catalytic Membranes (NCMs)

The advantages of nanostructured catalytic membranes (NCMs) are their capacity for optimization, short catalyst contact time, homogeneous catalytic sites, ease of industrial scale-up, and the ability to support sequential reactions.

According to Hyeok et al. (2009), membranes exposed to UV radiation and nanostructured TiO2 films aid in the degradation of organic pollutants, physical separation of water contaminants, anti-biofouling activity, and inactivation of microorganisms. Numerous membranes, including chitosan, polyvinylidene fluoride (PVDF), cellulose acetate, polysulfone, and many more, could immobilize the metallic nanoparticles. According to Jian et al. (2009), the immobilized metallic nanoparticles have several benefits, including low agglomeration, high reactivity, decreased surface passivation, and organic portioning.

Palladium acetate and polyetherimide have been used to create nanocomposite films, and the effectiveness of the water treatment process has been demonstrated by research into the particular interactions between hydrogen and the Pd-based nanoparticles. By annealing the precursor film under various circumstances utilizing both the in situ and ex situ methods, the metal nanoparticles were produced within the matrix.

This gives designers the chance to create materials with adjustable qualities (Clemenson et al. 2010). According to Hongwei et al. (2012), the N-doped "nutlike" ZnO nanostructured materials demonstrated antibacterial action, generated clean water with a steady high flux, and effectively eliminated water pollutants by boosting photodegradation activity.

8. Conclusions

Protecting the environment and public health requires efficient wastewater treatment, especially in agricultural areas where water contamination is becoming a bigger problem. Although traditional techniques such as filtration, sedimentation, and biological treatments provide fundamental answers, they frequently fail to satisfy contemporary reuse requirements. Innovative approaches to getting rid of complex pollutants including dyes, heavy metals, and organic contaminants are provided by advanced technologies like membrane bioreactors, nanosorbents, nanocatalysts, molecularly imprinted polymers, and bioactive nanoparticles. Wastewater management is made more effective, economical, and sustainable by combining classic and cutting-edge methods. Issues including system upkeep, financial viability, and public awareness need to be resolved if the advantages of these approaches are to be fully realized. Making wastewater a useful resource for sustainable agriculture and human well-being requires a multidisciplinary approach backed by technology, policy, and community involvement.

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ANTICANCER POTENTIAL OF AYURVEDIC MEDICINAL PLANTS: A REVIEW

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ABSTRACT

Plants are reservoirs for novel chemical entities and provide a promising line for research on cancer. Plants have been used for medical purposes since the beginning of human history and are the basis of modern medicine. Research suggests some herbal medicine may help people cope with cancer symptoms and side effects of cancer treatment. Several herbs may help control the side effects of conventional cancer treatment. For example, research done in humans suggests that mistletoe reduces the side effects of chemotherapy in lung cancer patients. Turmeric contains a compound know as curcumin, which research shows may be safe to combine with gemcitabine in cancer patients. Most chemotherapeutic drugs for cancer treatment are molecules identified and isolated from plants or their synthetic derivatives. The selected and careful use of this plant may definitely in antiangiogenic therapy and thus in cancer management. Plant derived anticancer agents are effective inhibitors of cancer cells lines, making them in high demand. Exploitation of these agents needs to be managed to keep up with demands and be sustainable. Effort has been made through this review to highlight the role of medicinal plants in cancer therapy.

No. of Pages: 5 **References: 12**

Keywords: Cancer, medicinal plants, diagnosis, therapy and herbs.

INTRODUCTION

Cancer is the world's most serious public health problem. Over the previous decades, it was responsible for 18.1 million cases and almost 10 million deaths. Cancer is generally considered to comprise more than 100 diseases, each characterized by uncontrolled growth and spread of abnormal cells. It is resulting from a chain of multiple genetic changes causing a lots of typical growth controls, leading to unregulated growth, lack of differentiation, apoptosis, genomic instability and metastasis. There are several internal (inherited mutation, hormones, immune condition and mutation that occur from metabolism) and external (tobacco, chemicals, radiation and infectious organisms) factors that cause cancer (Anon., 2012).

There are mainly four types of cancer according to body tissue from which they develop

1. **Carcinoma:** arises from epithelial cells lining lung, liver, breast, prostate, pancreas, etc
2. **Sarcoma:** develops from the cell of muscles, nerves and bones
3. **Lymphoma:** arises from cells in lymph glands
4. **Leukemia:** it is the cancer developing from blood forming tissue

I. IMPORTANCE OF MEDICINAL PLANTS IN ANTI-CANCER THERAPY

The world health organization (WHO) has listed 21,000 plants, which are used for medicinal purpose around the world. Among these 2,500 species are in India, out of which 150 species are used commercially on a fairly large scale. India is the largest producer of medicinal herbs and is called as "botanical garden of the world". Natural Products, especially plants, have been used for the treatment of various diseases for thousands of years.

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Terrestrial plants have been used as medicines in Egypt, China, India and Greece from ancient time and an impressive number of modern drugs have been developed from them. The first written records on the medicinal uses of plants appeared in about 2600 BC from the Sumerians and Akkaidians.

The "Ebers Papyrus", the best known Egyptian pharmaceutical record, which documented over 700 drugs, represents the history of Egyptian medicine dated from 1500 BC. The Chinese *Materia Medica,* which describes more than 600 medicinal plants, has been well documented with the first record dating from about 1100 BC. Documentation of the Ayurvedic system recorded in Susruta and Charaka dates from about 1000 BC.

Plants have a long history of use in the treatment of cancer. Hartwell, in his review of plants used against cancer, lists more than 3000 plant species that have reportedly been used in the treatment of cancer. The search for anti-cancer agents from plant sources started in earnest in the 1950s with the discovery and development of the vinca alkaloids, vinblastine and vincristine, and the isolation of the cytotoxic podophyllotoxins. These discoveries prompted the United States National Cancer Institute (NCI) to initiate an extensive plant collection program in 1960. This led to the discovery of many novel chemotypes showing a range of cytotoxic activities, including the taxanes and camptothecins (Kaur *et al.,* 2011).

Search for new medicine is a continuous endeavour to combat cancer. Many plants, around us, have been reported to possess anti-cancerous property (Nirmala *et al.,* 2011). There is an acute need to fight cancer with herbs. Tropical regions of world have a high amount of diversity in medicinal plants and these plants provide chemical foundation to pharmaceutical research in cancer therapy. In this seminar, the clinical research works on anticancer property of some tropical medicinal plants is covered.

II. CANCER GLOBALLY

Every year, cancer is diagnosed in 10 million people and accounts for 7.1 million (12.5 % of global total) deaths. It is second to cardiovascular diseases as a cause of death. Global cancer rates could increase by 50% to 15 million by 2020 (WHO). This alarming increase is due to smoking and adoption of unhealthy lifestyles. In United States, every one out of four people die because of cancer.

III. DIAGNOSIS OF CANCER

There are mainly three ways (therapies) to cure or to treat cancer. 'Surgery' is the oldest known treatment among the cancer treatments. In this, the growing cancer cells or tumors are removed by surgery. Cancer can be cured by this method only if it has not metastasized. Cancer can be cured by radiation which is known as 'radio therapy'. In this therapy cancer cells are treated and killed with high energy rays (X, gamma, and UV rays). The rays not only kill cancer cells but also affect the surrounding normal cells and may cause side effects. 'Chemotherapy' is the safer, effective treatment for cancer. In this method, toxic drugs are used with main focus to trigger the apoptotic programme. These drugs act on cancer cells by inhibition, blocking effect, anti progression, etc. The drugs may be from natural sources or synthetic sources or both. Natural sources include plants, microbes, minerals, etc. with plants as major source.

Table 1: Some anti-cancerous plants used in cancer therapy.

Plant species	**Experiments on various cancer cells**	**Mechanism of action**
Catharanthus roseus	Leukemias, lyphomas and lung cancer	Mitotic block
Berberineeris sp.	Breast, prostrate and lung cancer	Apoptosis
Gloriosa superba	Leukemia	Anti-mitotic
Curcuma longa	Colon and pancreatic cancer	Unknown
Zingiber officinalis	Breast and lung cancer	Un known
Andrographis paniculata	Colon cancer	Apoptosis
Palargonium graveolens	Breast cancer	Un known
Boesenbergia pandurata	Breast and colon cancer	Apoptosis and cell cycle arrest
Ruta graveolens	Colon & prostate cancer	Cell cycle arrest
Ocimum sanctum	Lung cancer	Inhibition of invasion
Magnolia officinalis	Prostate cancer	Not known
Achyranthes aspera	Pancreatic cancer	Apoptosis
Solanum nigrum	colon and breast cancer	Apoptosis
Artemisia vulgaris	Prostate & colon cancer	Apoptosis

1. *Solanum nigrum* and *Artemisia vulgaris*

Solanum nigrum is commonly called as black nightshade and belongs to family solanaceae. Berries are the economic parts in this. It is mainly known for its antipyretic and diuretic properties and has a long history of use in the treatment of inflammation, edema, mastitis, cirrhosis of liver in oriental medicine (Nawab *et al*., 2011). *Artemisia vulgaris* is a member of asteraceae family. Artemisin is the active principle in this. In traditional medicines, it is used against intestinal worms, nervous and spasmodic affections, asthma, sterility, functional bleeding of the uterus and menstrual complaints (Tan *et al.,* 1998).

Components of the plants viz. *Artemisia vulgaris*, *Cichorium intybus*, *Smilax glabra*, *Solanum nigrum* and *Swertia chirayta* have been used in traditional folk medicine to treat various human ailments; however, the anticancer properties have not been elucidated. Nawab *et al*. (2011) evaluated the anticancer properties of aqueous extracts of these plants against various human prostate, breast and colorectal cancer cells. The Aqueous extracts of plant parts like inflorescence (*Artemisia vulgaris*), seeds (*Cichorium intybus*), rhizome (*Smilax glabra*), berries (*Solanum nigrum*) and whole plant (*Swertia chirayata*) were considered for assessment of anticancer properties.

2. ***Boesenbergia pandurata***

Members of the Zingiberaceae family have been reported to possess both antioxidant and anti-inflammatory activity. Such antioxidant and anti-inflammatory compounds have often been shown to be effective as anticancer agents (Surh, 1999). *Boesenbergia pandurata* or *Kaempferia pandurata,* commonly called as chinese ginger or finger root, is a member of zingiberaceae family. The chemical constituent (active principle) present in this is panduratin. The fresh rhizomes are used in cooking and traditional medicine to treat diarrhoea, dermatitis, dry cough, and mouth ulcers (Hyene, 1987).

3. ***Ruta graveolens***

Ruta graveolens is a medicinal and culinary plant that is native to the Mediterranean region of southern Europe and northern Africa. Widely grown in different parts of the world, this herb has historically been in use since the ancient times. Its documented therapeutic uses include the treatment of inflammatory conditions, eczema, ulcers, arthritis, fibromyalgia, antidote for venoms, insect repellent, and as an abortifacient (Fadlalla *et al*., 2011). They examined the potency of an extract from *R.graveolens* on cancer cell lines. The study shows that this extract has potent anticancer activity, exhibited through strong anti-proliferative and anti-survival effects on cancer cells.

1. Achyranthes aspera

The leaves and roots of Achyranthes aspera (Family Amaranthacea) is used as a therapeutic agent for cancer in Ayurvedic medical system. However, its anti tumor properties have not been validated by current scientific approaches, thus remain anecdotal.

Methanol extract of A. aspera leaves (LE) have cellular specific, dose and time dependent cytotoxicity to human cancer cells in vitro with reduced toxicity to normal cells. Some genes involved in tumor metastasis and angiogenesis were regulated by LE. However the in vivo efficacy of LE is not known (Subbarayan et al., 2010).

5. *Curcuma longa*

Docetaxel (Doc) has demonstrated extraordinary anticancer effects in vitro and in vivo against a variety of tumors, including lung, ovaries, breast cancers, etc. As recommended by the National Comprehensive Cancer Network, Doc is considered as first-line chemotherapy for the treatment of non-small cell lung cancer (Annon., 2011). However, chemotherapeutics sometimes lead to severe toxicity at their therapeutic dose even though the response rate of single drug chemotherapy remains 20% (Baker *et al*., 2008). In order to achieve higher antitumor efficacy and minimize the emergence of resistance, to search novel chemotherapy sensitizers become the focus in the field of cancer therapy. Curcumin (Cum), the principal polyphenolic curcuminoid, obtained from the turmeric (*Curcuma longa*) rhizome, has been reported for its potential chemopreventive and chemotherapeutic activity in a series of cancers. For example, in vitro and in vivo experiments showed Cum could inhibit skin squamous cell carcinoma growth and block tumor progression (Phillips *et al*., 2011).

6. *Ocimum sanctum*

Ocimum sanctum Linne (OS), commonly known as 'Holy basil' has attracted in the Ayurvedic system of medicine (Singh et al., 1996). It has been known that anti-oxidant enzymes play crucial roles in metastatic tumor growth (Llovet and Bruix, 2008). Kim *et al*. (2010) investigated the potential of ethanol extract of OS (EEOS) as a potent anti-metastatic candidate for lung cancer in vivo and in vitro.

2. *Withania somnifera*

The alcoholic extract of the roots of the Indian medicinal plant, *Withania somnifera* Dunal was found to inhibit the growth of Sarcoma 180 and Ehrlich ascites carcinoma in mice. The major component in the extract responsible for the antitumor effect was found to be the withanolide, withaferin A (WA), a steroidal lactone.

8. Magnolia officinalis

Magnolol, a hydroxylated biphenyl compound isolated from the stem bark of the Chinese herb Magnolia officinalis (Magnoliaceae), is commonly used to treat acute pain, cough, anxiety, and gastrointestinal disorders in Easter Asia. Magnolol also has been reported to exhibit anticancer activity, including induction of apoptosis in cultured HepG2 human hepatoma and Colo205 colon cancer cells.

CONCLUSION

To conclude, Medicinal plants maintain the health and vitality of individual and also cure various diseases including cancer without causing toxicity. Natural products discovered from medicinal plants have played an important role in treatment of cancer. Plants possess good immunomodulatry and antioxidant properties leading to anticancer activity. The tropical world is an important, major source of medicinal plants. Anticancer compounds from many plants have been found significantly active against various cancer cells in animal models. Further research on precise molecular mechanisms and targets for cell growth inhibition may lead to better treatment of cancer and it will be helpful to exploit novel anticancer drugs from medicinal plants.

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REVIEW ON NPK SENSOR USED ON SOIL

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ABSTRACT

This review article discusses the importance of soil fertility in agriculture and the role played by NPK (Nitrogen, Phosphorus, and Potassium) in plant growth. It explores a few NPK sensor technologies utilizing electrochemistry, optics, capacitors, and biosensors for soil monitoring in real time. The article mentions developments with IoT-based smart farming, augmenting precision agriculture as well as eco-sustainability. Various studies and various sensor models have been read and studied to confirm their accuracy and effectiveness as well as their limitations. Future studies focus on sensor longevity, AI training, and multi-sensor fusion for increased precision farming.

No. of Pages: 9 **References: 36**

Keywords: NPK sensors, Soil nutrient monitoring, Precision agriculture, Smart farming , IoT in agriculture, Electrochemical sensors , Optical soil sensors , Capacitive soil sensors , Biosensors , Real-time soil analysis, Fertilizer optimization , Soil fertility management , Sensor calibration , Wireless sensor networks (WSN) ,AI in agriculture.

INTRODUCTION

As the main substrate for plant growth and nutrient absorption, soil is the cornerstone of agriculture. Its fertility directly affects agricultural output and establishes the general health of crops. Essential macronutrients, organic matter, helpful microbes, and a balanced pH level are all found in healthy soil, and they all support the best possible plant growth. The three main macronutrients that are essential for soil health and plant growth are nitrogen (N), phosphorus (P), and potassium (K). To maintain soil fertility and guarantee excellent crop yields, these nutrients—collectively known as NPK—are frequently added through fertilizers. Each of these macronutrients has a distinct function in soil fertility and plant physiology, and balanced growth depends on the soil's ideal concentration of each:

As a crucial building block of proteins, amino acids, and chlorophyll, nitrogen (N) is necessary for photosynthesis, leaf development, and vegetative growth. For the best plant growth, soil should contain between 20 and 50 mg/kg (parts per million, or ppm) of nitrogen, while the exact amount needed depends on the type of crop. While too much nitrogen can create an imbalance and encourage too much foliage at the expense of fruit or grain production, too little nitrogen causes stunted development and yellowing of the leaves.

Phosphorus (P): A key component of ATP (adenosine triphosphate), phosphorus is essential for energy transfer in plants. It encourages the growth of roots, flowers, and seeds. For the majority of crops, the optimal soil phosphorus concentration is between 10 and 20 mg/kg (ppm). However, because phosphorus tends to interact with soil minerals and reduce plant accessibility, its availability is frequently restricted. Early plant growth and increased resistance to environmental stress depend on effective phosphorus management.

Potassium (K): Potassium is essential for water homeostasis, enzyme activity, and disease and

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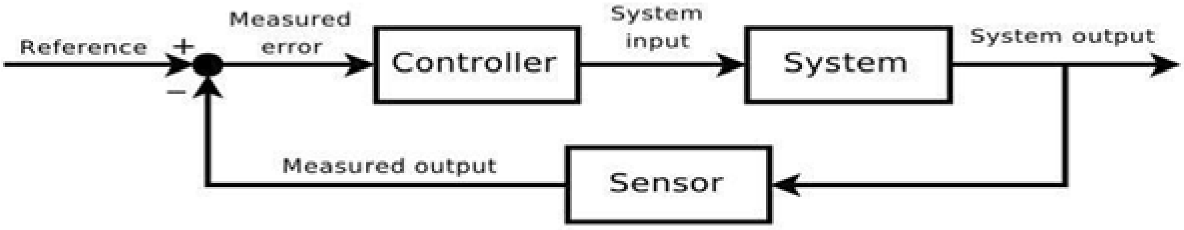
*Corresponding author: *tondharepr@rknec.edu* environmental stressor resistance, including drought. It promotes nutrient uptake, fortifies plant cell walls, and raises crop quality overall. Depending on the needs of the particular crop, the necessary potassium content in soil is typically between 100 and 200 mg/kg (ppm).

For sustainable farming methods and maximum crop yield, it is essential to keep a balanced ratio of these nutrients in the soil. However, real-time monitoring is required because traditional soil testing techniques are frequently labor-intensive and time-consuming.

NPK sensors have been created for real-time soil fertility monitoring in order to improve fertilizer application and handle the issues of nitrogen imbalance. Farmers can apply fertilizer more intelligently thanks to these sensors' accurate assessments of nutrient amounts. By limiting nutrient runoff and soil degradation, they help to improve crop yield and environmental sustainability by preventing excessive or insufficient fertilization.Electrochemical sensors – Employ ion-selective electrodes to determine and measure the concentration of specific ions of nitrogen, phosphorus, and potassium in the soil.

Optical sensors – Use spectroscopic methods like near-infrared (NIR) and fluorescence spectroscopy to measure light absorption patterns and calculate nutrient content.Capacitive and dielectric sensors – Detect changes in soil permittivity, which are related to ion concentrations, and thus reflect soil moisture and nutrient levels. Biosensors – Employ biological elements such as enzymes or microorganisms to facilitate highly specific detection of NPK components through biochemical reactions. Modern agriculture is changing as a result of precision farming methods combined with NPK sensors. These sensors maximize agricultural yields, lower expenses, and optimize resource use by enabling site-specific fertilization. Furthermore, NPK sensors can be included into automated soil monitoring systems thanks to developments in Internet of Things (IoT) technology, which expands the potential of smart farming.

Analyzing the function of NPK in soil fertility, developments in NPK sensor technology, and their uses in contemporary agriculture are the goals of this review study. This study intends to offer important insights into effective soil nutrient management strategies by combining recent advancements and technological breakthroughs. The significance of reviewing the papers for implementing it on hardware for future studies. This is also beneficial for farmers such as Increased crop yield , Cost-effectiveness , Environmental Sustainability and integration with Smart Farming.



The above block diagram shows precision agriculture can use this closed-loop control system and to ensure ideal soil nutrient levels, the controller modifies fertilizer application based on real-time NPK sensor data. The controller receives feedback from the sensor's continuous monitoring of soil fertility, reducing variations from the target nutrient levels. This automated system encourages sustainable farming methods, improves crop growth, and uses less excess fertilizer.

LITERARURE REVIEW

Mohanty, S. [1] et al proposed that Smart agriculture uses IoT, AI, and fog computing to enhance the utilization of resources and yield of crops. This study suggests a fog-assisted recommendation system for forecasting soil moisture and NPK content using hybrid machine learning algorithms on the IFogSim platform. The method improves the quality of the soil, irrigation efficiency, and stability and decreases soil erosion. It also finds use in the mining industry for structural protection and slope stabilization.

Musa, P. et al [3] proposed that the study developed a digital monitoring system for measuring NPK , and soil humidity using Arduino Nano and JXCT NPK sensor. Findings indicate accuracy of 80% in detecting NPK and optimal soil moisture in three sawahs. Analysis of soil content of fertilizer elements indicates fluctuation between sawahs, with sawah 2 exhibiting highest nitrogen and kalium levels. The system is expected to assist farmers to manage land more efficiently and enhance rice productivity.

Musa, P. et al proposed thatthis research investigates how Wireless Sensor Networks (WSNs) can be utilized in NPK macronutrient monitoring to boost agricultural yields. The research looks into types of sensors, where sensors are placed, wireless communication, and transmission rate for precision agriculture. The research identifies an error rate of 8.47% in NPK sensor readings relative to laboratory results, signifying dependable performance. Future breakthroughs will seek to maximize yields and facilitate the cultivation of crops across varied points of location.

Kumar, L. L. et al [4] proposed that this project designs a soil NPK sensor with an Arduino board and OLED display to monitor nitrogen, phosphorus, and potassium in real-time. The sensor supports farmers in optimizing soil fertility and productivity by providing accurate monitoring of nutrients. Measurement is done through a probe, processed on the Arduino, and read for visibility. The technology supports precision agriculture, providing an easier and quicker alternative to manual soil testing techniques.

Adhikary et al [5]proposed thatthis research introduces a new neural network method to enhance the precision of agricultural parameter estimates from sensor measurements, accounting for external variability. The model performs better than conventional techniques in predicting soil moisture and nutrient content under varied conditions. Multi-site real-time data confirm its utility for precision agriculture. Future work will incorporate deep learning and edge computing to scale up and improve real-time response.

Fauziah et al [6] proposed that This research investigates the potential of IoT in soil nutrient analysis for smart agriculture, with existing challenges and potential future applications. A bibliometric review of 395 papers found gaps in mass validation and standard agricultural practices. Results indicate the majority of nutrient management systems are still in the prototype phase without plant testing validation. Future work on IoT-based NPK sensors seeks to increase agricultural efficiency and farmer accessibility.

Amado et al [7] proposed that This research employs cutting-edge sensors, such as an ISFET pH sensor, soil moisture sensor, and RGB color sensor, to improve soil nutrient tracking. Coupled with an Arduino MEGA 2560, these sensors report real-time soil characteristics. Machine learning processes over 300 soil samples to estimate nitrogen, phosphorus, and potassium content. This method enhances precision agriculture by maximizing soil management and nutrient management.

Cheruvu et al [8] proposed that his article describes the implementation of IoT-based smart agriculture for increasing productivity and resource use. The system monitors real-time soil nutrients, temperature, humidity, and moisture through sensors. A recommendation system recommends the most suitable crops based on sensor readings, allowing farmers to make decision-making easier. This efficient and easy-to-implement system optimizes farm methods for food requirements in the future.

Ivan Lionel et al [9] states that this research tests the precision and specificity of sensors in determining soil NPK nutrient levels in accurate fertilization. Analyses with various NPK compounds found the sensor not very specific, reading unintended components. The regression analysis indicated high correspondence ($R^2 \approx 1$) due to dependence on the electroconductivity method. The sensor did not also distinguish between various NPK fertilizer concentrations, which demonstrates the necessity for better measurement methods. In January 2020, Akriti Jain et al [10] proposed that this study employs a TCS3200 color sensor to measure nitrogen (N), phosphorus (P), and potassium (K) content in soil for better fertility control. The sensor examines light absorption and reflection to conclude nutrient levels, with the information being processed by a NodeMCU microcontroller. In contrast to conventional liquid-based NPK kits, this process operates directly on solid soil samples for improved suitability. The system is designed to advance future farming by allowing accurate and affordable nutrient control.

Paper Title	**Sensor Type**	**Measurement Principle**	**Calibration Method**	**Limitations**
Sachin Chandravadan Karad's [11]	Optical-electrical, Wireless, NMR-based	Optical sensing, Wireless IoT monitoring, NMR-based spectroscopy	Field calibration through LED-based detection	High cost of NMR sensors, Wireless connectivity issues
Munezero Alphonse et al [12]	IoT-Enabled Soil Sensors	ML-based Fertilizer Prediction	AI-based optimization	Model performance depends on data quality
Misbah et al [13]	Remote Sensing (Hyperspectral, Multispectral)	Imaging spectroscopy for soil and crop nutrient mapping	Machine learning-based calibration	High computational requirements
Sana Tatli et al [14]	Electronic Nose (MOS Gas Sensors)	VOC emissions analyzed with statistical models	Multiple regression models (PLSR, PCR, MLR)	Less accurate for P and K, affected by plant metabolic variations
Darmawan et al [15]	Electrical (Capacitive & Conductive)	Conductivity and Capacitance correlation with NPK levels	Linear regression analysis	Affected by soil moisture levels, requires combination of multiple parameters
R. Madhumathi et al [16]	Color Sensor, Photodetectors	Colorimetry	MATLAB-based calibration	Limited accuracy due to environmental factors
Akande et al [17]	pH Sensor, Soil Moisture Sensor	pH-based NPK Approximation	pH-NPK Correlation Chart	Accuracy depends on pH estimation
Potdar et al [18]	Optical (Spectroscopy, Colorimetry)	Reflectance, Absorption, and Transmission Spectroscopy	Comparison with standard lab methods	Environmental factors affect accuracy

HaristianPratama et al [19] states that this research employs an NPK sensor with NodeMCU to sense nutrients in soil and report data to ThingSpeak for convenient monitoring. The system assists citrus seedling farmers in maximizing growth by offering real-time nutrient testing. In a test, wet soil was found to contain more nutrients, with the sensor attaining 90% accuracy.

Bhatnagar et al [20] states thatthe proposed study is on a wireless system to measure real-time soil NPK levels, obviating the lag associated with conventional lab analysis. It enables farmers to read soil nutrients directly on their Android mobile phone. This ensures no nutrient shortages and lessened possible economic loss.

Reis et al [21] proposed that this research assesses the evolution of NPK sensors for precision agriculture based on an analysis of 95 patent documents. Results indicate that 66% of sensors are applied in both soil and bio-management, with China dominating patent filings (96%), especially in Jiangsu. The study emphasizes the importance of innovation in maximizing fertilizer use and crop yields.

Madhumathi et al [22] states that precision agriculture leverages IoT and colorimetry to analyze soil nutrients and optimize fertilizer application. A fuzzy expert system with Mamdani inference rules recommends precise nutrient quantities, with data processed in MATLAB and sent to ThingSpeak. This system enables farmers to monitor soil health via a mobile app, promoting efficient green farming.

Tolentino et al [23] states thatthis research develops a digital single-probe sensor to simultaneously monitor soil NPK, temperature, moisture, and pH. Using electrical conductivity and resistivity, the probe determines nutrient levels, with reagents enhancing accuracy. A Wi-Fi module enables real-time monitoring, with the device showing a 12% error in soil fertility assessment.

Jain et al [24] proposed thatthis study employs a TCS3200 color sensor to measure soil NPK content through light reflection and absorption analysis of solid soil samples. The reflected light is converted into frequency signals by the sensor, which are then processed by a NodeMCU microcontroller for nutrient evaluation. This approach provides a more practical and affordable solution compared to liquid-based NPK kits for precision agriculture.

Dacay et al [25] states this research enhances the "NPK-lyzer," an optical transducer device that measures soil NPK content with LEDs and a photodiode sensor. Experimentation revealed its reliability in meeting Department of Agriculture laboratory results, detecting low nutrient content in soil. An app on a smartphone allows users to scan and track soil nutrient information easily.

Phong et al [26] statesthis research mimics nutrient distribution in farm soils with soil electrical conductivity (EC) fluctuations simulated by a convection-diffusion equation. COMSOL software precisely forecasts ion transfer from NPK fertilizers, with RMSE ranging from 0.001 to 0.048. The model helps optimize fertilizer application to reduce environmental footprint.

Nair et al [27] proposedthis research investigates the application of MEMS-based cantilever beam sensors for NPK nutrient detection in soil via localized heating due to light absorption. The sensor has high sensitivity and miniaturization into optoelectronic devices. The method helps determine soil fertility for better crop development.

Paper Title	**Sensor Type**	**Measurement Principle**	**Calibration Method**	**Limitations**
HaristianPratama et al [19]	NPK Soil Sensor	Measures soil nutrient content and transmits data via IoT	Requires manual calibration for accuracy	Limited battery life of IoT devices
Bhatnagar et al [20]	Electrochemical (ISFET, ISE)	Ion absorption & electrochemical reactions	Comparison with soil nutrient standards	Short lifespan of sensors, need for frequent calibration
Reis et al [21]	Various (Optical, Electrochemical, Wireless)	Patent mapping study on existing NPK sensors	Not applicable	Lack of standardization in sensor technology
Madhumathi et al [22]	Colorimetric sensor	Light transmission and detection for NPK concentration measurement	Uses fuzzy logic-based inference for calibration	Colorimetric analysis may be affected by soil texture and external factors
Tolentino et al [23]	Single Probe NPK Sensor, pH Sensor	Electrical Conductivity	Direct calibration with soil samples	12% error in soil fertility detection
Jain et al [24]	Optical (Color Sensor)	Light absorption and reflection using color sensor TCS3200	Standard absorption wavelengths comparison	Accuracy affected by soil conditions
Dacay et al [25]	Optical (LED-Photodiode System)	Optical transducer with wavelength detection	Comparison with Department of Agriculture soil lab dat	Limited to qualitative nutrient assessment

Phong et al [26]	Electrical Conductivity (EC) sensor	Simulation of ion movement in soil using EC variation	Validation through experimental monitoring of soil EC	Does not directly measure NPK, relies on EC correlation
Nair et al [27]	MEMS Sensor	Miniaturized sensor for detecting NPK levels based on microelectromechanical technology	On-site calibration with standard soil samples	Sensitivity to environmental variations, initial calibration required

Coutinho et al [28] states this research analyzes the effect of soil sample preparation on NPK content analysis through Vis-NIR and Mid-Infrared spectroscopies. Vis-NIR spectroscopy demonstrated improved predictive performance with drying temperature and soil particle size not having a significant impact. Yet, high prediction errors would restrict its application in variable-rate fertilizer application in precision agriculture.

Monteiro-Silva et al [29] states this work investigates a small, modulated sensing system based on UV-Vis spectroscopy and optical fibers to measure NPK in fertilizing water. Severe spectral interference was addressed using an AI self-learning algorithm, which provided robust nutrient prediction. The results validate real-time NPK monitoring for micro-irrigation systems.

Nameesha Chauhan et al [30] states this study examines soil macronutrients and the impact of *Azadirachta indica* extract as an organic fertilizer. The extract enhances the fertility of the soil, reduces the amount of nitrogen runoff, and reduces the use of chemical fertilizers. Electrochemical sensors quantify nutrient content, allowing for sustainable agriculture.

Masrie et al [31] states this project establishes an optical sensor-based system for detecting soil macronutrients (NPK) through LED transmission and photodiode detection. The intensity of the nutrients is determined by their light absorption, and signal amplification for measurement. Results show absorption response voltages of 32.0V for Nitrogen, 4.6V for Phosphorus, and 19.8V for Potassium.

Liu et al [32] states new MEMS-based chip-level colorimeter was designed for high-accuracy NPK detection in soil. It has a low-cost, compact design with reduced error, surpassing commercial colorimeters. This technology improves precision agriculture and soil monitoring networks.

Yusof et al [33] statesthis research investigates spectroscopy for quick soil macronutrient analysis with a Deuterium-Halogen light source and an Ocean Optic spectrometer. Absorbance values of N, P, and K were measured in various soil samples, determining peak wavelengths for each of the nutrients. Future research will focus on creating a low-cost LED-based optical system for soil spectroscopy.

Ramane et al [34] says that the color sensor in the form of a fiber optic is utilized to inspect the nitrogen (N), phosphorus (P), and potassium (K) levels in the soil based on its color. It informs whether they are in high, medium, low, or absent quantity. This assists farmers in using only the required fertilizers, thus making the soil healthier and crops improved.

Sørensen et al [35] statesthat portable NMR sensor is created for online analysis of nitrogen (N), phosphorus (P), and potassium (K) in animal manure. Based on a 1.5 T Halbach magnet, it measures the most important nutrients directly, avoiding rough estimates or time-consuming laboratory tests. The sensor gives precise data, comparing well with industrial laboratory measurements.

SV, M. G., &Galande et al [36] statesan advanced wireless sensor network (WSN) is developed to monitor agricultural field soil nutrient (NPK), pH, temperature, and humidity. WSN is applied to assist farmers with optimal fertilization and irrigation using the provision of real-time data from WiFi sensor nodes. This improves the utilization of resources, prevents over-fertilization, and supports increased crop production.

Paper Title	Sensor Type	Measurement Principle	Calibration Method	Limitations
Coutinho et al [28]	Vis-NIR, Mid-Infrared Spectroscopy	Spectroscopy-based soil fertility analysis	Standardized spectroscopic calibration	High prediction error limits practical application
Monteiro-Silva et al [29]	Optical (UV-Vis Spectroscopy)	Absorption spectra with AI-based correction	Self-learning AI algorithm for spectral interference correction	High spectral interference, low P and K accuracy in conventional models
Nameesha Chauhan et al [30]	Electrochemical	Ion-selective electrode (ISE) & Ion Selective Field-Effect Transistor (ISFET)	Flow Injection Analysis (FIA) for electrochemical sensing	Response time limitations, environmental dependencies
Masrie et al [31]	Optical (LED-Photodiode System)	Light absorption by nutrients using LEDs and photodiodes	Tested with varying optical path lengths	Requires optimization of LED-photodiode distance
Liu et al [32]	Optical (Colorimeter)	Beer-Lambert's Law	Standard solutions (20 ppm)	Ambient light interference, potential signal loss
Yusof et al [33]	Spectroscopy-based sensor	Light absorption at specific wavelengths for NPK detection	Uses Deuterium-Halogen light source and Ocean Optic spectrometer	Limited to non-agriculture soil; high-cost spectrometer
Ramane et al [34]	Optical (Fiber Optic Sensor)	Colorimetric measurement of aqueous soil solution using fiber optic probe	Standard color chart comparison	Limited by soil sample preparation and environmental factors
SV, M. G., & Galande et al [36]	Wireless Sensor Network (WSN)	Uses multiple sensors for detecting soil parameters	Requires periodic recalibration of soil sensors	Connectivity issues in remote areas, potential sensor drift
Sørensen et al [35]	Nuclear Magnetic Resonance sensor	Uses 14n,17o,31p&39k nmr for direct detection of ammonium N,total P & K	No user side calibration required	Sensitivity challenges with quadrupolar nuclei,large magnet requirement

CONCLUSION

This review summarizes the strengths and weaknesses of some NPK soil sensors in terms of their performance, durability, and IoT connectivity. Highest Accuracy: Electrochemical sensors (ISE, ISFET) have high accuracy but need frequent calibration, while optical sensors (spectroscopy, colorimetry) provide fast, non-destructive measurements but are affected by soil content.

Most Durable: Capacitive and conductivity sensors are durable and long-lasting, yet biosensors have a limited lifespan even though they possess better selectivity. Ideal for IoT & AI: Though electrochemical and optical sensors are suitable for smart agriculture, WSNs provide for large-scale real-time monitoring. To realize maximum precision agriculture and environmental sustainability, upcoming research must target improving sensor durability, enhancing AI calibration, and integrating multi-sensor networks.

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NANO IONIC FORMULA BIOSTIMULANT FOR ACCELERATED GROWTH AND YIELD OF PECHAY

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ABSTRACT

This study aimed to verify the efficiency of Essegro Nano Ionic Formula Biostimulant on pechay (Brassica rapa), particularly on its growth and yield performance. The study was conducted at Apokon, Tagum City, with a duration of 2 months from December 2022 to February 2023. A Randomized Complete Block Design (RCBD) was used as the experimental design which was composed of six treatments, and replicated three times. The treatments were: (T1) Control, (T2) RR of inorganic NPK fertilizer based on soil analysis, (T3) RR of inorganic NPK + 0.5 rr of Essegro Nano Ionic Formula Biostimulant, (T4) RR of inorganic NPK + rr of Essegro Nano Ionic Formula Biostimulant, (T5) RR of inorganic NPK + 1.5 rr of Essegro Nano Ionic Formula Biostimulant, and (T6) rr of Essegro Nano Ionic Formula Biostimulant. Data on growth and yield components were gathered and analyzed using Analysis of Variance (ANOVA) and differences between treatments were compared using the Honest Significant Difference (HSD) Test. Based on the results of the study, the growth and yield performance of pechay were significantly affected by Essegro Nano Ionic Formula Biostimulant in terms of root length, plant height, fresh weight, leaf length and width and pechay yield but not the number of leaves. Results showed that T2= RR of inorganic NPK fertilizer based on soil analysis got the longest root length among treatments. Hence, Essegro Nano Ionic Formula Biostimulant did not influence the root length of pechay. The (T4) RR of inorganic NPK + rr of Essegro Nano Ionic Formula Biostimulant increased the fresh weight of pechay up to two times than the (T1) control and (T6) RR of inorganic NPK + rr of Essegro Nano Ionic Formula Biostimulant. Also, (T4) RR of inorganic NPK + rr of Essegro Nano Ionic Formula Biostimulant had the widest leaf which are significantly higher by 33% than the (T1) control and (T6) RR of inorganic NPK + rr of Essegro Nano Ionic Formula Biostimulant. The leaf length of pechay in (T4) RR of inorganic NPK + rr of Essegro Nano Ionic Formula Biostimulant and (T3) RR of inorganic NPK + rr of Essegro Nano Ionic Formula Biostimulant were significantly longer than that of the control (T1) by 35%. Highest height of pechay was observed in (T3) RR of inorganic NPK + rr of Essegro Nano Ionic Formula Biostimulant yet comparable to the rest of the treatments using HSD test. The yield of pechay was increased up to three times in (T4) RR of inorganic NPK + rr of Essegro Nano Ionic Formula Biostimulant and (T5) RR of inorganic NPK + 1.5 rr of Essegro Nano Ionic Formula Biostimulant which than the control (T1). Essegro Nano Ionic Formula Biostimulant therefore increased the growth and yield performance of pechay

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Keywords: Pechay, Nano Ionic, Biostimulant, Growth, Yield, Brassica rapa.

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INTRODUCTION

Pechay (*Brassica napus* L.) belongs to the Brassiceae family and is one of the most known vegetables in the Philippines. It is also known as one of the oldest green vegetables in Asia. It therefore plays an important role in the Philippines economy as well as in the nutrition of the Filipino people. Pechay is used mainly for its immature, but fully expanded tender leaves (http://www.darfu4b.da.gov.ph/pechay.html). As reported by Siemonsma & Piluek (1994), the crop is considered the most consumed leafy vegetable in the Philippines and contributes a very good income provider for farmers due to its short duration harvesting. This crop can be harvested 30-45 days after planting, the seedling foundation of this crop strongly affects performance as it contributes to almost half of the duration in cropping.

From 2019 to 2021, an average increase of 0.9 percent was noted in the production of pechay. From 47.30 thousand metric tons in 2019, it went up to 47.50 thousand metric tons in 2020 and increased further to 48.12 thousand metric tons in 2021. The average production of pechay was 47.64 thousand metric tons during the period (PSA 2022). About 86.3 percent of the country's total Chinese pechay production came from the Cordillera Administrative Region. Central Visayas came next with 7.0 percent share. Northern Mindanao, Davao Region and the rest of the country had a combined share of 6.7 percent (PSA 2019). The crop is considered the most consumed leafy vegetable in the Philippines and contributes a very good income provider for farmers due to its short duration harvesting. This crop can be harvested 30-45 days after planting, the seedling foundation of this crop strongly affects performance as it contributes to almost half of the duration in cropping (Siemonsma & Piluek 1994). Hence, a considerate effort to sustain vegetable production through efficient fertilization techniques is a wise alternative.

Types and levels of fertilizer applied to crops are very important in crop production and play an important role in cropping systems. Relying on inorganic or chemical fertilizers is a major constraint due to its prohibitive cost though identified as an important factor in meeting the food requirements of a growing population (Bandera, 2020). According to Ojeniyi (2002) there are certain advantages of inorganic fertilizers which makes them a potent candidate to enhance agricultural productivity. There is no need for direct decomposition as the nutrients in mineral fertilizers are relatively high, and the release of these nutrients is quick. Inorganic fertilizers increase the growth rate and plant's overall productivity more rapidly. There is abundant evidence that inorganic fertilizers can improve crop yield significantly. Nowadays, nanotechnology has been used in many agricultural fields such as production, processing, storing, packaging and transport of agricultural products (Mousavi and Rezai 2011; Ditta 2012). Fertilizer derived from nanotechnology has started to attract attention in agriculture. Nanotechnology can have a profound impact on energy, the economy and environment, by improving fertilizer products. Nanofertilizer can be encapsulated inside nanomaterials, coated with a thin protective polymer film, or delivered as particles or emulsions of nanoscale dimensions (DeRosa et al. 2010). Roshdy and Refaai (2016), revealed that when compared to the usage of conventional fertilizer, the usage of nano-fertilizer that was put to the soil boosted the production of date palms as well as their growth.

Prior studies using various fertilizers and foliar supplements have been tested to maximize the growth and yield of various crops (Magbalot-Fernandez et al. 2024, 2020; Pauya et al. 2024; Fernandez et al. 2023, 2015; Fernandez & De Guzman 2021; Magbalot-Fernandez & De Guzman 2022, 2019; Fernandez & Agan 2021; Magbalot-Fernandez & Montifalcon 2019; Eroy 2019; Montifalcon & Fernandez 2017; Fernandez & Andigan 2017; Fernandez & Sabay 2016; Fernandez and Caballes 2016; Fernandez & Quilab-Tud 2016; Fernandez & Miñoza 2015; Fernandez & Lumbo 2015; Lopez-Fabal et al. 2014; Lo pez-Mosquera et al. 2014; Fernandez & Tipay 2013; Fernandez & De Guzman 2013).

This study is therefore conducted to verify the use of Essegro Nano Ionic Formula Biostimulant for vegetable crops such as pechay.

Objectives:

1. To determine the efficiency of Essegro Nano Ionic Formula Biostimulant on pechay growth and yield performance; and
2. To verify the best treatment combination that will increase the growth and yield performance of pechay.

METHODOLOGY

Site and Duration

To evaluate the efficiency of the Essegro Nano Ionic Formula Biostimulant application on the growth and yield performance of pechay, field experiment was conducted at the experimental area of Apokon, Tagum City for two months. The area has a flat topography with nutrient-deficient soil.

Experimental Design and Layout

The experiment was carried out in Randomized Complete Block Design (RCBD). Field experiment was composed of six treatments replicated three times. There were 128.4 pechay plants in a 12" x 12" planting distance with a plot size of 12m^2 per replication in 3x4 m for a total area of 216 m^2 with a total of 2,311 pechay plants. Each plot was provided with a 1m alleyway.

Soil Analysis

Soil analysis was done to determine the nutrient requirement of the area for pechay. Before the conduct of the experiment, soil samples were collected at random in the area following the standard procedure of the DA Regional Soil Laboratory, Davao City and analyzed for nutrient requirements. Table 1 shows the result of the soil analysis (Appendix A). Based on the soil analysis, the recommended rate of inorganic NPK fertilizer is 150-20-15 kg/ha/year.

Treatments

The recommended rate of fertilizer was applied based on the recommendation of soil analysis. Inorganic fertilizers were purchased based on the recommendation in bags/ha and the Essegro Nano Ionic Formula Biostimulant was applied based on the following treatments: T_1 = control; T_2 = RR of inorganic NPK (150-20-15 kg/ha/year) fertilizer based on soil analysis; T_3 = RR of inorganic NPK (150-20-15 kg/ha/year) + 0.5 rr of Essegro Nano Ionic Formula Biostimulant; T_4 = RR of inorganic NPK (150-20-15 kg/ha/year) + rr of Essegro Nano Ionic Formula Biostimulant; T_5 = RR of inorganic NPK (150-20-15 kg/ha/year) + 1.5 rr of Essegro Nano Ionic Formula Biostimulant; T_6 = rr of Essegro Nano Ionic Formula Biostimulant. The recommended rate of Essegro Nano Ionic Formula Biostimulant WAS applied as foliar spray from sowing and transplanting up to one week before harvest. One tablespoon of Essegro Nano Ionic Formula Biostimulant was dissolved in 20 liters of water and sprayed on pechay based on various treatments.

Cultural Management

Sowing. Pechay can be planted directly or indirectly in the soil. Direct seeding was accomplished through broadcasting or row sowing. Seeds were sown in a prepared seed box with ordinary garden soil. Land preparation. Plowing and harrowing the soil thoroughly makes it more friable and more porous suited for good quality produce. Raised beds 1 meter wide with paths of about 20-25 cm width between the beds are a common practice. The field was plowed and harrowed once using animal-drawn implement.

Transplanting and Thinning

Two to three seedlings were transplanted per hill, one-two weeks after planting from the seed box. One seedling per hill was maintained one week after transplanting. Weeding. Hoeing of the weeds may be necessary at an early stage of weeds growth before the plants shade the spaces in between plants. Manual weeding was done weekly whenever necessary. Watering. To obtain maximum growth and tenderness it must be supplied with adequate moisture. The plants was watered daily whenever necessary using a sprinkler. Pesticide application. Insecticide and fungicide were applied whenever necessary at recommended dosage and interval. Rotation use of pesticides was done to avoid the development of resistance to pests.

Fertilizer Application. The different fertilizer treatments were applied based on soil analysis NPK (150-20-15 kg/ha/year) and manufacturer's recommendation. Basal application of inorganic fertilizers was done one week before planting and side dress application was done two weeks after planting based on the soil analysis. Ten grams each of Ammosul, ammophos, 20g urea and 2.5g MOP were applied basally per quarter per plot per application. This is computed based on the 12 sqm area per plot from the soil analysis NPK (150-20-15 kg/ha/year) recommendation as shown in Appendix A. The 1/3 of the recommended nitrogen fertilizer with the potash and phosphate dressing were applied at 8-14 days before planting. Topdress application with the remaining fertilizer was done 2-5 weeks after planting. The recommended rate of Essegro Nano Ionic Formula Biostimulant was applied as foliar spray from sowing and transplanting up to one week before harvest. One tablespoon of Essegro Nano Ionic Formula Biostimulant was dissolved in 20 liters of water and sprayed on pechay based on various treatments. Approximately 1 liter of foliar spray was applied per plot and increased to 1 liter every week until harvest.

Harvesting

Pechay (pak-choi cultivar) was harvested at maturity, 21 days after transplanting. The pechay was already matured at three weeks after transplanting the 1-2 weeks old seedlings from the seedbed. So it took 35-40 days for pechay from planting to harvesting. Land preparation took 2-3 weeks which covers two months for pechay production from clearing, land preparation upto harvesting. This was based on Davao Area region climatic conditions and years of experience in pechay production and research. Pechay production guide publications may differ in conditions per region. Harvesting of pechay was done manually using cutting scissors. Dried leaves and damaged parts were trimmed off and washed in cleaning running water. Freshly harvested leaves were weighed and recorded.

DATA GATHERED

All marketable plant parts per 3x4 m plot excluding border plants were weighed using a digital weighing scale and converted to tons/ha using the formula:

$$\text{Yield (tons/ha)} = \frac{\text{plot yield (kg)}}{\text{area (sq.m.)}} \times \frac{10{,}000}{1{,}000}$$

The following growth parameters were taken at harvest. Plant heights of ten pechay sample plants per replication were measured from the base up to the tip of the plants using a ruler. The number of leaves were counted each from the ten sample plants per replication. The longest leaf lengths and widest leaf widths of the ten sample plants per replication were measured using a ruler. The root length of the ten sample plants per replication were measured using a ruler. The average fresh weight of the ten sample plants per replication were measured using a digital weighing scale. The incidence of pests and diseases as well as beneficial organisms were also monitored during the conduct of the study. No serious infestations were observed during the conduct of the study. Data were analyzed using Analysis of Variance (ANOVA) and differences between treatments were compared using the Honest Significant Difference (HSD) Test.

RESULTS AND DISCUSSION

Root Length (cm)

There was a significant difference on the root length of pechay as shown in Table 1 at 30 days after transplanting (DAT). Results showed that T_2= RR of inorganic NPK fertilizer based on soil analysis got the longest root length among treatments. This implies that supplementation of Essegro Nano Ionic Formula Biostimulant did not influence the root length of pechay.

Table 1 : Root length (cm) of pechay as influenced by Essegro Nano Ionic Formula Biostimulant at 30 days after transplanting (DAT).

	REPLICATION			
TREATMENT	**I**	**II**	**III**	**MEAN****
T1 – CONTROL	7.90	10.90	9.40	9.40 b
T2 – RR OF INORGANIC NPK.	14.30	12.80	15.80	14.30 a
T3 – RR OF INORGANIC NPK+ 0.5. RR OF Essegro Nano Ionic Formula Biostimulant	10.40	11.80	11.10	11.10 b
T4 – RR OF INORGANIC NPK+ RR OF Essegro Nano Ionic Formula Biostimulant	9.80	9.80	9.80	9.80 b
T5 – RR OF INORGANIC NPK + 1.5. RR OF Essegro Nano Ionic Formula Biostimulant	11.90	10.40	11.40	11.23 b
T6 – RR OF Essegro Nano Ionic Formula Biostimulant	11.25	10.40	12.10	11.25 b

C.V (%) = 9.37 %

* * =significant at 1% level

Means with the same letter are not significantly different at 5% level of probability using HSD.

Number of Leaves

The number of leaves of pechay was also not significantly affected by Essegro Nano Ionic Formula Biostimulant at 30 days after transplanting (DAT) as shown in Table 2. This indicates that the number of leaves of pechay in all treatments were significantly comparable which ranged from 7-11 leaves.

Table 2: Number of leaves of pechay as influenced by Essegro Nano Ionic Formula Biostimulant at 30 days after transplanting (DAT).

	REPLICATION			
TREATMENT	**I**	**II**	**III**	**MEAN****
T1 – CONTROL	10.9	10.2	10.5	7.20
T2 – RR OF INORGANIC NPK	11.3	11.3	13.1	11.90
T3 – RR OF INORGANIC NPK+ 0.5 RR OF Essegro Nano Ionic Formula Biostimulant	10.8	10.8	11.1	10.90
T4 – RR OF INORGANIC NPK+ RR OF Essegro Nano Ionic Formula Biostimulant	11.7	11.7	10.9	11.43
T5 – RR OF INORGANIC NPK + 1.5 RR OF Essegro Nano Ionic Formula Biostimulant	11.0	10.3	12.3	11.20
T6 – RR OF Essegro Nano Ionic Formula Biostimulant	9.8	9.5	12.0	10.43

C.V (%) = 21.40 %
ns=not significant

Average Fresh Weight (g) of ten sample plants
The Essegro Nano Ionic Formula Biostimulant significantly affected the average fresh weight of ten sample pechay at 30 days after transplanting (DAT) as shown in Table 3. The average fresh weight of ten sample plants per replication were weighed using a digital weighing scale. The (T4) RR of inorganic NPK + rr of Essegro Nano Ionic Formula Biostimulant had the heaviest weight which are significantly higher than the (T1) control and (T6) RR of inorganic NPK + rr of Essegro Nano Ionic Formula Biostimulant. This indicates that the fresh weight of pechay was increased two times by the application of (T4) RR of inorganic NPK + rr of Essegro Nano Ionic Formula Biostimulant.

Table 3: Average Fresh weight (g) of ten sample pechay as influenced by Essegro Nano Ionic Formula Biostimulant at 30 days after transplanting (DAT).

	REPLICATION			
TREATMENT	**I**	**II**	**III**	**MEAN****
T1 – CONTROL	51.0	69.0	60.0	60.00 c
T2 – RR OF INORGANIC NPK.	112.0	112.0	189.0	137.66 ab
T3 – RR OF INORGANIC NPK+ 0.5. RR OF Essegro Nano Ionic Formula Biostimulant	104.0	143.0	123.5	123.50 ab
T4 – RR OF INORGANIC NPK+ RR OF Essegro Nano Ionic Formula Biostimulant	160.0	160.0	155.0	158.33 a
T5 – RR OF INORGANIC NPK + 1.5. RR OF Essegro Nano Ionic Formula Biostimulant	107.0	116.0	131.0	118.00 abc
T6 – RR OF Essegro Nano Ionic Formula Biostimulant	77.5	51.0	104.0	77.50 bc

C.V (%) = 18.95 %
**=significant at 1% level
Means with the same letter are not significantly different at 5% level of probability using HSD.

Leaf Width

Table 4 shows that the leaf width of pechay was significantly affected by Essegro Nano Ionic Formula Biostimulant at 30 days after transplanting (DAT). (T4) RR of inorganic NPK + rr of Essegro Nano Ionic Formula Biostimulant had the widest leaf which are significantly higher than the (T1) control and (T6) RR of inorganic NPK + rr of Essegro Nano Ionic Formula Biostimulant. This verified that the leaf width of pechay was increased by 33% in (T4) RR of inorganic NPK + rr of Essegro Nano Ionic Formula Biostimulant.

Table 4: Leaf Width (cm) of pechay as influenced by Essegro Nano Ionic Formula Biostimulant at 30 days after transplanting (DAT).

	REPLICATION			
TREATMENT	I	II	III	MEAN**
T1 – CONTROL	12.50	12.00	12.25	12.25 c
T2 – RR OF INORGANIC NPK BASED ON SOIL ANALYSIS	15.80	14.70	16.90	15.80 ab
T3 – RR OF INORGANIC NPK+ 0.5. RR OF Essegro Nano Ionic Formula Biostimulant	13.80	15.50	14.65	14.65 ab
T4 – RR OF INORGANIC NPK+ RR OF Essegro Nano Ionic Formula Biostimulant	16.20	16.20	15.90	16.10 a
T5 – RR OF INORGANIC NPK + 1.5. RR OF Essegro Nano Ionic Formula Biostimulant	15.10	14.50	14.50	14.70 ab
T6 – RR OF Essegro Nano Ionic Formula Biostimulant	13.65	12.40	14.90	13.65 bc

C.V (%) = 5.43 %

**=significant at 1% level

Means with the same letter are not significantly different at 1% level of probability using HSD.

Leaf Length

The leaf length of pechay was also significantly affected by Essegro Nano Ionic Formula Biostimulant at 30 days after transplanting (DAT) as indicated in Table 5. The leaf length of pechay in (T4) RR of inorganic NPK + rr of Essegro Nano Ionic Formula Biostimulant and (T3) RR of inorganic NPK + rr of Essegro Nano Ionic Formula Biostimulant were significantly longer than that of the control (T1). This means that the (T4) RR of inorganic NPK + rr of Essegro Nano Ionic Formula Biostimulant and (T3) RR of inorganic NPK + rr of Essegro Nano Ionic Formula Biostimulant enhanced the leaf length of pechay by 35%.

Plant Height

The pechay height was further significantly affected by Essegro Nano Ionic Formula Biostimulant at 30 days after transplanting (DAT) (Table 6). Highest height of pechay was observed in (T3) RR of inorganic NPK + rr of Essegro Nano Ionic Formula Biostimulant. However, its was just comparable to the rest of the treatments using the HSD test. Hence, the height of pechay was not increased by supplementation of Essegro Nano Ionic Formula Biostimulant.

Table 5: Leaf Length (cm) of pechay as influenced by Essegro Nano Ionic Formula Biostimulant at 30 days after transplanting (DAT).

	REPLICATION			
TREATMENT	**I**	**II**	**III**	**MEAN****
T1 – CONTROL	12.5	15.5	14.0	14.00 b
T2 – RR OF INORGANIC NPK.	18.0	17.0	19.0	18.00 ab
T3 – RR OF INORGANIC NPK+ 0.5. RR OF Essegro Nano Ionic Formula Biostimulant	18.2	20.2	19.2	19.20 a
T4 – RR OF INORGANIC NPK+. RR OF Essegro Nano Ionic Formula Biostimulant	19.5	19.5	19.5	19.50 a
T5 – RR OF INORGANIC NPK + 1.5. RR OF Essegro Nano Ionic Formula Biostimulant	20.6	17.4	16.7	18.23 ab
T6 – RR OF Essegro Nano Ionic Formula Biostimulant	16.9	14.3	19.5	16.90 ab

C.V (%) = 9.71 %
*=significant at 5% level
Means with the same letter are not significantly different at 1% level of probability using HSD.

Table 6: Plant Height (cm) of pechay as influenced by Essegro Nano Ionic Formula Biostimulant at 30 days after transplanting (DAT).

	REPLICATION			
TREATMENT	**I**	**II**	**III**	**MEAN****
T1 – CONTROL	24.1	24.5	24.3	24.30 a
T2 – RR OF INORGANIC NPK	24.2	24.2	28.4	25.60 a
T3 – RR OF INORGANIC NPK+ 0.5 RR OF Essegro Nano Ionic Formula Biostimulant	27.0	29.2	28.1	28.10 a
T4 – RR OF INORGANIC NPK+ RR OF Essegro Nano Ionic Formula Biostimulant	26.6	25.1	24.3	25.33 a
T5 – RR OF INORGANIC NPK + 1.5. RR OF Essegro Nano Ionic Formula Biostimulant	28.6	26.6	27.7	27.63 a
T6 – RR OF Essegro Nano Ionic Formula Biostimulant	22.4	21.7	26.8	23.63 a

C.V (%) = 6.47 %
*= significant
Means with the same letter are not significantly different at 1% level of probability using HSD.

Yield (tons/ha)

The effect of Essegro Nano Ionic Formula Biostimulant on the yield of pechay per plot was highly significant (Table 7, Figures 1,2). The yield was based on the total harvested marketable pechay per plot excluding borders in a 3x4 m plot and converted to tons/ha. The highest yield of pechay was obtained in (T4) RR of inorganic NPK + rr of Essegro Nano Ionic Formula Biostimulant and (T5) RR of inorganic NPK + 1.5 rr of Essegro Nano Ionic Formula Biostimulant. These were significantly higher than the control (T1). This implies that the Essegro Nano Ionic Formula Biostimulant and RR inorganic fertilizer will increase the yield of pechay up to three times.

The previous study indicated that T3 – (RR of inorganic NPK + 0.5 rr of Essegro Nano Ionic Formula Biostimulant) significantly increased pechay yield by 100 % more compared to the control or no application (Fernandez et al. 2023).

This also supports previous study which increased yield in pechay using FOLF (Eroy 2019). The yield was significantly improved by the mere application of Full On Liquid Fertilizer at its recommended dose (T5) resulting to 86.11% additional yield. However, this yield level was further increased when 50% (T4) or full dose of the reference fertilizer (T6) was added. The recommended rate (rr) of NPK with and without 1.5 rr foliar fertilizer gave the best result on growth and yield of pechay. It increased plant height and length of leaves as much as 45%, width of leaves by 40%, leaf number by 20%, fresh weight up to two times and yield by three times higher (Fernandez & Miñoza 2015). Stimulate hormones increased plant height of pechay by 37%, length of leaves by 44%, width of leaves by 39%, fresh weight by 2 times, yield by 3 times, and number of leaves (Andigan & Fernandez 2017).

The application of RR of inorganic NPK + rr of DR. BO'S FARM ESSENTIALS got the heaviest weight as much as two times, the widest leaf by 100%, the highest height by 53%, and the highest yield of pechay up to three times than the control (Magbalot-Fernandez et al. 2024). Further studies verified that soil supplements with RR inorganic fertilizer increased the growth and yield of pechay (Magbalot-Fernandez et al. 2024; Fernandez et al. 2023; Fernandez & Agan 2021; Eroy 2019). Roshdy and Refaai (2016), revealed that when compared to the usage of conventional fertilizer, the usage of nano-fertilizer that was put to the soil boosted the production of date palms as well as their growth. The effect of nano-fertilizers on the growth of fruit as well as the developmental and phytochemical processes in the date palm fruit was significant.

Table 7: Yield (ton/ha) of pechay as influenced by Essegro Nano Ionic Formula Biostimulant at 30 days after transplanting (DAT).

	REPLICATION			
TREATMENT	I	II	III	MEAN**
T1 – CONTROL	0.510	0.640	0.600	0.58 b
T2 – RR OF INORGANIC NPK	1.195	1.120	1.270	1.19 ab
T3 – RR OF INORGANIC NPK+ 0.5 RR OF Essegro Nano Ionic Formula Biostimulant	0 .990	1.235	1.115	1.11 ab
T4 – RR OF INORGANIC NPK+ RR OF Essegro Nano Ionic Formula Biostimulant	1.580	2.210	1.895	1.89 a
T5 – RR OF INORGANIC NPK + 1.5 RR OF Essegro Nano Ionic Formula Biostimulant	2.610	1.450	2.080	2.04 a
T6 – RR OF Essegro Nano Ionic Formula Biostimulant	1.030	.510	1.550	1.03 ab

C.V (%) = 27.64 %
**=significant at 1% level
Means with the same letter are not significantly different at 1% level of probability using HSD.

SUMMARY, CONCLUSION AND RECOMMENDATION

The study was conducted at Apokon, Tagum City, with a duration of 2 months which started from December 2022 to February 2023. The objectives of the study were the following: To determine the efficiency of Essegro Nano Ionic Formula Biostimulant on pechay growth and yield performance; and verify the best treatment combination that will increase the growth and yield performance of pechay.

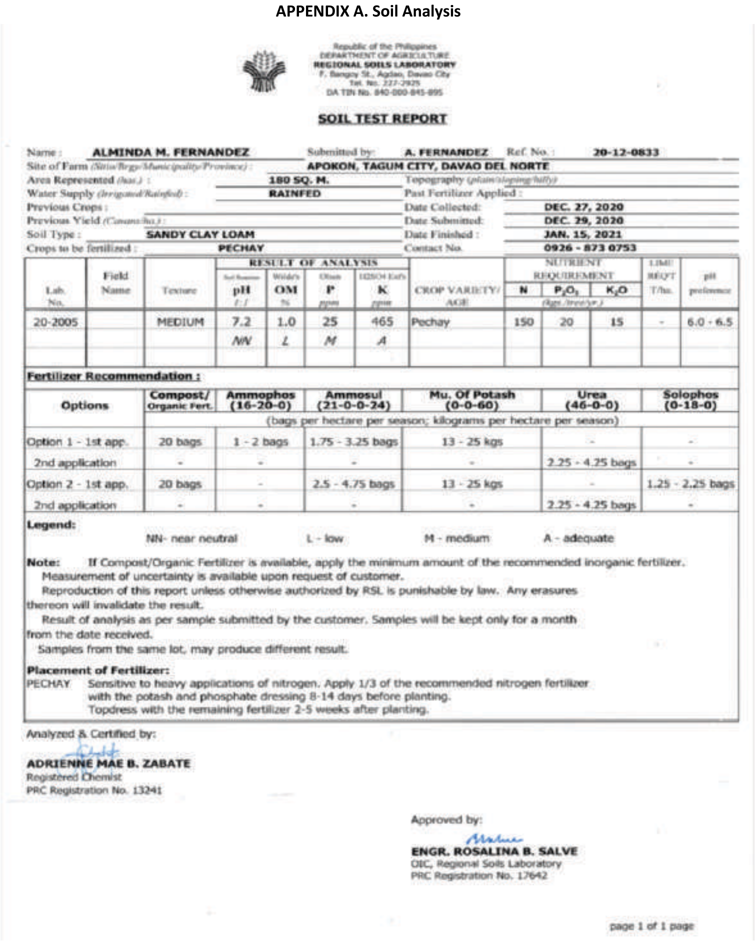
A Randomized Complete Block Design (RCBD) was used as the experimental design which was composed of six treatments, and replicated three times. The treatments were: (T1) Control, (T2) RR of inorganic NPK fertilizer based on soil analysis, (T3) RR of inorganic NPK + 0.5 rr of Essegro Nano Ionic Formula Biostimulant, (T4) RR of inorganic NPK + rr of Essegro Nano Ionic Formula Biostimulant, (T5) RR of inorganic NPK + 1.5 rr of Essegro Nano Ionic Formula Biostimulant, and (T6) rr of Essegro Nano Ionic

Formula Biostimulant. Data on growth and yield components were gathered and analyzed using Analysis of Variance (ANOVA) and differences between treatments were compared using the Honest Significant Difference (HSD) Test. Based on the results of the study, the growth and yield performance of pechay were significantly affected by Essegro Nano Ionic Formula Biostimulant in terms of root length, plant height, fresh weight, leaf length and width and pechay yield. However, the number of leaves did not have significant differences among treatments.

Results showed that T_2= RR of inorganic NPK fertilizer based on soil analysis got the longest root length among treatments. This implies that supplementation of essegro plant biostimulant did not influence the root length of pechay. The (T4) RR of inorganic NPK + rr of Essegro Nano Ionic Formula Biostimulant increased the fresh weight of pechay up to two times which are significantly higher than the (T1) control and (T6) RR of inorganic NPK + rr of Essegro Nano Ionic Formula Biostimulant. Also, (T4) RR of inorganic NPK + rr of Essegro Nano Ionic Formula Biostimulant had the widest leaf which are significantly higher by 33% than the (T1) control and (T6) RR of inorganic NPK + rr of Essegro Nano Ionic Formula Biostimulant. The leaf length of pechay in (T4) RR of inorganic NPK + rr of Essegro Nano Ionic Formula Biostimulant and (T3) RR of inorganic NPK + rr of Essegro Nano Ionic Formula Biostimulant were significantly longer than that of the control (T1) by 35%. Highest height of pechay was observed in (T3) RR of inorganic NPK + rr of Essegro Nano Ionic Formula Biostimulant. However, it was just comparable to the rest of the treatments using the HSD test.

The yield of pechay was increased up to three times in (T4) RR of inorganic NPK + rr of Essegro Nano Ionic Formula Biostimulant and (T_5) RR of inorganic NPK + 1.5 rr of Essegro Nano Ionic Formula Biostimulant which were significantly higher than the control (T1). Essegro Nano Ionic Formula Biostimulant therefore increased the growth and yield performance of pechay (Brassica rapa). The author therefore, recommends the use of RR of inorganic NPK + 1.0-1.5 rr of Essegro Nano Ionic Formula Biostimulant to boost pechay production and to enhance the yield performance of pechay (*Brassica rapa*).

APPENDIX A. Soil Analysis



APPENDIX A. Soil Analysis

Republic of the Philippines
DEPARTMENT OF AGRICULTURE
REGIONAL SOILS LABORATORY
F. Bangoy St., Agdao, Davao City
Tel. No. 227-2925
DA TIN No. 840-000-845-895

SOIL TEST REPORT

Name : **ALMINDA M. FERNANDEZ** Submitted by: **A. FERNANDEZ** Ref. No. : **20-12-0833**
Site of Farm *(Sitio/Brgy/Municipality/Province)* : **APOKON, TAGUM CITY, DAVAO DEL NORTE**
Area Represented *(has.)* : **180 SQ. M.** Topography *(plain/sloping/hilly)*
Water Supply *(Irrigated/Rainfed)* : **RAINFED** Past Fertilizer Applied :
Previous Crops : Date Collected: **DEC. 27, 2020**
Previous Yield *(Cavans/ha.)* : Date Submitted: **DEC. 29, 2020**
Soil Type : **SANDY CLAY LOAM** Date Finished : **JAN. 15, 2021**
Crops to be fertilized : **PECHAY** Contact No. **0926 - 873 0753**

Lab. No.	Field Name	Texture	RESULT OF ANALYSIS				CROP VARIETY/ AGE	NUTRIENT REQUIREMENT			LIME REQ'T T/ha.	pH preference
			pH	OM %	P ppm	K ppm		N	P_2O_5	K_2O		
20-2005		MEDIUM	7.2	1.0	25	465	Pechay	150	20	15	-	6.0 - 6.5
			NN	L	M	A						

Fertilizer Recommendation :

Options	Compost/ Organic Fert.	Ammophos (16-20-0)	Ammosul (21-0-0-24)	Mu. Of Potash (0-0-60)	Urea (46-0-0)	Solophos (0-18-0)
	(bags per hectare per season; kilograms per hectare per season)					
Option 1 - 1st app.	20 bags	1 - 2 bags	1.75 - 3.25 bags	13 - 25 kgs	-	-
2nd application	-	-	-	-	2.25 - 4.25 bags	-
Option 2 - 1st app.	20 bags	-	2.5 - 4.75 bags	13 - 25 kgs	-	1.25 - 2.25 bags
2nd application	-	-	-	-	2.25 - 4.25 bags	-

Legend:

NN- near neutral	L - low	M - medium	A - adequate

Note: If Compost/Organic Fertilizer is available, apply the minimum amount of the recommended inorganic fertilizer.
Measurement of uncertainty is available upon request of customer.
Reproduction of this report unless otherwise authorized by RSL is punishable by law. Any erasures thereon will invalidate the result.
Result of analysis as per sample submitted by the customer. Samples will be kept only for a month from the date received.
Samples from the same lot, may produce different result.

Placement of Fertilizer:
PECHAY Sensitive to heavy applications of nitrogen. Apply 1/3 of the recommended nitrogen fertilizer with the potash and phosphate dressing 8-14 days before planting.
Topdress with the remaining fertilizer 2-5 weeks after planting.

Analyzed & Certified by:

ADRIENNE MAE B. ZABATE
Registered Chemist
PRC Registration No. 13241

Approved by:

ENGR. ROSALINA B. SALVE
OIC, Regional Soils Laboratory
PRC Registration No. 17642

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Appendix Figures

Figure 1: Effect of Essegro Nano Ionic Formula Biostimulant on pechay growth. (T1) Control, (T2) RR of inorganic NPK fertilizer based on soil analysis, (T3) RR of inorganic NPK + 0.5 rr of Essegro Nano Ionic Formula Biostimulant, (T4) RR of inorganic NPK + rr of Essegro Nano Ionic Formula Biostimulant, (T5) RR of inorganic NPK + 1.5 rr of Essegro Nano Ionic Formula Biostimulant, and (T6) rr of Essegro Nano Ionic Formula Biostimulant.

Figure 2: Harvested pechay at 28 days after transplanting. (T1) Control, (T2) RR of inorganic NPK fertilizer based on soil analysis, (T3) RR of inorganic NPK + 0.5 rr of Essegro Nano Ionic Formula Biostimulant, (T4) RR of inorganic NPK + rr of Essegro Nano Ionic Formula Biostimulant, (T5) RR of inorganic NPK + 1.5 rr of Essegro Nano Ionic Formula Biostimulant, and (T6) rr of Essegro Nano Ionic Formula Biostimulant.

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REVITALIZING DEGRADED SOILS: UTILIZING SOIL CONDITIONER FOR SUSTAINABLE PECHAY PRODUCTION

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ABSTRACT

To test the effect of soil conditioner on acidity and pechay (*Brassica pekinensis*) growth and yield performance, this study was conducted at Indangan, Davao City for four months duration. A Randomized Complete Block Design (RCBD) was used with seven treatments and three replications. The treatments were: T_1 = control; T_2 = RR NPK (140-60-30 kg/ha) based on soil analysis; T_3 = RR NPK + 0.5 rr soil conditioner; T_4= RR NPK + rr soil conditioner; T_5 = RR NPK + 1.5 rr soil conditioner; T_6 = rr soil conditioner; and T_7 = 0.5 RR NPK + rr soil conditioner. Growth and yield data were analyzed using ANOVA and HSD tests. Results showed that the highest root length was NPK + 1.5 rr soil conditioner followed by NPK + rr soil conditioner by 95% more than control. It increased leaves by 1.5 times more, enhanced fresh weight three times higher, and leaf length by 42% more than control. The yield of 0.5 RR NPK + rr soil conditioner was higher by 100% than control. NPK + rr soil conditioner and NPK + 1.5 rr soil conditioner got the widest leaves by 100% than control followed by NPK + rr soil conditioner and rr soil conditioner. Moreover, height was increased by 0.5 RR NPK + rr soil conditioner by 54% compared to control. Hence, the application of soil conditioner with half RR NPK increased root length, leaf width and length, leaves, plant height, fresh weight and yield of pechay. The control and NPK applied treatments had pH of 5.2 after four weeks from treatment applications, while treatments with soil conditioner had pH of 5.3-5.9. This implies the significant role of soil conditioner in reducing soil acidity and restoring the productivity of the land.

No. of Pages: 14 **References: 35**

Keywords: Soil Conditioner, Soil Neutralizer, Land Degradation, Pechay, *Brassica pekinensis*.

INTRODUCTION

According to Pascual et al. (2013), to produce high yield, most growers use synthetically-based products, thus, the possibility of pesticides and chemical residue accumulation is very serious that poses threat to human health. Synthetically-based fertilizers are the most common fertilizers used by the farmers. However, its use incurs a high cost and its supply is sometimes limited that many farmers now are still adapting the idea of using organic fertilizers no matter how long and laborious the preparation is.

Fertilizer application using either inorganic or organic fertilizer sources is one of the most common cultural management practices in vegetable production. According to Masarirambi et al. (2010), commercial

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and subsistence farming has been and is still relying on the use of inorganic fertilizers for growing crops. This is because they are easy to use, quickly absorbed and utilized by crops. However, these fertilizers are believed to contribute substantially to human, animal, food intoxication and environmental instability or degradation.

Earlier studies using various fertilizers and supplements have been tested to maximize the growth and yield of various crops (Magbalot-Fernandez et al. 2024, 2020; Pauya et al. 2024; Fernandez et al. 2023, 2015; Fernandez & De Guzman 2021; Magbalot-Fernandez & De Guzman 2022, 2019; Fernandez & Agan 2021; Magbalot-Fernandez & Montifalcon 2019; Eroy 2019; Montifalcon & Fernandez 2017; Fernandez & Andigan 2017; Fernandez & Sabay 2016; Fernandez and Caballes 2016; Fernandez & Quilab-Tud 2016; Fernandez & Miñoza 2015; Fernandez & Lumbo 2015; Lopez-Fabal et al. 2014; Lopez-Mosquera et al. 2014; Fernandez & Tipay 2013; Fernandez & De Guzman 2013).

Fulcrum+TM (Concentrate) is a natural, 100% biodegradable, active-colloid based formulation, consisting of natural surfactants, emulsifying agents derived from vegetable fatty-acids, other nutrients, and natural non-toxic proprietary formulas. It contains Palm Oil (20%), Corn Oil (20%), Soy Oil (15%), Sunflower Seed Oil (10%), Molasses (10%), SeaWeed (5%), Bacillus Bacteria (2.5), Polysorbate (7.5%), and Water (10%) which are natural ingredients.

Pechay (*Brassica napus* L.) belongs to the Brassiceae family and one of the most known vegetables in the Philippines. It is also known as one of the oldest green vegetables in Asia. It therefore plays an important role in the Philippines economy as well as in the nutrition of the filipino people. Pechay is used mainly for its immature, but fully expanded tender leaves (http://www.darfu4b.da.gov.ph/pechay.html).

According to Siemonsma & Piluek (1994) the crop is considered the most consumed leafy vegetable in the Philippines and contributes a very good income provider for farmers due to its short duration harvesting. This crop can be harvested 30-45 days from planting seedling foundation of this crop strongly affects performance as it contributes to almost half of the duration in cropping.

About 86.3 percent of the country's total Chinese pechay production came from the Cordillera Administrative Region. Central Visayas came next with 7.0 percent share. Northern Mindanao, Davao Region and the rest of the country had a combined share of 6.7 percent (PSA 2019). The crop is considered the most consumed leafy vegetable in the Philippines and contributes a very good income provider for farmers due to its short duration harvesting. This crop can be harvested 30-45 days after planting, the seedling foundation of this crop strongly affects performance as it contributes to almost half of the duration in cropping (Siemonsma & Piluek 1994). From 2019 to 2021, an average increase of 0.9 percent was noted in the production of pechay. From 47.30 thousand metric tons in 2019, it went up to 47.50 thousand metric tons in 2020 and increased further to 48.12 thousand metric tons in 2021. The average production of pechay was 47.64 thousand metric tons during the period (PSA 2022). Hence, a considerate effort to sustain the increase vegetable production through efficient fertilization techniques is a wise alternative.

This study is therefore conducted to verify the use of Soil Conditioner for vegetable crops such as pechay.

Objectives:

1. To test the efficacy of Soil Conditioner in increasing the yield of pechay; and
2. To determine the best treatment combination that will increase the yield of pechay.

METHODOLOGY

Site and Duration

To evaluate the efficacy of the Soil Conditioner application on the yield of pechay, field experiments were conducted at the experimental area at Indangan, Davao City for two months duration from February to March 2024. The area was in a flat topography with nutrient-deficient soil.

Climatic Condition

Meteorological data of the area were taken from the nearest Agromet station within the duration of the study.

Experimental Design and Layout

The experiment was carried out in Randomized Complete Block Design (RCBD). Field experiment was composed of seven treatments replicated three times (Figure 1). There were 128.4 pechay plants in a 12" x 12" planting distance with a plot size of 12m^2 per replication for a total area of 228 m^2 with a total of 2,696 pechay plants. Each plot was provided with a 1m alleyway.

Soil Analysis

Soil analysis was done to determine the nutrient requirement of the area for pechay. Before the conduct of the experiment, soil samples were collected at random in the area following the standard procedure of the DA Regional Soil Laboratory, Davao City and analyzed for nutrient requirements (Appendix A).

Treatments

The recommended rate of fertilizer was applied based on the recommendation of soil analysis. Inorganic fertilizers were purchased based on the recommendation in bags/ha and the FULCRUM was applied based on the following treatments: T_1 = control; T_2 = RR of inorganic NPK fertilizer based on soil analysis; T_3 = RR of inorganic NPK + 0.5 rr of FULCRUM+™; T_4 = RR of inorganic NPK + rr of FULCRUM+™; T_5 = RR of inorganic NPK + 1.5 rr of FULCRUM+™; T_6 = rr of FULCRUM+™; T_7 = 0.5 RR of inorganic NPK + rr of FULCRUM+™. The recommended rate of FULCRUM+™ was applied as: First application applied immediately during planting the seeds; Second application after transplanting the pechay; Foliar application only if needed for pests prior to maturity. (FULCRUM acts as an anti-fungal and insect repellant.)

Cultural Management

Sowing. Seeds were sown in a prepared seed box with ordinary garden soil. Land preparation. The field was plowed and harrowed once using animal-drawn implements. Transplanting and Thinning. Two to three seedlings were transplanted per hill, one-two weeks after planting from the seed box. One seedling per hill wad maintained one week after transplanting. Weeding. Manual weeding was done weekly whenever necessary. Watering. The plants were watered daily whenever necessary using a sprinkler. Pesticide application. Insecticide and fungicide were applied whenever necessary at recommended dosage and interval. Rotation use of pesticides was done to avoid the development of resistance to pests. Fertilizer Application. The different fertilizer treatments were applied based on soil analysis and manufacturer's recommendation. Basal application of inorganic fertilizers (140-60-30 kg/ha) was done one week before planting and side dress application was done two weeks after planting based on the soil analysis. The recommended rate of FULCRUM was applied once before transplanting pechay seedlings in the field. It was mixed thoroughly with the garden soil in 1kg/plot and allowed to rest for one week. Harvesting. Pechay (pak-choi cultivar) was harvested at maturity, 21 days from transplanting. The pechay is already matured at three weeks after transplanting the 1-2 weeks old seedlings from the seedbed. So it took 35-40 days for pechay from planting to harvesting. Land preparation took 2-3 weeks so it covered two months for pechay production from clearing, land preparation upto harvesting. This is based on Davao Area region climatic conditions and years of experience in pechay production and research. Pechay production guide publications may differ in conditions per region. Harvesting of pechay was done manually using cutting scissors. Dried leaves and damaged parts were trimmed off and washed in cleaning running water. Freshly harvested leaves were weighed and recorded.

DATA GATHERED

All marketable plant parts per plot was weighed and converted to tons/ha using the formula:

$$\text{Yield (tons/ha)} = \frac{\text{plot yield (kg)}}{\text{area (sq.m.)}} \times \frac{10{,}000}{1{,}000}$$

The following growth parameters were taken at harvest. Plant heights of ten pechay sample plants per replication was measured from the base up to the tip of the plants using a ruler. The number of leaves was counted each from the ten sample plants per replication. The longest leaf lengths and widest leaf widths of the ten sample plants per replication was measured using a ruler. The root length of the ten sample plants per replication was measured using a ruler. The average fresh weights of the ten sample plants per replication were measured using a digital weighing scale.

Data on pH and salinity of the soils were taken before and after FULCRUM applications to verify the effectiveness of FULCRUM as soil conditioner.

Data were analyzed using Analysis of Variance (ANOVA) and differences between treatments were compared using the Honest Significant Difference (HSD) Test.

RESULTS AND DISCUSSION

Root Length (cm)

There was a significant difference on the root length of pechay as shown in Table 1 and Figure 4, at 30 days after transplanting (DAT). Results showed that highest root length was obtained from T5 = RR of inorganic NPK + 1.5 rr FULCRUM followed by T4 = RR of inorganic NPK + rr FULCRUM. This implies that supplementation of FULCRUM enhances the root length of pechay by as much as 95% more than the control.

Table 1: Root length (cm) of pechay is influenced by FULCRUM at 30 days after transplanting (DAT).

TREATMENT	I	II	IIII	MEAN**
T1 = control	9	10	8	9.0 e
T2 = RR of inorganic NPK (140-60-30 kg/ha) based on soil analysis	13	14	12	13.0 cd
T3 = RR of inorganic NPK + 0.5 rr of FULCRUM	15	16	13	14.6 bc
T4 = RR of inorganic NPK + rr of FULCRUM	18	19	15	17.3 ab
T5 = RR of inorganic NPK + 1.5 rr of FULCRUM	18	19	16	17.6 a
T6 = rr of FULCRUM	11	16	13	13.3 cd
T7= 0.5 RR of NPK + rr of FULCRUM	12	13	10	11.6 de

C.V (%) = 6.83
**= highly significant at 1% level

Number of Leaves

The number of leaves of pechay was significantly affected by FULCRUM at 30 days after transplanting (DAT) as shown in Table 2. Results indicate that the most number of leaves of pechay was observed in T7 = 0.5 RR of inorganic NPK + rr FULCRUM followed by T5 = RR of inorganic NPK + 1.5 rr FULCRUM. This implies that FULCRUM increased the number of leaves of pechay by as much as 1.5 times than the control.

Table 2: Number of leaves of pechay as influenced by FULCRUM at 30 days after transplanting (DAT).

TREATMENT	I	II	IIII	MEAN **
T1 = control	10	8	9	9.0 d
T2 = RR of inorganic NPK (140-60-30 kg/ha) based on soil analysis	10	12	13	11.6 d
T3 = RR of inorganic NPK + 0.5 rr of FULCRUM	12	10	11	11.0 d
T4 = RR of inorganic NPK + rr of FULCRUM	16	16	17	16.3 c
T5 = RR of inorganic NPK + 1.5 rr of FULCRUM	19	20	22	20.3 ab
T6 = rr of FULCRUM	18	18	20	18.6 bc
T7= 0.5 RR of NPK + rr of FULCRUM	24	22	23	23.0 a

C.V. (%) = 6.54
**= highly significant at 1% level

Average Fresh Weight (g) of ten sample plants

The average fresh weight of ten sample plants significantly affected the fresh weight at 30 days after transplanting (DAT) as shown in Table 3. Treatments with T7 = 0.5 RR of inorganic NPK + rr FULCRUM followed by T5 = RR of inorganic NPK + 1.5 rr FULCRUM were significantly higher than without fertilizer applications. This shows that application of NPK with FULCRUM enhanced the fresh weight of pechay as much as three times higher than the control.

Table 3: Average Fresh weight (g) of pechay as influenced by FULCRUM at 30 days after transplanting (DAT).

TREATMENT	I	II	IIII	MEAN **
T1 = control	47	43	30	40.0 e
T2 = RR of inorganic NPK (140-60-30 kg/ha) based on soil analysis	62	67	80	69.6 d
T3 = RR of inorganic NPK + 0.5 rr of FULCRUM	70	76	83	76.3 cd
T4 = RR of inorganic NPK + rr of FULCRUM	75	80	78	77.6 cd
T5 = RR of inorganic NPK + 1.5 rr of FULCRUM	108	110	115	111.0 b

T6 = rr of FULCRUM	95	90	98	94.3 bc
T7= 0.5 RR of NPK + rr of FULCRUM	152	150	180	160.6 a

C.V. (%) = 9.04
**= highly significant at 1% level

Leaf Width

Table 4 shows that the leaf width of pechay was significantly affected by FULCRUM at 30 days after transplanting (DAT) using ANOVA. The T7 = 0.5 RR of inorganic NPK + rr FULCRUM and T5 = RR of inorganic NPK + 1.5 rr FULCRUM got the widest leaves followed by T4 = RR of inorganic NPK + rr FULCRUM and T6 = rr of FULCRUM. This suggests that fertilizer application supplemented with FULCRUM increased leaf width of pechay as much as 100% than the control.

Table 4: Leaf Width (cm) of pechay as influenced by FULCRUM at 30 days after transplanting (DAT).

TREATMENT	I	II	IIII	MEAN **
T1 = control	9	8	10	9.1 d
T2 = RR of inorganic NPK (140-60-30 kg/ha) based on soil analysis	10	11	12	11.0 cd
T3 = RR of inorganic NPK + 0.5 rr of FULCRUM	10	12	13	11.6 c
T4 = RR of inorganic NPK + rr of FULCRUM	15	15	17	15.6 b
T5 = RR of inorganic NPK + 1.5 rr of FULCRUM	18	17	19	18.0 a
T6 = rr of FULCRUM	15	14	16	15.0 b
T7= 0.5 RR of NPK + rr of FULCRUM	18	19	20	19.0 a

C.V. (%) = 4.73
**= significant at 1% level

Leaf Length

The leaf length of pechay also has significant differences at 30 days after transplanting (DAT) as indicated in Table 5 based on ANOVA. Still, T7 = 0.5 RR of inorganic NPK + rr FULCRUM followed by T5 = RR of inorganic NPK + 1.5 rr FULCRUM got the longest leaf length of pechay. Hence, this verifies that leaf length of pechay was enhanced using FULCRUM by as much as 42% than the control.

Table 5: Leaf Length (cm) of pechay as influenced by FULCRUM at 30 days after Transplanting (DAT).

TREATMENT	I	II	IIII	MEAN **
T1 = control	20	21	18	19.6 d
T2 = RR of inorganic NPK (140-60-30 kg/ha) based on soil analysis	25	23	20	22.6 bcd
T3 = RR of inorganic NPK + 0.5 rr of FULCRUM	21	20	23	21.3 cd
T4 = RR of inorganic NPK + rr of FULCRUM	24	25	23	24.0 bc
T5 = RR of inorganic NPK + 1.5 rr of FULCRUM	27	26	25	26.0 ab
T6 = rr of FULCRUM	26	24	22	24.0 bc
T7= 0.5 RR of NPK + rr of FULCRUM	28	29	27	28.0 a

C.V. (%) = 5.82
**= significant at 1% level

Plant Height

The pechay height was further significantly affected by various treatments at 30 days after transplanting (DAT) (Table 6). The highest height of pechay was observed in T7 = 0.5 RR of inorganic NPK + rr FULCRUM, T5 = RR of inorganic NPK + 1.5 rr FULCRUM and T4 = RR of inorganic NPK + rr FULCRUM which is comparable to the fertilizer treatments applied with inorganic NPK or FULCRUM except the control. Moreover, the height of pechay was increased by 0.5 RR NPK + rr FULCRUM by as much as 54% compared to the control.

Table 6: Plant Height (cm) of pechay as influenced by FULCRUM at 30 days after transplanting (DAT).

TREATMENT	I	II	IIII	MEAN **
T1 = control	19	15	12	15.5 b
T2 = RR of inorganic NPK (140-60-30 kg/ha) based on soil analysis	21	18	19	19.7 ab
T3 = RR of inorganic NPK + 0.5 rr of FULCRUM	20	22	19	20.3 ab
T4 = RR of inorganic NPK + rr of FULCRUM	21	22	24	22.3 a
T5 = RR of inorganic NPK + 1.5 rr of FULCRUM	22	23	24	23.0 a
T6 = rr of FULCRUM	21	20	19	20 ab
T7= 0.5 RR of NPK + rr of FULCRUM	24	23	25	24.0 a

C.V. (%) = 9.49
** = significant at 1% level

Yield (ton/ha)

The effect of FULCRUM on the yield of pechay per plot was highly significant (Table 7, Figures 2,3). The highest yield of pechay was obtained in T7 = 0.5 RR of inorganic NPK + rr FULCRUM and T5 = RR of inorganic NPK + 1.5 rr FULCRUM followed by T4 = RR of inorganic NPK + rr FULCRUM and T6 = rr of FULCRUM. The 0.5 RR of inorganic NPK + rr of FULCRUM was significantly higher by 100% than the control (T1). This indicates that the application of FULCRUM with RR inorganic fertilizer increased the yield of pechay.

This supports previous study where the recommended rate (rr) of NPK with and without 1.5 rr foliar fertilizer increased plant height and length of leaves as much as 45%, width of leaves by 40%, leaf number by 20%, fresh weight up to two times and yield by three times higher (Fernandez & Miñoza 2015). Stimulate hormones increased plant height of pechay by 37%, length of leaves by 44%, width of leaves by 39%, fresh weight by 2 times, yield by 3 times, and number of leaves (Andigan & Fernandez 2017). The application of RR of inorganic NPK + rr of DR. BO'S FARM ESSENTIALS got the heaviest weight as much as two times, the widest leaf by 100%, the highest height by 53%, and the highest yield of pechay up to three times than the control (Magbalot-Fernandez et al. 2024). Further studies verified that soil supplements with RR inorganic fertilizer increased the growth and yield of pechay (Magbalot-Fernandez et al. 2024; Fernandez et al. 2023; Fernandez & Agan 2021; Eroy 2019).

Table 7: Yield (ton/ha) of pechay as influenced by FULCRUM at 30 days after transplanting (DAT).

TREATMENT	I	II	IIII	MEAN **
T1 = control	0.922	0.845	0.706	0.824 b
T2 = RR of inorganic NPK (140-60-30 kg/ha) based on soil analysis	0.972	0.867	0.898	0.912 b
T3 = RR of inorganic NPK + 0.5 rr of FULCRUM	0.657	0.785	0.654	0.698 b
T4 = RR of inorganic NPK + rr of FULCRUM	1.059	1.346	1.564	1.323 ab
T5 = RR of inorganic NPK + 1.5 rr of FULCRUM	2.325	1.998	1.367	1.896 a
T6 = rr of FULCRUM	1.078	1.574	1.566	1.406 ab
T7= 0.5 RR of NPK + rr of FULCRUM	2.045	1.687	1.980	1.904 a

C.V. (%) = 20.98 **= highly significant at 1% level

Soil pH

Data on pH of the soils were taken before and after FULCRUM applications. There was an increase of pH after applications of FULCRUM treatments. The pH of the field before FULCRUM treatment applications were strongly acidic with a pH of 5.2. As indicated in Table 8, four weeks after the application of various levels of fertilizers with FULCRUM and lime pH increased which ranged from 5.3-5.9. While the control and inorganic fertilizer treatments maintained its pH to 5.2. This implies the significant role of FULCRUM as soil conditioner reducing acidity of the soil.

Table 8: Average Soil pH of the pechay field as influenced by FULCRUM applications.

TREATMENT	pH before FULCRUM Application	pH four weeks after FULCRUM application
T1 = control	5.2	5.2
T2 = RR of inorganic NPK (140-60-30 kg/ha) based on soil analysis	5.2	5.2
T3 = RR of inorganic NPK + 0.5 rr of FULCRUM	5.2	5.8
T4 = RR of inorganic NPK + rr of FULCRUM	5.2	5.4
T5 = RR of inorganic NPK + 1.5 rr of FULCRUM	5.2	5.3
T6 = rr of FULCRUM	5.2	5.9
T7= 0.5 RR of NPK + rr of FULCRUM	5.2	5.5

SUMMARY, CONCLUSION AND RECOMMENDATION

The study was conducted at Indangan, Davao City, with a duration of 2 months which started from February to March 2024. The objectives of the study were the following: To determine the efficiency of FULCRUM on pechay growth and yield performance; To verify the effects of FULCRUM application on the growth and yield parameters; fresh weight, plant height, leaf width and length, number of leaves and root length; and to determine the best treatment combination that will increase the growth and yield performance of pechay.

A Randomized Complete Block Design (RCBD) was used as the experimental design which was composed of six treatments, and replicated three times. The treatments were: T_1 = control; T_2 = RR of inorganic NPK fertilizer (140-60-30 kg/ha) based on soil analysis; T_3 = RR of inorganic NPK + 0.5 rr of FULCRUM+™; T_4 = RR of inorganic NPK + rr of FULCRUM+™; T_5 = RR of inorganic NPK + 1.5 rr of FULCRUM+™; T_6 = rr of FULCRUM+™; and T_7 = 0.5 RR of inorganic NPK + rr of FULCRUM+™.

Data on growth and yield components were gathered and analyzed using Analysis of Variance (ANOVA) and differences between treatments were compared using Honest Significant Difference (HSD) Test.

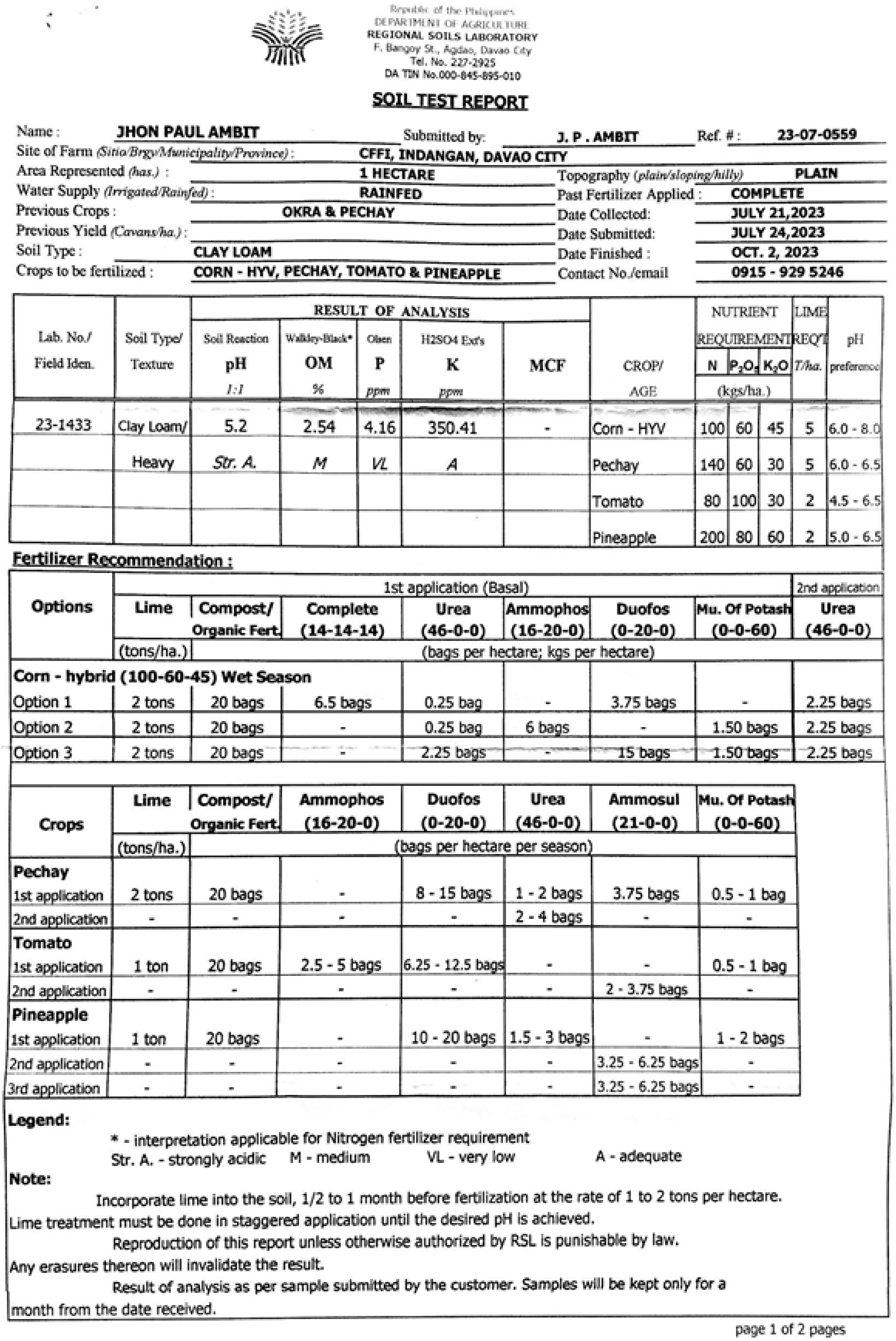
Based on the results of the study, the growth and yield performance of pechay were significantly affected by FULCRUM in terms of plant height, fresh weight, leaf width, leaf length, root length, number of leaves and pechay yield.

Results showed that highest root length was obtained from T5 = RR of inorganic NPK + 1.5 rr FULCRUM followed by T4 = RR of inorganic NPK + rr FULCRUM by as much as 95% more than the control. It also increased the number of leaves of pechay by as much as 1.5 times than the control, enhanced the fresh weight of pechay as much as three times higher than the control, and leaf length of pechay was enhanced using FULCRUM by as much as 42% than the control. The yield of 0.5 RR of inorganic NPK + rr of FULCRUM was significantly higher by 100% than the control (T1).

The T7 = 0.5 RR of inorganic NPK + rr FULCRUM and T5 = RR of inorganic NPK + 1.5 rr FULCRUM got the widest leaves by as much as 100% than the control followed by T4 = RR of inorganic NPK + rr FULCRUM and T6 = rr of FULCRUM. Moreover, the height of pechay was increased by 0.5 RR NPK + rr FULCRUM by as much as 54% compared to the control.

Hence, the application of rr FULCRUM with half RR inorganic fertilizer is recommended for increased growth and yield of pechay.

After four weeks from FULCRUM applications, the control and inorganic NPK applied treatments maintained its pH to 5.2 while treatments with FULCRUM had increased pH which ranged from 5.3-5.9. This implies the significant role of FULCRUM as soil conditioner reducing acidity of the soil.



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DEPARTMENT OF AGRICULTURE
REGIONAL SOILS LABORATORY
F. Bangoy St., Agdao, Davao City
Tel. No. 227-2925
DA TIN No.000-845-895-010

SOIL TEST REPORT

Name : **JHON PAUL AMBIT** Submitted by: **J. P . AMBIT** Ref. # : **23-07-0559**
Site of Farm *(Sitio/Brgy/Municipality/Province)* : **CFFI, INDANGAN, DAVAO CITY**
Area Represented *(has.)* : **1 HECTARE** Topography *(plain/sloping/hilly)* **PLAIN**
Water Supply *(Irrigated/Rainfed)* : **RAINFED** Past Fertilizer Applied : **COMPLETE**
Previous Crops : **OKRA & PECHAY** Date Collected: **JULY 21,2023**
Previous Yield *(Cavans/ha.)* : Date Submitted: **JULY 24,2023**
Soil Type : **CLAY LOAM** Date Finished : **OCT. 2, 2023**
Crops to be fertilized : **CORN - HYV, PECHAY, TOMATO & PINEAPPLE** Contact No./email **0915 - 929 5246**

Lab. No./ Field Iden.	Soil Type/ Texture	RESULT OF ANALYSIS					CROP/ AGE	NUTRIENT REQUIREMENT (kgs/ha.)			LIME REQ'T T/ha.	pH preference
		Soil Reaction pH *1:1*	Walkley-Black* OM %	Olsen P *ppm*	H2SO4 Ext's K *ppm*	MCF		N	P_2O_5	K_2O		
23-1433	Clay Loam/	5.2	2.54	4.16	350.41	-	Corn - HYV	100	60	45	5	6.0 - 8.0
	Heavy	*Str. A.*	*M*	*VL*	*A*		Pechay	140	60	30	5	6.0 - 6.5
							Tomato	80	100	30	2	4.5 - 6.5
							Pineapple	200	80	60	2	5.0 - 6.5

Fertilizer Recommendation :

Options	1st application (Basal)							2nd application
	Lime	**Compost/ Organic Fert.**	**Complete (14-14-14)**	**Urea (46-0-0)**	**Ammophos (16-20-0)**	**Duofos (0-20-0)**	**Mu. Of Potash (0-0-60)**	**Urea (46-0-0)**
	(tons/ha.)	(bags per hectare; kgs per hectare)						
Corn - hybrid (100-60-45) Wet Season								
Option 1	2 tons	20 bags	6.5 bags	0.25 bag	-	3.75 bags	-	2.25 bags
Option 2	2 tons	20 bags	-	0.25 bag	6 bags	-	1.50 bags	2.25 bags
Option 3	2 tons	20 bags	-	2.25 bags	-	15 bags	1.50 bags	2.25 bags

Crops	**Lime**	**Compost/ Organic Fert.**	**Ammophos (16-20-0)**	**Duofos (0-20-0)**	**Urea (46-0-0)**	**Ammosul (21-0-0)**	**Mu. Of Potash (0-0-60)**
	(tons/ha.)	(bags per hectare per season)					
Pechay							
1st application	2 tons	20 bags	-	8 - 15 bags	1 - 2 bags	3.75 bags	0.5 - 1 bag
2nd application	-	-	-	-	2 - 4 bags	-	-
Tomato							
1st application	1 ton	20 bags	2.5 - 5 bags	6.25 - 12.5 bags	-	-	0.5 - 1 bag
2nd application	-	-	-	-	-	2 - 3.75 bags	-
Pineapple							
1st application	1 ton	20 bags	-	10 - 20 bags	1.5 - 3 bags	-	1 - 2 bags
2nd application	-	-	-	-	-	3.25 - 6.25 bags	-
3rd application	-	-	-	-	-	3.25 - 6.25 bags	-

Legend:

* - interpretation applicable for Nitrogen fertilizer requirement
Str. A. - strongly acidic M - medium VL - very low A - adequate

Note:

Incorporate lime into the soil, 1/2 to 1 month before fertilization at the rate of 1 to 2 tons per hectare. Lime treatment must be done in staggered application until the desired pH is achieved.

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Result of analysis as per sample submitted by the customer. Samples will be kept only for a month from the date received.

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Figure 1. Field Layout of the experiment in RCBD with 7 treatments and 3 replications at Indangan, Davao City. T_1 = control; T_2 = RR of inorganic NPK fertilizer (140-60-30 kg/ha) based on soil analysis; T_3 = RR of inorganic NPK + 0.5 rr of FULCRUM+™; T_4 = RR of inorganic NPK + rr of FULCRUM+™; T_5 = RR of inorganic NPK + 1.5 rr of FULCRUM+™; T_6 = rr of FULCRUM+™; and T_7 = 0.5 RR of inorganic NPK + rr of FULCRUM+™.

Figure 2: Effect of FULCRUM on pechay growth four weeks from planting at Indangan, Davao City. T1 = control; T2 = RR of inorganic NPK fertilizer (140-60-30 kg/ha) based on soil analysis; T3 = RR of inorganic NPK + 0.5 rr of FULCRUM+™; T4 = RR of inorganic NPK + rr of FULCRUM+™; T5 = RR of inorganic NPK + 1.5 rr of FULCRUM+™; T6 = rr of FULCRUM+™; and T7 = 0.5 RR of inorganic NPK + rr of FULCRUM+™.

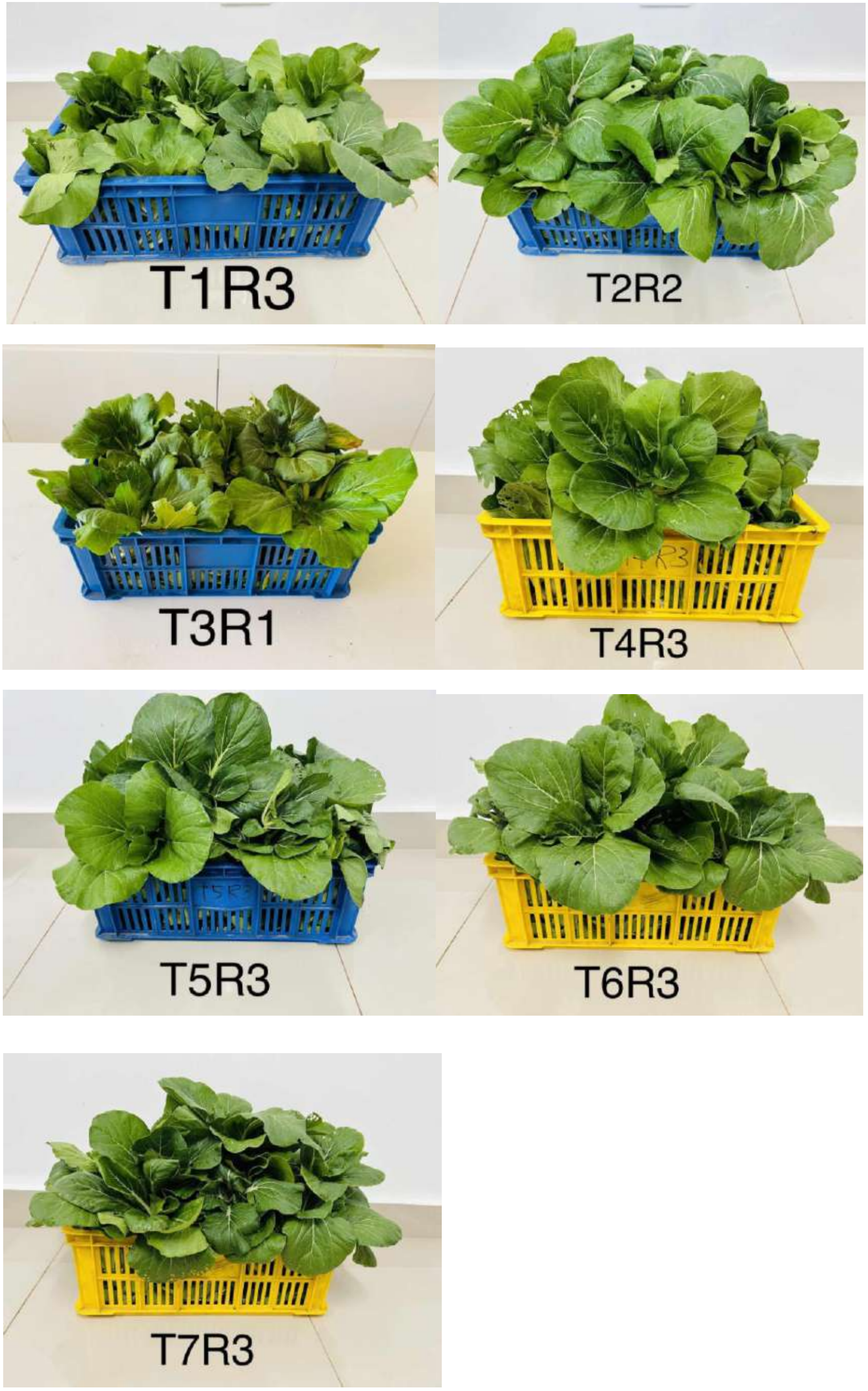

Figure 3: Harvested pechay at 30 days after planting. T1 = control; T2 = RR of inorganic NPK fertilizer (140-60-30 kg/ha) based on soil analysis; T3 = RR of inorganic NPK + 0.5 rr of FULCRUM+™; T4 = RR of inorganic NPK + rr of FULCRUM+™; T5 = RR of inorganic NPK + 1.5 rr of FULCRUM+™; T6 = rr of FULCRUM+™; and T7 = 0.5 RR of inorganic NPK + rr of FULCRUM+™.

Figure 4: Roots of harvested pechay at 30 days after planting. T1 = control; T2 = RR of inorganic NPK fertilizer (140-60-30 kg/ha) based on soil analysis; T3 = RR of inorganic NPK + 0.5 rr of FULCRUM+™; T4 = RR of inorganic NPK + rr of FULCRUM+™; T5 = RR of inorganic NPK + 1.5 rr of FULCRUM+™; T6 = rr of FULCRUM+™; and T7 = 0.5 RR of inorganic NPK + rr of FULCRUM+™.

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MEDICINAL PROPERTIES OF PERIWINKLE [*CATHARANTHUS ROSEUS* (L.) G. DON]

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ABSTRACT

Madagascar periwinkle [(*Catharanthus roseus* (L.) G. Don], also known as the "Madagascar vinca," is a plant native to Madagascar that has significant commercial prospects in agriculture and industry, particularly in the pharmaceutical industries. It can grow and thrive as an invasive species in certain conditions, impacting local indigenous flora. Originally native to Madagascar, this plant has been widely cultivated as an ornamental and medicinal plant. It is hardy and adaptable to various climates, particularly tropical and subtropical regions. Grown for its attractive flowers in gardens and landscapes; with proper care and adherence to these agronomic conditions, Madagascar periwinkle can be a profitable crop for both medicinal and ornamental purposes. Extracts are used to produce anticancer drugs. Madagascar periwinkle contains over 100 alkaloids, several of which are pharmacologically active. The two most notable alkaloids are vincristine and vinblastine, which are used in modern cancer treatments. However, its invasive potential in non-native ecosystems warrants careful management.

No. of Pages: 10 **References: 33**

Keywords: Madagascar periwinkle, *Catharanthus roseus,* phytochemicals, vincristine, vinblastine, medicinal, ornamental, ethnobotany, ethnomedicine

INTRODUCTION

The periwinkle plant [(*Catharanthus roseus* (L.) G. Don], also known as Madagascar periwinkle (Ghannam et al., 2024), is a small flowering plant native to Madagascar (Ehrenworth and Peralta-Yahya, 2017). It is a small, evergreen shrub that typically grows up to 1 meter tall (**Fig. 1**) and is known for its attractive, glossy green leaves (**Fig. 2**). The plant is widely grown as an ornamental plant due to its beautiful flowers that are bright, star-shaped and can be pink, white, or purple in colour (Sreevalli et al., 2002) (**Fig. 3**). It thrives in tropical and subtropical climates and is also grown in many parts of the world for its medicinal properties (El-Tanbouly et al., 2024).

Fig 1: Variation among habits of different Madagascar periwinkle cultivars. *Photo credit: Saikat Kumar Basu.*

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The periwinkle plant is renowned for its alkaloids, particularly vincristine and vinblastine Fig. 4), which are used in cancer treatment (Faraouk et al., 2022). These compounds are effective in treating various cancers, including leukaemia, Hodgkin's lymphoma, and breast cancer (Baskara and Jhang, 2016). Traditional medicine systems use periwinkle for treating diabetes, high blood pressure, and microbial infections (Ehrenworth and Peralta-Yahya, 2017). Vincristine and vinblastine are vital components of chemotherapy regimens (Faraouk et al., 2022). Other alkaloids from the plant are being studied for potential therapeutic applications (El-Sheikh et al., 2019). The plant is popular in landscaping and gardening because of its hardiness and ability to bloom continuously in different environments (Sreevalli et al., 2002). In some cultures, it is used in rituals or symbolic contexts (Ghannam et al., 2024).

Fig 2: The diversity of leaf shape, size, texture and phyllotaxy among different cultivars of periwinkle. Photo credit: *Saikat Kumar Basu*.

Distribution and Adaptability

The Madagascar periwinkle is native to Madagascar, where it evolved in the island's tropical and subtropical ecosystems (El-Sheikh et al., 2019). Within its native range, it primarily occurs in dry forests and sandy or well-drained areas along the coast (Sreevalli et al., 2003). However, due to its ornamental value, medicinal properties, and adaptability, Madagascar periwinkle has been widely introduced and naturalized in tropical and subtropical regions worldwide (Baskara and Jhang, 2016; Ehrenworth and Peralta-Yahya, 2017). Its current distribution includes parts of Asia (*e.g.*, India, Sri Lanka, the Philippines), Africa (beyond Madagascar), Central and South America, the Caribbeans, Australia and the Pacific islands (Baskara and Jhang, 2016; El-Tanbouly et al., 2024). It thrives in a variety of environments, including disturbed areas, roadsides, and gardens, making it an invasive species in some regions (El-Tantaway et al., 2023). Despite its wide distribution, it remains closely associated with its origins in Madagascar (Das et al., 2020).

Fig 3: Diversity of Madagascar periwinkle cultivars with diverse colour of petals across various biogeographic regions. Photo credit: *Saikat Kumar Basu.*

Periwinkle is a low-maintenance plant that can thrive in poor soils and is often used for erosion control (El-Tanbouly et al., 2024). Despite its benefits, periwinkle can become invasive in some areas, outcompeting native vegetation (Sharma et al., 2020). Careful management is required when cultivating it in non-native regions (Baskara and Jhang, 2016). The plant has widely adapted to habitats outside its natural range due to several biological and ecological traits, as well as human intervention (Faraouk et al., 2022; El-Tanbouly et al., 2024). Here are the key factors contributing to its adaptability:

Hardiness and Tolerance: The plant is highly drought-tolerant and can thrive in poor soils, allowing it to grow in a wide range of climates (Sreevalli et al., 2003). It can grow in sandy, loamy, or rocky soils, tolerating conditions that many plants cannot (Ghannam et al., 2024). It has natural alkaloids that deter pests and herbivores, helping it survive in unfamiliar environments (Ehrenworth and Peralta-Yahya, 2017).

Reproductive Success: The plant produces numerous seeds, increasing its chances of spreading. Although it is capable of cross-pollination, it can also self-pollinate, ensuring reproduction even when isolated from other plants (Ghannam et al., 2024). The plant matures quickly, allowing it to colonize new areas efficiently (Ehrenworth and Peralta-Yahya, 2017).

Medicinal and Ornamental Value: Humans have spread the plant globally because of its ornamental beauty and its use in traditional and modern medicine (*e.g.*, for producing alkaloids like vincristine and vinblastine, used in cancer treatment) (Sharma et al., 2020). Its ease of cultivation and low maintenance make it a popular choice in gardens and landscaping (Ehrenworth and Peralta-Yahya, 2017).

Invasive Potential: In non-native areas, the Madagascar periwinkle often outcompetes local vegetation due to its robust growth and ability to tolerate stress (Das et al., 2020). Its ability to naturalize and spread in disturbed habitats, roadsides, and urban areas has made it an invasive species in some regions (Sreevalli et al., 2003; Sharma et al., 2020).

Climatic Compatibility: Originally native to Madagascar's tropical climate, the plant's ability to adapt to both tropical and subtropical conditions has allowed it to establish itself in similar climates worldwide (Sreevalli et al., 2003; Sharma et al., 2020).

This combination of ecological versatility, human dissemination, and competitive advantages has made the Madagascar periwinkle a globally widespread plant (El-Tanbouly et al., 2024).

Phytochemical compounds

Madagascar periwinkle is a well-known medicinal plant valued for its diverse array of phytochemicals (Wang et al., 2011). These compounds, particularly alkaloids, have significant pharmacological activities (El-Tanbouly et al., 2024). Madagascar periwinkle is a phytochemical reservoir, with its alkaloids, flavonoids, tannins, and terpenoids contributing to its pharmacological importance (Sreevalli et al., 2002). A detailed discussion of the primary phytochemicals found in Madagascar periwinkle is presented below:

Alkaloids: The plant is particularly famous for its alkaloids, which are nitrogen-containing organic compounds with complex chemical structures (Ghannam et al., 2024). The discovery and synthesis of compounds like vincristine and vinblastine underscore the plant's value in modern medicine (Gawade et al., 2023). Over 130 alkaloids have been isolated from this species (El-Tanbouly et al., 2024). The key alkaloids are Vincristine ($C_{46}H_{56}N_4O_{10}$) and Vinblastine ($C_{46}H_{58}N_4O_9$) (Sharma et al., 2022) (Fig. 4). Both are complex dimeric indole alkaloids derived from tryptophan and terpenoid pathways (Tang et al., 2022). Vincristine and vinblastine are anti-mitotic agents, disrupting cell division by binding to tubulin and inhibiting microtubule formation (Sharma et al., 2022). These are widely used as chemotherapeutic agents to treat cancers, such as leukaemia, lymphoma, and breast cancer (Sharma et al., 2022). Another important alkaloids found in this plant is ajmalicine ($C_{21}H_{24}N_2O_3$), a monomeric alkaloid that acts as a vasodilator and antihypertensive agent that improves cerebral blood flow and is used to treat circulatory disorders (Sharma et al., 2022). Serpentine ($C_{21}H_{20}N_2O_3$) is another indole alkaloid that exhibits hypotensive and sedative effects that is investigated for use in traditional and modern medicine for cardiovascular diseases (Talaat et al., 2005).

Among other indole alkaloids (Fig. 4) are catharanthine ($C_{21}H_{24}N_2O_2$) serving as a precursor for vincristine and vinblastine synthesis; and vindoline ($C_{25}H_{32}N_2O_2$) acting as a building block for vincristine and vinblastine biosynthesis (Sharma et al., 2020; Huang et al., 2024). The alkaloids in Madagascar periwinkle are synthesized via the monoterpenoid indole alkaloid pathway, which involves: tryptophan metabolism for indole synthesis, geraniol and iridoid pathways for terpenoid synthesis, coupling of the indole and terpenoid moieties to produce monomeric alkaloids (*e.g.*, vindoline, catharanthine), and dimerization of monomeric alkaloids to form vincristine and vinblastine (Pandey-Rai et al., 2006; Sharma et al., 2020).

Flavonoids: Flavonoids are phenolic compounds known for their antioxidant properties. In *Catharanthus roseus*, the flavonoids include: kaempferol ($C_{15}H_{10}O_6$), a flavonol with antioxidant and anti-inflammatory properties; and quercetin ($C_{15}H_{10}O_7$) (Fig. 4), another flavonol that acts as an anti-inflammatory, antihypertensive, and antidiabetic agent. Rutin ($C_{27}H_{30}O_{16}$) is a glycosylated flavonoid with vasoprotective and anti-inflammatory effects (Pandey-Rai et al., 2006; Sharma et al., 2020) (Fig. 4).

Tannins: Polyphenolic compounds (Fig. 4) present in the plant with astringent and antimicrobial properties. These compounds contribute to wound healing and protection against microbial infections (Pandey-Rai et al., 2006; Sharma et al., 2020).

Phenolic Acids: Gallic acid and caffeic acid (Fig. 4) are commonly present in Madagascar periwinkle. These compounds have antioxidant and anti-inflammatory activities, protecting the plant and its consumers from oxidative stress (Huang et al., 2024).

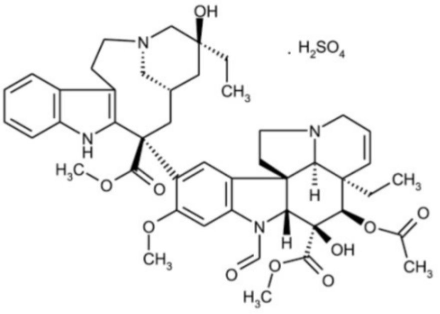
Terpenoids: Include monoterpenes, sesquiterpenes (Fig. 4), and diterpenes. These compounds often function as precursors for alkaloid biosynthesis and contribute to the plant's aroma and insect-repellent properties (Renjini et al., 2017).

Steroids: Stigmasterol and -sitosterol are common phytosterols in the plant. They exhibit anti-inflammatory and cholesterol-lowering effects.

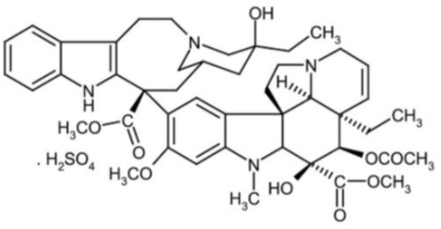
Glycosides: Cardiac glycosides (Fig. 4) are present, contributing to the plant's traditional use in treating heart conditions (Huang et al., 2024).

Saponins: Saponins are glycosides with foaming properties (Fig. 4). They have antimicrobial, antifungal, and immune-modulatory activities (Kumar et al., 2012).

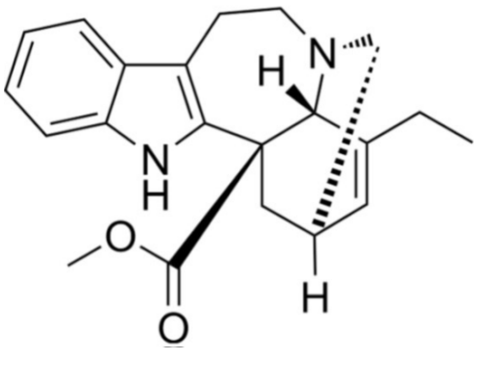
Essential Oils: Contain terrenes, sesquiterpenes, and volatile phenols. These oils have antimicrobial and insecticidal properties (Yokoyama and Inomata,1998).



Vincristine



Vinblastine



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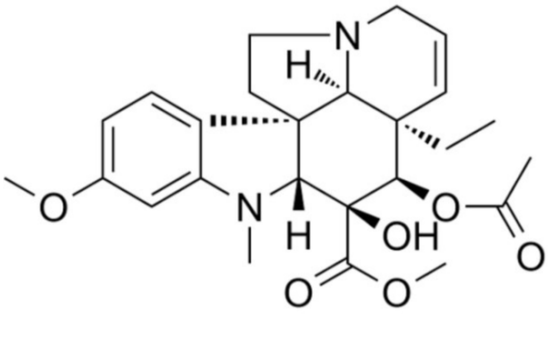
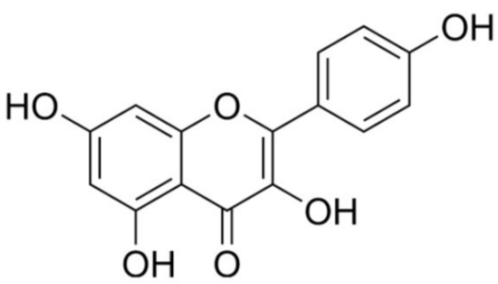
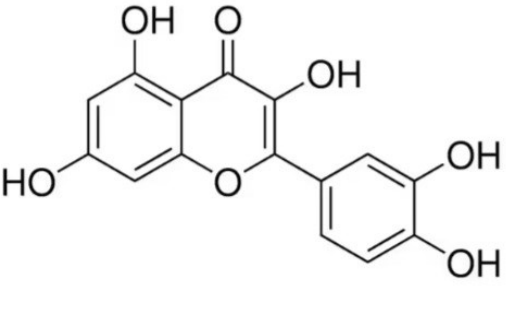


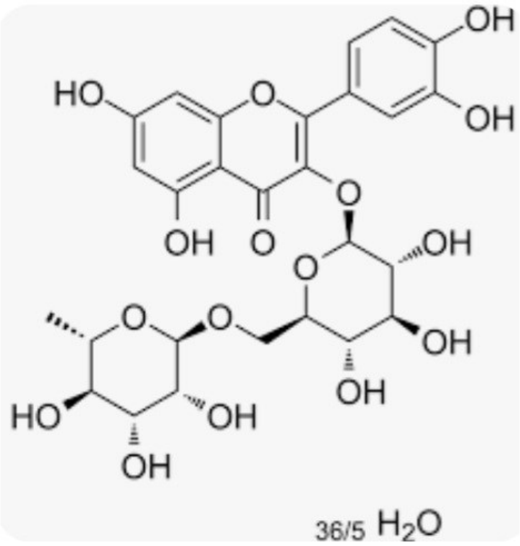
Vindoline



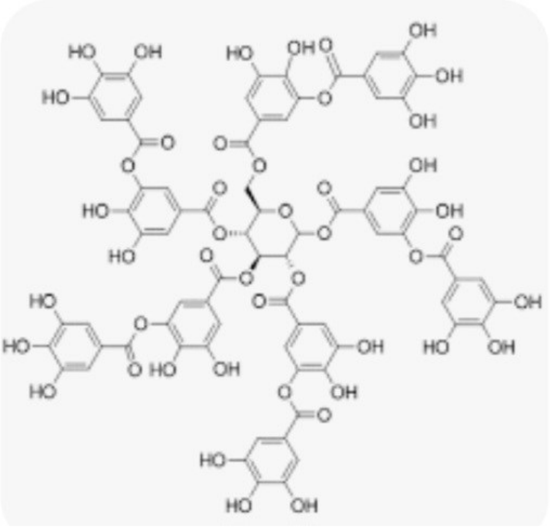
Kaempferol



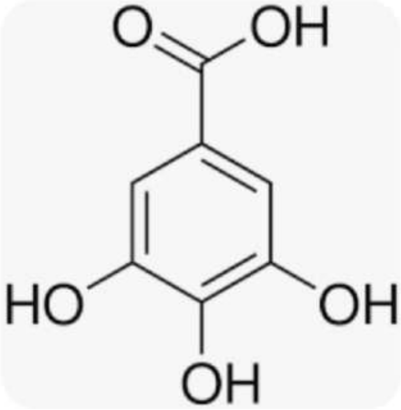
Quercetin



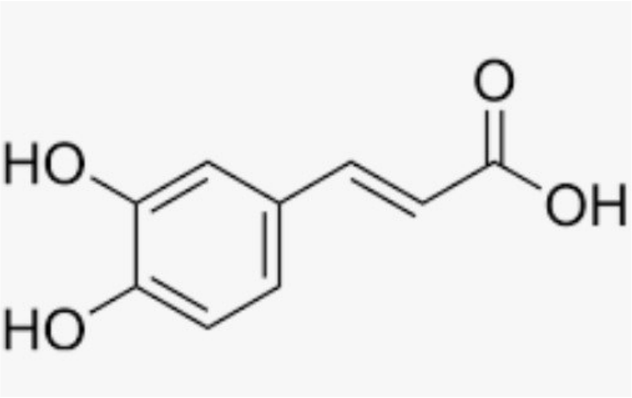
Rutin



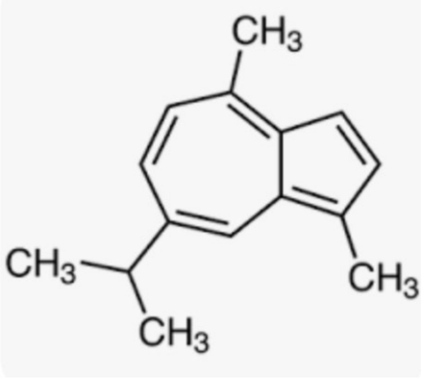
Tanin



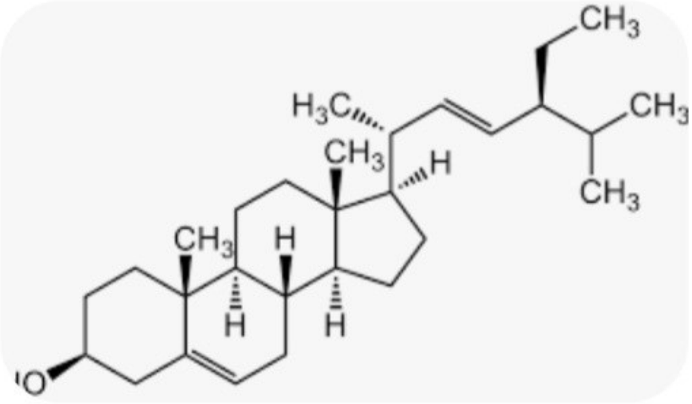
Gallic Acid



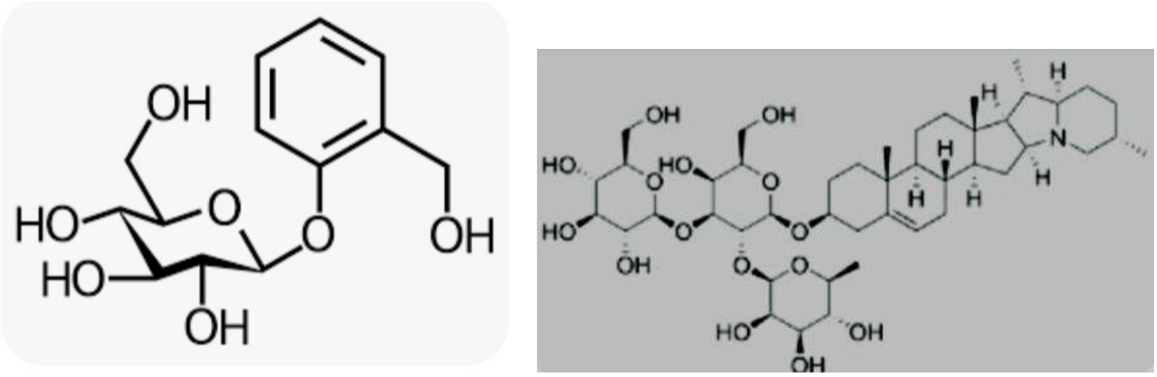
Caffeic Acid



Sesquiterpene



Stigmasterol



Glycoside **Saponin**

Fig 4: Important phytochemicals present in Madagascar periwinkle.

Medicinal Properties

The Madagascar periwinkle is renowned for its medicinal properties (Pandey-Rai et al., 2006). It contains alkaloids like vincristine and vinblastine, which are widely used in modern medicine (Nejat et al., 2015). While Madagascar periwinkle has potent medicinal properties, it is highly toxic if not used correctly (Rani et al., 2023). Direct consumption of raw plant parts is not advised due to the risk of poisoning, and pharmaceutical formulations should only be used under medical supervision (Kumar et al., 2012). Here are some diseases and conditions where it has applications or potential remedies:

Cancer Treatment: Vincristine and vinblastine are derived from the plant and are crucial in chemotherapy for leukaemia (especially childhood acute lymphoblastic leukaemia), lymphoma (Hodgkin's and non-Hodgkin's), breast cancer, lung cancer and testicular cancer (Bhaskar and Jhang, 2016). These alkaloids inhibit cell division by interfering with the microtubule formation, making them effective anticancer agents (Pandey-Rai et al., 2006; Gawade et al., 2023).

Diabetes: Traditionally, extracts from Madagascar periwinkle have been used to lower blood sugar levels. It is used in folk medicine for managing type 2 diabetes. However, clinical use for diabetes requires caution due to potential toxicity (Yokoyama and Inomata,1998).

Hypertension: Alkaloids in the plant have shown potential in regulating blood pressure, making it useful in traditional remedies for high blood pressure (Rai and Upadhayay, 2024).

Malaria: In traditional medicine, the plant has been used to treat malaria in some regions. Its antimalarial properties are linked to its alkaloid content (Pandey-Rai et al., 2006).

Infections and Wounds: The leaves and flowers are used as antiseptic poultices for treating wounds, skin infections, and ulcers in traditional medicine (Renjini et al., 2017).

Immune Modulation: Some studies suggest the plant has immune-modulatory effects, which may aid in conditions where immune function is compromised (Rady, 2019).

Other Traditional Uses: The plant has been used in folk remedies for treating fevers, and used to regulate menstruation in traditional medicine. Decoctions are commonly used to manage digestive issues like dysentery and diarrhoea (Gawade et al., 2023).

Uses in Alternative Medicine

The plant is globally recognized for its alkaloids, vincristine and vinblastine, which are used in modern medicine to treat cancers such as leukaemia and Hodgkin's lymphoma (El-Sheikh et al., 2019). While traditional uses are widespread, its therapeutic applications in alternative systems are often backed by anecdotal evidence or localized practices, rather than rigorous scientific studies (Yokoyama and Inomata,1998). Care must be taken due to its potential toxicity in high doses (Kumar et al., 2012). The plant is used in various traditional and alternative health systems like Ayurveda, Siddha, and Unani, though its applications vary (Singh, 2016).

Ayurveda: Known as Sadapushpa or Nityakalyani, it is used to treat conditions like diabetes, fever, skin diseases, and inflammation (Singh, 2016). The plant's extracts are sometimes applied to wounds for their antiseptic properties (Kulkarni, 1999).

Siddha: It is valued for its ability to control high blood sugar levels (anti-diabetic). It is also used for treating hypertension, ulcers, and as a blood purifier (Bhaskar and Jhang, 2016).

Unani: Unani practitioners use Madagascar periwinkle primarily for its anti-cancer, blood-purifying, and diuretic properties. It is considered useful in addressing chronic diseases like diabetes and some skin disorders (El-Tanbouly et al., 2024).

Homeopathy: Madagascar periwinkle is used in diluted forms to treat conditions like excessive menstrual bleeding, skin ailments, and ulcers (El-Sheikh et al., 2019).

Agronomic Practices

Madagascar periwinkle can be grown commercially, primarily for ornamental purposes or for its medicinal properties (Dagar et al., 2005; Hassan et al., 2009). It is a source of alkaloids like vincristine and vinblastine, which are used in cancer treatment (Abdolzadeh et al., 2006; Hassan et al., 2009). The crop prefers warm climates; optimal temperature is 20–30°C. It cannot tolerate frost, so it should be grown in frost-free areas (Dagar et al., 2005). The crop thrives in areas with moderate rainfall (750-2,000 mm annually). However, it can tolerate drought conditions due to its hardy nature (Hassan et al., 2009). Well-drained sandy loam or loamy soils are ideal; with pH: preference for slightly acidic to neutral soil (pH 5.5-7.5) (Ghannam et al., 2024). Moderately fertile soil is sufficient, but organic matter can improve growth; and requires full sunlight, though it can tolerate partial shade (Ghannam et al., 20240. The plant is primarily propagated through seeds or stem cuttings (Abdolzadeh et al., 2006).

Seeds should be sown directly in the field or raised in nurseries before transplantation (Dagar et al., 20050. Planting should be typically done during the early monsoon or spring season (Ghannam et al., 2024). Marinating a spacing of 30-40 cm between plants and 40-60 cm between rows is essential for optimum growth (Abdolzadeh et al., 2006; Hassan et al., 2009). The crop requires moderate irrigation. Overwatering should be avoided to prevent root rot. Irrigate every 7-10 days in dry conditions, but allow the soil to dry between watering. Applying a balanced fertilizer like NPK (10:10:10) (Ghannam et al., 2024). Incorporate organic manures (e.g., compost) before planting (Hashemabadi et al., 2015).

Madagascar periwinkle is highly drought-tolerant and can colonize disturbed areas, roadsides, and open spaces. It competes with native plants for resources like sunlight, water, and nutrients (Ghannam et al., 2024). The plant may release chemicals into the soil that inhibit the growth of nearby native plants (allelopathy), further reducing biodiversity. Its ability to produce numerous seeds and grow in poor soils allows it to establish quickly in new areas, displacing indigenous flora (Hashemabadi et al., 2015). To mitigate its impact, it's essential to: monitor its spread in sensitive ecosystems, removing it from areas where it threatens native plants, promoting the growth of native species to outcompete it, and regular weeding is essential, especially during the early stages of growth (Ghannam et al., 2024). Pests such as aphids, whiteflies, and caterpillars may attack the plants (Dagar et al., 2005). Use organic or chemical pesticides as needed. The plant is susceptible to leaf blight, root rot, and powdery mildew (Ghannam et al., 2024). Maintaining proper drainage and use of fungicides are important as preventive measures (Dagar et al., 2005). For medicinal use, leaves and stems are harvested 3-4 months after planting (Hashemabadi et al., 2015). Seeds can be collected after the pods mature if propagation is desired (Abdolzadeh et al., 2006).

Ethnobotany and Ethnomedicine

The Madagascar periwinkle has significant ethnobotanical uses and has been widely valued in traditional medicine and modern pharmacology and Pharmacognosy (Ehrenworth and Peralta-Yahya, 2017). It is an essential plant in ethnobotany, valued for its traditional uses and revolutionary contributions to modern medicine. Its dual role in traditional practices and pharmaceutical development highlights the importance of preserving and studying ethnobotanical knowledge (Sharma, 2016). Madagascar periwinkle has been used in various traditional healing systems, including in Africa, India, China, and the Caribbean (Abdolzadeh et al., 2006; Hassan et al., 2009). In traditional Indian medicine (Ayurveda), periwinkle leaves have been used to control blood sugar levels. Decoctions made from its leaves or roots are consumed for managing diabetes (Bhaskar and Jhang, 2016).

In many cultures, crushed leaves are applied topically to treat wounds, insect bites, and skin infections due to their antimicrobial and anti-inflammatory properties (Sharma et al., 2022). Infusions from the plant are used to treat diarrhoea, dysentery, and other gastro-intestinal issues (Abdolzadeh et al., 2006; Hassan et al., 2009). The plant has been used traditionally to reduce fevers and as a remedy for malaria in African and tropical regions (Kulkarni, 1999). It has been used for treating respiratory problems, menstrual irregularities, and hypertension in different cultural practices (Wang et al., 2011). In addition to its medicinal uses, Madagascar periwinkle has been used symbolically in rituals (Tang et al., 2022).

It is sometimes associated with protection and is planted around homes in some cultures to ward off evil spirits (Abdolzadeh et al., 2006; Hassan et al., 2009). The plant is occasionally used in ceremonial offerings in regions where it holds spiritual significance (Yokoyama and Inomata,1998). While Madagascar periwinkle has therapeutic benefits, it is also toxic if consumed in large quantities or prepared improperly. This toxicity is due to its potent alkaloids, which can cause adverse effects like nausea, vomiting, and organ damage (Tang et al., 2022). Traditional use often relies on expert knowledge to avoid harmful effects (Kulkarni et al., 2001).

Although widely cultivated, Madagascar periwinkle's wild populations in its native range face threats due to habitat destruction (Ehrenworth and Peralta-Yahya, 2017). Sustainable harvesting and cultivation practices are necessary to preserve its biodiversity (Kulkarni, 1999). Modern science has leveraged the plant's properties to produce synthetic analogs of its alkaloids, which are used in chemotherapy drugs. Its extensive use in research underscores its value both traditionally and in contemporary medicine (Acharjee and Kumar, 2022).

Nutraceutical and Functional Foods

Madagascar periwinkle has potential applications in the nutraceutical and functional food industries due to its bioactive compounds (Acharjee and Kumar, 2022). This plant is well-known for its rich content of alkaloids, flavonoids, tannins, phenolic acids, and other phytochemicals, many of which have antioxidant, anti-inflammatory, antimicrobial, and anticancer properties with key compounds for potential benefits, such as alkaloids like vincristine, Vvinblastine etc (Ehrenworth and Peralta-Yahya, 2017). These are widely used in pharmaceutical applications for their potent anticancer properties. Their potential inclusion in functional foods could support cancer prevention efforts (Yokoyama and Inomata,1998).

Flavonoids and phenolic compounds have strong antioxidant activity, which can help reduce oxidative stress and support overall health (Acharjee and Kumar, 2022). They may have applications in nutraceutical formulations for heart health and metabolic disorders (Renjini et al., 2017). Extracts from Madagascar periwinkle have shown antimicrobial effects against a range of pathogens. The plant is also traditionally used to manage diabetes, suggesting potential for blood sugar-regulating functional foods (Acharjee and Kumar, 2022). Compounds in the plant could be used to develop nutraceuticals aimed at reducing chronic inflammation, a root cause of many diseases (El-Tantaway et al., 2023).

Some alkaloids in Madagascar periwinkle, while therapeutic, are highly toxic and must be carefully dosed (Pandey-Rai et al., 2006; Sharma et al., 2020). The inclusion of such bioactive compounds in foods would require rigorous safety evaluations and regulatory approvals (Pandey-Rai et al., 2006). Effective methods to isolate and standardize active compounds for food-grade use would be essential. The plant holds promise for the nutraceutical and functional food industries, but further research, safety assessments, and regulatory clearances are required to unlock its full potential (Sharma et al., 2020).

Conclusion

The Madagascar periwinkle is a source of alkaloids, particularly vincristine and vinblastine, which are used in cancer treatments (*e.g.*, leukaemia, lymphoma, and testicular cancer). This makes the plant valuable for the pharmaceutical industry, with increasing global demand for cancer treatments (Pandey-Rai et al., 2006; Hashemabadi et al., 2015; Sharma et al., 2020; Tang et al., 2022). Expansion of use in drug development: Research is ongoing to discover more potential medicinal uses of the plant, which may lead to further commercial applications in treating diseases like diabetes and hypertension (Pandey-Rai et al., 2006; Sharma et al., 2020). The cultivation of Madagascar periwinkle is growing, particularly in tropical and subtropical climates. Countries with favourable growing conditions are focusing on producing high-quality plants for extraction of alkaloids (Hashemabadi et al., 2015; Sharma et al., 2020). However, the increasing global demand for periwinkle has raised concerns about sustainable harvesting practices, as wild populations are at risk due to overharvesting (Acharjee and Kumar, 2022).

Given the over-exploitation of the plant in the wild, some industries are investing in sustainable farming practices to ensure long-term supply (El-Tantaway et al., 2023). This includes cultivating the plant in controlled environments and enhancing yield through breeding programs (Sharma et al., 2020; El-Tantaway et al., 2023). Herbal medicine and cosmetics: In addition to pharmaceuticals, Madagascar periwinkle is also being explored for use in herbal medicine and cosmetic products, as its extracts are believed to have skin-healing and anti-inflammatory properties (Yokoyama and Inomata,1998; Hashemabadi et al., 2015).

Future Directions

Madagascar is the primary supplier of the periwinkle plant, and the global market relies heavily on its exports (El-Tantaway et al., 2023). With global awareness of the plant's medicinal benefits increasing, this gives Madagascar significant potential for economic growth if it can maintain sustainable cultivation practices and strengthen its export capacity (Sharma et al., 2020). The overharvesting of wild plants and the challenge of maintaining ecological balance in Madagascar's ecosystems pose a risk to the long-term commercial viability of periwinkle cultivation (Talaat et al., 2005; Hashemabadi et al., 2015). Madagascar's periwinkle exports are highly dependent on the demand for cancer drugs, which can fluctuate with market trends and research advancements (Tang et al., 2022). The global commercial prospects for Madagascar periwinkle are promising, particularly in the pharmaceutical industry (Wang et al., 2019). However, sustainability and the balancing of ecological preservation with economic development will be key factors in determining the long-term success of its cultivation and use (Pandey-Rai et al., 2006; Hashemabadi et al., 2015; Sharma et al., 2020).

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PESTICIDES, HERBICIDES AND THEIR EFFECTS ON POLLINATORS

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ABSTRACT

Pesticides used in agriculture, urban areas, and gardens are raising concerns about their impact on pollinators. Exposure to pesticides through direct contact, ingestion, and accumulation can harm pollinators. High pesticide concentrations cause immediate harm, while chronic exposure weakens their immune systems, impairs reproduction, and leads to population declines. Neonicotinoids, a type of insecticide, are especially problematic. They are absorbed by plants and spread to nectar and pollen, affecting foraging abilities, navigation, immunity, and reproductive success in pollinators. Integrated pest and pollinator management (IPPM), sustainable agriculture practices, and pesticide-free zones aim to maintain ecological balance and reduce chemical use. We observe lethal, sub lethal impacts on pollinator species including Honeybees (*Apis mellifera*), Bumblebees (*Bombus* spp.), butterflies, and other beneficial insects, and assess ecological consequences. Empirical data from field and laboratory studies are synthesized, and a comparative table summarizes pesticide usage and recorded pollinator mortality rates. Raising awareness about pollinator importance and pesticide impacts is crucial for conservation, and by balancing pest control with pollinator protection, long-term sustainability of agriculture and natural ecosystems dependent on pollination services can be ensured.

No. of Pages: 10 **Table: 1** **Fig.: 3** **References: 59**

Keywords: Pollinators, Pesticides, Herbicides, Honeybees, Sub-lethal Effects, Agriculture, IPPM.

INTRODUCTION

Pollinators, including bees, pollen wasps (Masarinae); ants; butterflies, moths, flies, beetles, and birds, (Figure.1) are indispensable agents in the reproduction of over 75% of leading global crops and nearly 90% of wild flowering plants (Klein et al., 2007; Baskar et al., 2017). Unfortunately, multiple pollinator species are currently experiencing contracting ranges and reductions in species richness and abundance (Evans *et al.,* 2018). For instance, domestic honeybee stocks declined by 59% in the USA between 1947 and 2005, and by 25% in Europe between 1985 and 2005. Even though beehives have increased by 45% since 1961, however, the proportion of agricultural crops depending on pollinators is increasing much more rapidly (>300%) so that the demand for pollination services could outstrip the increase in hive numbers (Aizen and Harder, 2019).

Pesticides are any substance or mixture of substances intended for preventing, destroying, repelling, or mitigating any pest including weeds. The term pesticide applies to insecticides, herbicides, fungicides, and various other substances used to control pests. Pesticides also include plant regulators, defoliants, and desiccants (Aoun, 2020; Arya *et al.,* 2021; Prakash and Verma, 2021). The introduction to the market in the early 1990s of Imidacloprid and thiacloprid opened the neonicotinoid era of insect pest control. This class of systemic water-soluble insecticides chemically related to nicotine affects the central nervous system of insects. Acting systemically, this class of neurotoxic insecticides taken by plants, primarily through the roots, and translocate to all parts of the plant through stem transport. This systemic property combined with very high toxicity to insects enabled formulating neonicotinoids for soil treatment and seed coating with typical doses high enough to provide long-lasting protection of the whole plant from

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pest insects (Van der Sluijs *et al.,* 2013). The declines of pollinator populations, excessive anthropogenic activities and pollution have raised alarms over potential cascading effects on biodiversity, ecosystem stability, and agricultural yield (Prakash and Verma, 2022; Verma and Prakash, 2022; Singh *et al.*, 2023). Concurrently, the intensification of agricultural practices has driven the extensive use of synthetic pesticides and herbicides to control pests and weeds. While these chemicals enhance crop output, they often exert unintended adverse effects on non-target organisms, particularly pollinators and field observations. Pollinators play an essential role in the sexual reproduction of most flowering plants while obtaining pollen and nectar rewards from their flowers. Most plant species on earth depends on pollination services from animal pollinators (Kearns *et al.,* 1998; Arya *et al.,* 2024).

Fig. 1: (16-22 June, 2025- Pollinator Week).

This mutualism is not only crucial for the maintenance of biodiversity but also provides important services, with an estimated 35% of global food production relying on insect pollination (Klein *et al.,* 2007). Other pesticides that can be harmful to pollinators include organophosphates such as diazinon, chlorpyrifos, disulfoton, azinphosmethyl, and fonofos. This class of organophosphorus compounds has been used widely in agriculture and in household applications as pesticides (Verma and Prakash, 2018; Prakash and Verma, 2020). Pyrethroids, a class of synthetic insecticides similar to natural pyrethrins, have neurotoxic effects on insects as well. These were introduces into widespread use for the control of insect pests and disease vectors more than three decades ago (Aoun, 2020). Pollinators can be bare to pesticides not only in agricultural areas but in urban areas as well. Surface water residue data suggest that the intensity of pesticide use in urban areas may sometimes exceed that of agricultural areas, and for some pesticides, labeled application rate can be much higher for non-agricultural than for agricultural use. This is the case of pesticides used for mosquito abatement and in aerial application in response to fears of insect-borne virus. These were found to be a major contaminant of pollen collected by honeybees (Long and Krupke, 2016; Guarino, 2016).

1. Pesticides, Herbicides vs Pollinators:

Types of Pesticides and Herbicides:

1. **Neonicotinoids:** Systemic insecticides (e.g., Imidacloprid, Clothianidin) that bind to nicotinic acetylcholine receptors in insects.
2. **Organophosphates:** Acetylcholinesterase inhibitors (e.g., Chlorpyrifos) reducing neural function.
3. **Pyrethroids:** Synthetic analogues of pyrethrins (e.g., cypermethrin) affecting sodium channel gating.
4. **Glyphosate:** Broad-spectrum herbicide inhibiting the shikimate pathway enzyme EPSP synthase.
5. **Atrazine:** Triazine herbicide that disrupts photosynthesis by inhibiting photosystem II.

Key Pollinator Species: (Figure. 2)

1. Honeybees (*Apis mellifera*): Economically dominant, managed colonies.
2. Bumblebees (*Bombus* spp.): Wild and managed, critical in cooler climates.
3. Butterflies and Moths (Order Lepidoptera): Indicators of environmental health.
4. Hoverflies (Family Syrphidae): Dual-role pollinators and aphid predators.

Fig 2: Honeybee, Humming bird, butterfly and beetle.

Insect pollinators in particular bees (Hymenoptera: Anthophila) are uniquely specialized for pollen transport and account for the bulk of pollination services. European honeybees (*Apis mellifera*) often considered as the most valuable agricultural pollinator. However, wild pollinators, such as wild bumblebees (*Bombus* spp.), solitary bees, flies, wasps, and Lepidoptera pollinate certain and prevalent crops such as oilseed rape and orchard fruit species and contribute approximately the same value toward crop production as managed bees do (Kleijn *et al.,* 2015). Pollinator loss impact two broad groups of pollinator-dependent flowering plants: wild flowers and cultivated crops. In wild plant species, almost 80% are directly dependent on insect pollination for fruit and seed set, although this may vary markedly between sites and seasons (Potts *et al.,* 2010).

One of the most frequent proximate causes of reproductive impairment of wild plant populations in fragmented habitats is careful pollination limitation. In cultivated crops, until now, most growers have either matched their pollinator needs by renting honeybees or utilized the “free” services of wild bee species foraging in farm fields, a component of pollination services that has mostly overlooked in economic calculations. It has been likely that without bees, some 60 species of crop plants would fail to produce fruit (Heard, 1999); the economic consequences of this impact are obvious. The global annual economic value of insect pollination was estimated to be approximately153 billion during 2005 (i.e., 9.5% of the total economic value of world agricultural output considering only crops that are used directly for human food. Complete pollinator loss would translate into a production deficit over current consumption levels of 12% for fruits and 6% for vegetables (Halm *et al.,* 2006).

In addition, declining pollinator supply has the potential of increasing costs of food production. Increased yields are usually the result of increasing farm inputs such as fertilizers, labor, and water. For some crops, this increasingly intensive management may have overcome any losses in pollination services, but it also increases production costs. There is also evidence that one response to lower yield growth for highly pollinator-dependent crops is a growing demand for land in a time when farmland is contracting as development replaces agriculture (Aizen and Harder, 2009). Of particular importance is the collapse of honeybee (*Apis mellifera*) colonies in America and other developed countries, because they provide honey and wax commodities to our society. One of the main fronts advanced for their decline along with other pollinators is the use of pesticides, including not only insecticides and acaricides but also fungicides and herbicides (Sanchez-Bayo and Goka, 2014; Siviter *et al.,* 2018).

Instances of “bee kills” associated with use of pesticides have documented since the late 19th century. But the discovery in the mid-2000s of parallel declines in wild pollinators and plants depending on pollinators. Along with widespread losses of managed honey bees raisedthe possibility that the effects of pesticides on pollinators might be more than merely episodic (Sponsler *et al.,* 2019).Pesticides and herbicides target specific physiological pathways in pests and weeds but can cross-react with similar pathways in pollinators. Systemic uptake leads to residues in pollen and nectar, exposing foraging insects. Global pesticide usage exceeded 3.5 million tons in 2020, with neonicotinoids accounting for 25% of insecticide market share (Wanner *et al.,* 2022). Herbicide application rates have risen by 30% over the past two decades, primarily driven by glyphosate-resistant crop cultivation. Pollination services are valued at an estimated USD 235–577 billion annually (Gallai et al., 2009). Loss of pollinators jeopardizes fruit set, seed quality, and nutritional diversity. The diversity and abundance of pollinators is crucial in maintaining biodiversity on land and food production demands by the agricultural industry. Unfortunately, multiple pollinator species are currently experiencing contracting ranges and reductions in species richness and abundance (Evans *et al.,* 2018).

3. Effects of Pesticides and Herbicides on Pollinators:

In agricultural areas, an adverse relationship was found between pesticide use on agriculture sites and pollinator abundance, group richness, and diversity. Pollinators in agriculture areas can be visible to plant protection products in two ways (Arya and Dubey, 2013; Sanchez-Bayo and Goka, 2014):

1. By direct exposure to either drift droplets, which are scattered during the foliar spraying of crops, dust from seed drilling at planting, or inhalation of volatile pesticides during or after application to the crops.
2. By exposure to residues present in pollen, wax, nectar, honey, and guttation drops, which may result either from direct spray contamination of flowers, translocation through the treated plants or soil, or direct contamination during treatment of the combs (for honey bees only). In fact, the most frequently detected pesticides for honey bees and the two that occur in the highest quantity are those used by beekeepers to control Varroa mites (coumaphos and fluvalinate) (Mullin *et al.,* 2010).

Bees also drink water and were observed drinking from paddy field waters contaminated with pesticides. Although herbicides target plants, surfactants and adjuvants can be toxic to insects. Glyphosate formulations cause mortality in bee larvae at high application rates (Balbuena et al., 2015). Herbicide-driven reduction of flowering weeds diminishes forage diversity and floral resources. Atrazine use in field margins reduced wildflower richness by 60%, affecting bumblebee foraging ranges (Rundlof *et al.*, 2015). Pesticides encompass a diverse range of chemicals used in agriculture, forestry, and public health to manage pests. In the agricultural sector alone, pesticides play a pivotal role in ensuring food security by protecting crops from insects, weeds, and diseases. They can have short-term toxic effects on directly exposed organisms, and long-term effects can result from changes to habitats and the food chain. Excess use of pesticides may lead to the destruction of biodiversity (Prakash and Verma, 2014; Masih, 2021; Arya *et al.,* 2023).

1.1 Acute Toxicity and Mortality

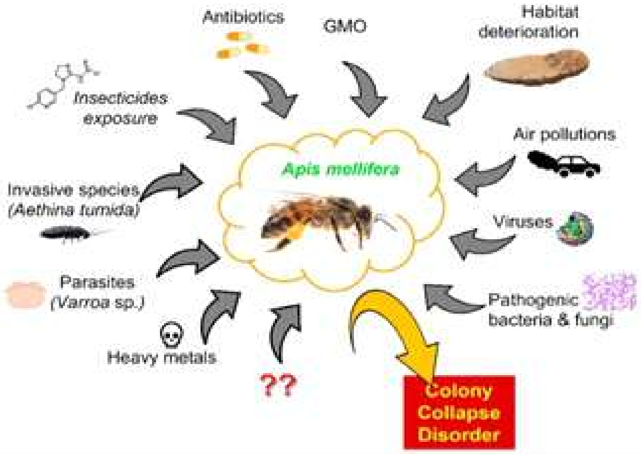
The toxicity of hydrophobic pesticides is mostly by contact exposure, whereas the toxicity of hydrophilic pesticides is mainly by oral ingestion of residues in pollen and honey. It should be noted that pyrethroids, which are highly hydrophobic compounds, are on average three times more toxic to bees by contact than by oral exposure. By contrast, 60% of the systemic (hydrophilic) pesticides have oral toxicities higher than their contact toxicities, up to13 times higher for some products (Sanchez-Bayo and Goka, 2014). Trials report median lethal dose (LD_{50}) values for imidacloprid at 3.7 ng/bee (Decourtye et al., 2003). Field exposures often exceed sublethal thresholds, causing acute colony losses during peak application periods. Neonicotinoids pose the highest direct threat to bees due to their acute toxicity, while herbicides like glyphosate and atrazine cause significant indirect effect by altering bee habitats and food sources. Understanding both direct and indirect pathways is crucial in evaluating the overall impact of agro-chemicals on pollinator populations.

3.2 Sublethal Effects on Behavior and Physiology of Pollinators:

Exposure to pesticides can be lethal or sub lethal with chronic detrimental effect on the individual pollinator and the colony. Sub lethal neonicotinoid concentrations impair navigation, foraging efficiency, brood development, and immune function (Henry et al., 2012).Chronic exposure leads to reduced colony growth, reproductive success and increased disease susceptibility. Chronic toxicity by constant dietary exposure to residues found in pollen and honey affects the mortality of individual bees and the growth and reproduction of their colonies. Such effects include not only sub lethal impairments but also delayed mortality (Tennekes and Sanchez-Bayo, 2011). Pesticide use, fate dynamics, and environmental conditions determine the spatiotemporal patterns of pesticide contamination in the environment (Prakash and Verma, 2020). Connecting patterns of contamination to patterns of pollinator exposure, however, requires an understanding of the behavioral and life history traits that govern the interactions between pollinators and their environment, and hence the spatiotemporal intersection between pollinators and environmental contaminants (Sponsler and Johnson, 2017; Kopit and Pitts-Singer, 2018).

3.3 Colony Collapse Disorder (CCD):

Foraging bees are exposed to multiple pesticides sprayed directly on to crops found on plant tissues including flowers. Thus, foraging bees can suffer combinatorial effect of multiple pesticides. High exposures to pesticides can cause acute mortality of foraging bees, while, at low levels, pesticide exposure has been associated with changes in individual bee behavior such as reduced foraging efficiency and decreases in colony queen production (Kuan *et al.,* 2018).



(Figure 3 - Factors of CCD (Colony Collapse Disorder) Source: Leska et al.2021)

There are many putative factors of CCD, (Figure.3) such as air pollution, GMO, viruses, or predators (such as wasps and hornets). However, it believed that pesticides and microorganisms play a huge role in the mass extinction of bee colonies. Insecticides are chemicals that are dangerous to both humans and the environment. They can cause enormous damage to bees' nervous system and permanently weaken their immune system, making them vulnerable to other factors. Some of the insecticides that negatively affect bees are, for example, neonicotinoids, coumaphos, and chlorpyrifos. Microorganisms can cause various diseases in bees, weakening the health of the colony and often resulting in its extinction. Infection with microorganisms may result in the need to dispose of the entire hive to prevent the spread of pathogens to other hives. Many aspects of the impact of pesticides and microorganisms on bees are still unclear. The need to deepen knowledge in this matter is crucial, bearing in mind how important these animals are for human life. (Leska *et al.,* 2021) Managing plant pests at the time of flowering period is very crucial to achieve maximum yield in agriculture. However, often this step displays undesirable effects on the foraging bees, which are very active at flowering, thus making their foraging trip into a hazardous trip. Due to common behavior of licking and grooming of bees, the pesticides can contaminate to other bees and thereby affecting the entire colony. The affected colony shows decline in its pollen and nectar collection and honey production ultimately resulting in the colony collapse. Honeybees already stressed by a poor diet have been found to be more sensitive to several pesticides (Challa *et al.,* 2019).

4. Experiential Data and Comparative Analysis

Data were compiled from peer-reviewed studies (2010–2023) and national pesticide usage databases in table 1. Pollinator impact metrics include LD_{50}, colony loss percentages, and visitation rate changes.

Table 1: Comparative Table of Pesticide Usage and Pollinator Impact.

S. No	Pesticides	Active Ingredient	Annual Use (tons)	LD_{50} (ng/bee)	Observed Colony Loss (%)
1.	Neonicotinoids	Imidacloprid	110,000	3.7	20–35
2.	Organophosphates	Chlorpyrifos	80,000	30	10–15
3.	Pyrethroids	Cypermethrin	70,000	35	8–12
3.	Glyphosate	Glyphosate	820,000	N/A	Indirect (15–25)
5.	Triazines	Atrazine	60,000	N/A	Indirect (10–20)

5. Mitigation Strategies and Best Practices

1. Integrated Pest and Pollinator Management (IPPM):

Integrated Pest Management (IPM) is a program of prevention, monitoring, and control which offers the opportunity to eliminate or drastically reduce the use of pesticides, and to minimize the toxicity of and exposure to any products, which are used. IPM does this by utilizing a variety of methods and techniques, including cultural, biological and structural strategies to control a multitude of pest problems. IPM is a term that is used loosely with many different definitions and methods of implementation. IPM can mean virtually anything the practitioner wants it to mean. Beware of chemical dependent programs masquerading as IPM. Those who argue that IPM requires the ability to spray pesticides immediately after identifying a pest problem are not describing IPM. Conventional pest control tends to ignore the causes of pest infestations and instead rely on routine, scheduled pesticide applications. Pesticides are often temporary fixes, ineffective over the long term (Arya and Dubey, 2013). Integrated Pest and Pollinator Management IPPM emphasizes for the integration of various pest management strategies, such as cultural practices, monitoring, biological controls, and judicious chemical use to minimize pollinator exposure (Chreil and Maggi, 2023).

2. Alternative Agrochemicals and Bio pesticides:

Bio pesticides (e.g., *Bacillus thuringiensis*, neem oil) offer lower non-target toxicity (Verma, 2017). Crop varieties with pest-resistant traits reduce chemical reliance. Neem oil form a coating on the insect body, which block the breathing process and suffocating the insect. Neem oil also work as a repellent on certain insect pests and mites also. The various parts of this tree live neem oil, neem seed cake, neem leaves, neem extracts, neem bark and roots are used in insect-pests management. Azadirectin can act as a feeding differentiates against a number of insect pests including beetles. It reduces the level of the insect hormone 'Ecdysone' by disrupting the insect's molting process so that the immature larvae cannot develop in to adult (Arya and Dubey, 2017). Nanobiopesticides have higher pesticide activity, targeted or controlled release with top-notch biocompatibility and biodegradability. Due to the drawbacks of synthetic pesticides, an alternative means of pest control is being encouraged, which is the use of bio pesticides. The effectiveness of bio pesticides in pest management comes from various modes of action, which include actions that regulate gut disruption, pest growth, and pest metabolism. Bio pesticides work by denaturing protein, causing metabolic disorder and paralysis, activating target-poisoning mechanisms, exhibiting multisite inhibitory actions, and releasing neuromuscular toxins and bioactive compounds. (Ayilara *et al.,* 2023).

3. Pollinator-friendly farming practices and Habitat restoration:

Understanding pesticide-induced changes to plants, microbes, and pollinator attraction is a particularly relevant question. Question given widespread initiatives to plant pollinator-friendly wildflowers in urban, suburban, and agricultural settings, which may inadvertently expose pollinators to pesticides (Williams *et al.,* 2015).Conserving and restoring pollinator habitat, such as native wildflower meadows and hedgerows, plays a crucial role in mitigating the impacts of pesticides. By providing alternative forage sources and nesting sites, pollinators can access pesticide-free areas, reducing their exposure and promoting their overall well-being. (Fountain, 2022). Pollinator-friendly farming enhances biodiversity and crop productivity by supporting bees, butterflies, and other pollinators. Key practices include planting diverse native flowering plants, maintaining wildflower strips and hedgerows, reducing pesticide use, and adopting integrated pest management. Providing nesting habitats, using organic or low-till methods, and preserving natural areas also help sustain pollinator populations. These approaches not only improve pollination and crop yields but also contribute to long-term ecological balance and farm sustainability (Rundlof *et al.*, 2022).

4. Public Awareness and citizen science:

Increasing awareness and providing education and training to farmers, beekeepers, pesticide applicators, and the public are essential for promoting responsible pesticide use and minimizing harm to pollinators. By understanding the importance of pollinators and the potential impacts of pesticides, individuals can make informed decisions and adopt practices that prioritize pollinator health. The Global Action on Pollination Services for Sustainable Agriculture provides guidance to member countries and relevant tools to use and conserve pollination services that sustain agroecosystem functions and to formulate policies that will ensure sustainability of these ecosystem services. At a legal level, some environmental organizations and several beekeeping organizations and concerned citizens filed lawsuits in federal courts in the USA against registration or use of neonicotinoid insecticides linked with destruction of bee colonies and other beneficial insects. At societal level, accumulative role of Non-Governmental organizations (NGOs) that advise native managers around pollinator health (Sponsler *et al.,* 2019).

5. Policy and Regulatory Frameworks

The first major restriction of pesticide use prompted by concern for pollinator safety occurred in 1999, when France Suspended the insecticide fipronil and the neonicotinoid insecticide imidacloprid applied as seed treatment to pollinator-attractive sunflower crops (Suryanarayanan and Kleinman, 2014). This was followed by a more extensive European Union-wide moratorium in 2013 on three neonicotinoid insecticides (imidacloprid, clothianidin, and thiamethoxam)applied as seed treatments to pollinator-attractive crops (European Commission 2013). Recently, the European Union has issued a ban on all outdoor use of neonicotinoid insecticides (The European Commission, 2018), citing a European Food Safety Authority report concluding that the compounds pose an unacceptable risk to bees (European Food Safety Authority, 2018). In North America, United States Environmental Protection Agency (USEPA), working in collaboration with Health Canada Pest Management Regulatory Agency (PMRA) developed beginning in 2012 a conceptual framework for quantifying risks to bees, is resulting in the 2014 harmonized Guidance for Assessing the Risk of Pesticides to Bees (US Environmental Protection Agency, 2014). Therefore, in 2013, USEPA ordered the revision of thousands of pesticide labels to reduce acute exposure of bees to neonicotinoid insecticides at bloom on crops requiring contracted pollination services. Regulatory measures, such as the EU's neonicotinoid restrictions (2013), demonstrate efficacy in reducing pollinator mortality. National guidelines should incorporate buffer zones and application timing restrictions.

In January 2017, USEPA released its policy to mitigate the acute risk to bees from pesticide products, which affects a broader range of pesticide classes (Fishel *et al.,* 2017), focusing on pesticide use by agricultural applicators when beekeepers are under contract to provide pollination services. When evaluating the safety of pesticides. There is a need to consider several parameters including the risk of exposure to multiple pesticides, or of the same pesticide being applied to different (adjacent) crops, and the need for longer-term toxicity testing on both adult bees and larvae. New protocols to detect cumulative toxicity effects and separate risk assessment schemes for different pollinator species are needed (Gill *et al.,* 2012). These will have clear implications for the conservation of insect pollinators in areas of agricultural intensification, particularly social bees with their complex social organization and dependence on a critical threshold of workers performing efficiently to ensure colony success. It is worthy to note here that the science of exposure to pesticides is still crude for honeybees, nascent at best for wild bees, and practically nonexistent for non-bee pollinators (Sponsler *et al.,* 2019).

Not only synthetic pesticides need to be assessed for safety on pollinators but also botanical pesticides. Few studies showed that field applications of botanical pesticides might represent a risk as the applications of synthetic compounds, indicating that these alternative products should also be submitted to risk assessments comparable to those required for synthetic products (Challa *et al.,* 2019; Tschoeke *et al.,* 2019). It is critical to recognize that the legitimate need to manage harmful pests underlies the phenomenon of pesticide use. Particularly in agriculture accordingly; efforts to protect pollinators from pesticide impacts should reconcile pest control needs with the conservation of pollinators, incorporating pollinator conservation into integrated pest management (IPM) frameworks rather than seeing pesticide use per se as an antagonist of conservation (Biddinger and Rajotte, 2015).

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BIOGAS PRODUCTION FROM AGRICULTURAL WASTE IN CROP FARMS

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ABSTRACT

Agricultural waste, including crop residues like straw, stalks, and leaves, presents a significant opportunity for sustainable energy production through anaerobic digestion. This process converts organic matter into biogas, primarily methane, which can serve as a renewable energy source. This paper explores the potential of agricultural waste for biogas production, examining pretreatment methods, co-digestion strategies, and the integration of biogas systems into crop farming operations. Additionally, it discusses the environmental and economic benefits, challenges, and policy frameworks supporting the adoption of biogas technologies in agriculture.

No. of Pages: 2 **References: 5**

Keywords: Biogas, Anaerobic Digestion, Agricultural Waste, Crop Residues, Renewable Energy, Circular Economy, Co-Digestion, Sustainable Farming.

1. Introduction

The global agricultural sector generates vast quantities of organic waste annually, such as straw, leaves, and stalks. Traditional disposal practices like burning contribute significantly to air pollution and greenhouse gas emissions. Anaerobic digestion provides a sustainable method to convert these residues into biogas, which is primarily composed of methane (CH) and carbon dioxide (CO). This paper explores the utilization of agricultural waste for biogas production in crop farming and assesses its environmental, economic, and policy dimensions.

2. Anaerobic Digestion of Agricultural Waste

Anaerobic digestion (AD) is a biological process involving microorganisms breaking down organic matter in the absence of oxygen. Crop residues, which are rich in lignocellulosic materials, can be challenging to digest, but pretreatment methods such as enzymatic hydrolysis or biological treatment with fungi (e.g., *Trichoderma* spp.) have been shown to enhance biogas yield (Alengebawy et al., 2024).

Co-digestion, combining crop waste with other organic materials like livestock manure, balances carbon-to-nitrogen (C:N) ratios, improving microbial activity and overall methane production (Sharma et al., 2023).

3. Environmental and Economic Benefits

Utilizing crop waste for biogas production reduces dependency on fossil fuels and mitigates methane emissions from unmanaged agricultural residues. The digestate, a by-product of AD, serves as a nutrient-rich organic fertilizer, reducing the need for synthetic alternatives and promoting soil health (Singh, Singh, & Yadav, 2022).

Economically, on-farm biogas systems can decrease energy expenditures and provide income from surplus energy sales, particularly when upgraded to biomethane for grid injection or vehicle fuel (Zhang & Zhang, 2023).

4. Challenges in Implementation

Despite its benefits, several barriers impede the widespread use of biogas in crop farms:

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- **Feedstock Logistics**: Crop residues are spatially dispersed, making collection and transport logistically and economically challenging.
- **High Initial Investment**: The capital cost for anaerobic digesters, gas storage, and purification systems remains high.
- **Lack of Technical Expertise**: Farmers often lack training in the design, operation, and maintenance of biogas systems.
- **Policy Inconsistencies**: Inadequate policy support and fragmented incentives deter adoption in many regions (Charan, 2025).

5. Policy Support and Future Outlook

Governments across the globe, including India and the EU, have initiated programs to promote bioenergy. India's National Bio-Energy Mission and PM-KUSUM scheme aim to support decentralized energy generation from agricultural sources (Charan, 2025). There is also growing interest in state-level schemes promoting residue management to combat stubble burning.

Future directions should focus on:

- Cost reduction through local manufacturing of digesters
- R&D on lignocellulose degradation
- Farmer education and technical support

6. Conclusion

Biogas production from agricultural waste is a promising approach for enhancing energy security and environmental sustainability in crop farming. By addressing logistical, economic, and technical challenges through coordinated policy efforts and innovations, this green energy pathway can be successfully integrated into modern agricultural practices.

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