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THE STRAWBERRY HANDBOOK: ADVANCED METHODS FOR HIGH YIELD FARMING

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ABSTRACT

The paper is aimed at modern strawberry producers, who want to maximize productivity, efficiency and sustainability. This article focuses into novel agricultural practices, focusing on advanced techniques such as hydroponics, vertical farming, micropropagation, and soilless media systems. Hydroponics provides exact control over fertilizer supply, resulting in maximum growth and resource efficiency. Vertical farming uses space-saving, multi-tier systems to increase productivity in small areas, making it ideal for urban and indoor settings. Micropropagation techniques enable the quick, large-scale generation of disease-free, high-quality planting material, therefore meeting the rising need for dependable strawberry plants. Furthermore, the usage of soilless media promotes plant development by creating customized substrate habitats that optimize water and nutrient retention. This handbook is a valuable resource for farmers, agronomists and researchers who want to implement cutting-edge strategies in sustainable strawberry farming. Together, these methods not only increase yield but also reduce environmental impact, conserve resources and promote year-round production.

Key words : Techniques, Micro propagation, *In-vitro*, Soilless media, Hydroponics.

Introduction

Strawberry, also known as *Fragaria ananassa*, is a short-day plant rich in ellagic acid, which has antioxidant, anti-inflammatory, anti-neurodegenerative, and anti-cancer properties (Katel *et al*., 2022). Strawberry is a lovely mild tart, sweet and nutritious red fruit whose flavor is determined by three ingredients: sugar (0.5%), acid (0.90-1.85%) and aromatic components (Sahana *et al*., 2020). Strawberry (*Fragaria* × *ananassa* Duch.) is popularly recognized as the “Queen of Fruits”. It contains significant quantities of vitamin C and antioxidants, which promote cardiovascular health and regulate blood sugar levels (Hannum, 2004; Janse *et al*., 2001). Strawberry production may take place in a variety of environments, including open fields, polyhouses, kitchen gardens, vertical farming, and hydroponics, making it a popular income crop worldwide. Strawberries are sensitive and prone to illness in their natural habitat (Afzaal *et al*., 2021). Strawberry plants face several biotic stimuli during their growth, including pests and diseases such insects, viruses, fungus, and bacteria (Wenchao, 2022). Abiotic variables like as sun insolation, cold, water deficiency, soil salinity, and chemical toxicity from mineral fertilizers have been identified as impacting them. Prioritizing crop quality increases the economic benefits of strawberry cultivation (Baggio *et al*., 2020).

Hydroponic greenhouses generate higher yields than open-field farming. Strawberry agriculture is on the rise due to its short growing season, high yield and market value (Jared Rubinstein, 2015). According to (Hossan *et al*., 2013), there is a need for rapid strawberry production to fulfill rising demand from local market sellers. Greenhouses with hydroponic or aquaponic systems can alleviate the high water need and atmosphere for strawberry growing, making indoor production more feasible (Jared Rubinstein, 2015). As cultivable land area decreases and food demand rises, greenhouse horticulture using hydroponic techniques can address issues of open field farming, improve food security, and produce higher-quality goods. According to Cantliffe *et al.* (2003), hydroponic strawberry growing can boost yields, improve harvest efficiency, reduce pesticide use and protect against temperature and rainfall. Gilbert Ellis Bailey, an American geologist, coined the phrase "vertical farming" in 1915, referring to rooftop gardening practices. In 1951, vertical farming evolved to include hydroponic towers. In 1991, Professor Dickson Despommier proposed bringing food production units closer to customers to reduce carbon footprint, despite the expansion of vertical farming through hydroponics and greenhouses (Garraway *et al.,* 2021).

Strawberry cultivation systems

Soilless growth medium has various advantages over soil in terms of physical, biological, and chemical aspects (Wang *et al*., 2016). These media are porous, lightweight, free of toxic chemicals, low in phytopathogenic microorganisms, and easy to fertilize based on crop requirement. It possesses exceptional water and moisture retention ability (Giménez *et al*., 2008). There are two basic classifications: solid substrate (other than soil) and hydroponics (water). Solid growth material may be used in hydroponic cultivation to maintain proper plant position. Strawberry cultivation requires ideal circumstances in the environment or soil to be planted. Soilless growing substrates reduce weed infestation, reduce soil-borne diseases, maximize fruit yield, are ideal for regions with poor soil conditions, promote root development, and improve water efficiency. Therefore, it plays a crucial function in strawberry cultivation. New technologies and procedures have been developed to properly manage and determine soil conditions. In research conducted, soil moisture content, humidity level, and soil temperature were measured using modern technology available today. In addition to these factors, an Arduino microcontroller, moisture sensor, temperature/humidity sensor, and GSM module were shown to be capable of determining maximum and lowest temperatures and humidity levels. A DHT 11 sensor put in the greenhouse may provide precise temperature and humidity data through SMS communication (Elenzano *et al*., 2021).

Advanced Strawberry Production methods

Hydroponics

Hydroponic plant production systems are a rapidly increasing field in horticulture. Hydroponic crop output grew by 20% globally from 2016 to 2019. In addition, the output value in dollar terms climbed from 6.9 to 8.3 × 109 USD in the same time, with an expected 45% growth by 2025 (Shahbandeh, 2019). Hydroponics are increasingly used for greenhouse strawberry growing to eliminate the soil-borne diseases and insect damage. Hydroponics facilitates increased yields and improved product quality via proper fertilizer and water management (De Cal *et al.*, 2005; Martinez *et al.*, 2017). There are six types of hydroponic systems: wick, drip, ebb-flow, deep water culture, nutrient film methods, and aeroponic. Hydroponic systems are a mixture of six main kinds, with several variants.

Ebb and flow system : This is the first commercial hydroponic system that follows the flood and drain technique. A water pump with a timer pumps fertilizer solution and water from a reservoir onto a growth bed, providing nutrients and moisture to plants (Sharma *et al.*, 2019). The timer is configured for activation multiple times each day based on plant size, kind, temperature, humidity, and growth media (Dunn, 2013). Growing various crops can lead to root rot, algae and mold (Nielsen *et al.*, 2006), necessitating the need of a filtration unit in certain systems.

Drip system : This hydroponic system is likely to be the most frequently employed in both residential and commercial settings across the world (Dunn, 2013). The pump distributes water and nutrient solution from the reservoir to each plant roots in the right proportion (Rouphel and Colla, 2005). Plants are often put on a moderately absorbent growth medium where the nutrient solution drips slowly. Crops may be cultivated more efficiently with proper water conservation.

Wick system : Dunn (2013) describes the simplest hydroponic system, which does not require power, pumps, or aerators. Plants are planted in absorbent mediums such as coco coir, vermiculite, or perlite, with a nylon wick leading from the roots to a reservoir of nutritional solution (Sharma *et al*., 2019). Two wicks are used to pull nutrient solution from the reservoir into the growth media by capillary action. Because there are no moving parts, this system is termed passive and requires maintenance rather than ebbing and flowing. This technique is suitable for tiny plants, herbs, and spices, but not for thirsty crops. This is the single downside of the system (Kang *et al.*, 2009).

Deep water culture system : Deep water cultivation involves suspending plant roots in nutrient-rich water and providing direct air to the roots via an air stone (Sharma *et al.*, 2018). The bucket system is a prime example of this system. Plant roots rapidly develop when floating in nutritional solution. Monitoring oxygen, nutrition, salinity and pH levels is necessary (Domingues *et al.*, 2012). This technique is ideal for cultivating large fruit output plants such as tomatoes, cucumbers and strawberries.

Aeroponic system : This is considered the most advanced sort of hydroponic system. Air is mostly used for growth medium, such as N.F.T. (Dunn, 2013) reports that roots are misted with nutritional solution while hanging in the air. Aeroponic systems require a short cycle timer to run the pump for a few seconds every few minutes. This system is used in a protected environment. This technique is ideal for leafy vegetables like lettuce and spinach.

Nutrient film techniques (NFT) : This technology maintains a steady flow by circulating water or nutrient solution throughout the system and entering the grow tray via a water pump without a timer (Domingues *et al.*, 2012). The system is slightly tilted to allow nutrients to flow through the roots and back to the reservoir (Sharma *et al.*, 2018). Fungal infections can affect the roots due to their constant exposure to water. This technique is globally recognized for lettuce production.

Vertical farming (VF) in strawberry production

Human population growth, urbanization, pollution and soil erosion have all contributed to a progressive decrease in arable land area. The world's urban population now stands at 60%, but it is projected to reach 68% by 2050 due to increased immigration in the 2030s (UNDA, 2018; Khan *et al.*, 2020). Vertical farming can help address these concerns. Vertical farming, also known as controlled-environment agriculture, achieves excellent yields with few inputs in a small space. (Touliatos *et al.*, 2016).

However, in Vertical Farming applications, high-efficiency production may be achieved with significantly fewer resources, including water and space (Zhou *et al.*, 2017). Hydroponic vertical farming is a cutting-edge, eco-friendly agriculture practice that does not destroy biodiversity. In recent years, due to negative factors such as climate change in agricultural lands, pollution of soils due to the intensity of agricultural practices, use of agricultural lands as settlement areas and deterioration of soil structure, plant production companies and their investors have pioneered the use of vertical farming techniques, which is a different and alternative method for strawberry production (Bin, 2017).

Micropropagation technique in strawberry production

Boxus (1974) published the first study on strawberry propagation *in vitro*. Strawberry micropropagation produces healthy plants from runners (Boxus, 1974). Tissue-grown propagules need less storage space than typical runner plants and may be stored in vitro at any stage of development (Swartz *et al.*, 1981). Micropropagated strawberry plants have significantly reduced disease transmission through plants and soil. Strawberry plants may be effectively micropropagated using nodal cuttings grown *in vitro* (Karhu *et al.*, 2002). Successful strawberry planting requires a large number of runners and proper planting material. Strawberries may be propagated using various combinations of plant growth regulators, including runner/nodal segments (Anuradha, 2013 and Jhajhra *et al.*, 2018) and runner tips in vitro micro propagation (Ashrafuzzaman *et al.*, 2013). Strawberry plants may be successfully micropropagated from nodal cuttings *in vitro* (Karhu, 2002) as proven by previous research. Plant growth regulators, such as auxins and cytokinins, are added to culture conditions to control the morphogenesis and organogenesis of explants grown in vitro. Cytokines play an important role in the hormonal control of plant development. Plants have an effective strategy for maintaining physiologically active cytokinin levels. When exogenous cytokinins are administered. The nutritive medium, the apical meristem, and a group of micro-shoots develop all at the same time (Avalbayev *et al.*, 2012 and Kukharchik, 2019).

In this system, Young strawberry plantlets obtained from meristems are initially maintained in a medium containing undiluted Knop solution, the micro-elements used by (Murashige and Skoog, 1962), nicotinic acid 0.5 mg/L, pyridoxine HCl 0.5 mg/L, glycine 2.0 mg/L, thiamine HCl 0.1 mg/L, meso-inositol 100.0 mg/L, indolybutyric acid 1.0 mg/L, glucose 40.0 g/L, agar 8.0 g/L, and an adjusted pH of 5. This medium is a combination of two media as (Vine, 1968) advised for strawberry meristem growth (Boxus, 1974).

Process of micropropagation in strawberry

Shoot tip disinfection : Aseptic cultures were started from 3 to 4 cm long runner tips of two-month-old healthy strawberry plants of the varieties 'Sweet Charlie' and 'Winter Dawn'. To eliminate adherent dust, shoot-tips were rinsed under running tap water for 10 minutes. The shoot tips were immersed in 3% Teepol (liquid soap solution) for 5 minutes before being cleaned with running tap water for 10 minutes. Shoot tips were disinfected under aseptic conditions with 1% Bavistin (a fungicide solution containing carbendazin 12% and mancozeb 63%) for 10 minutes. Later, the shoot tips were treated with a 0.5% sodium hypochloride solution for 7 to 8 minutes, then immersed in 0.05% mercuric chloride for 1 minute, and rinsed three times with sterilized RO water. Shoot tips were clipped (0.4 to 0.5 cm) at the cut end before being inoculated into culture initiation media (Dhukate *et al.*, 2021).

Culture media : The culture media was (Murashige and Skoog's, 1962) nutritional medium, which included 0.75% tissue culture grade agar, 0.7 g L^{-1} ascorbic acid (AA), 10 mg L^{-1} adenine sulphate (ADS), and 4% table sugar. The pH of the culture media was adjusted to 5.8, and about 50 mL of medium was put into glass bottles with semi-transparent polypropylene screw covers and autoclaved for 15 minutes at 121°C. Shoot clumps were subcultured every 35 days (Dhukate *et al.*, 2021).

Shoot multiplication : To reduce culture loss due to endophytic contamination, the first two subcultures were grown on MS medium with 1 mg L^{-1} BA and 0.01 mg L^{-1} KN. To avoid vitrification and stunted growth, three shoot clumps were maintained on 3/4 strength MS medium with 0.5 mg L^{-1} BA and 0.1 mg L^{-1} KN commencing with the third subculture. Following the ninth subculture, cultures were resumed with micropropagated plants produced in the greenhouse (Dhukate *et al.*, 2021).

***In-vitro* rooting :** The cut ends of *in vitro* produced shoots were treated with 500 mg L^{-1} indole-3-butyric acid (IBA) solution for 30 seconds before being cultured on MS medium containing 1 mg L^{-1} IBA, 0.1% activated charcoal, and 6% table sugar (Dhukate *et al.*, 2021).

Acclimatization and plantlets Hardening : For primary hardening, in vitro rooted shoots were removed from the culture media, carefully rinsed with tap water to remove any remaining medium and placed to nursery trays with sterilized cocopeat in a polyhouse. For 10 days, nursery trays were covered with clear polythene in a low tunnel to maintain high relative humidity (95%), as well as protect them from water and light stress. These plants were watered with Sardar WSF-19-19-19TM, a 0.2% (w/v) liquid nitrogen, phosphorous, and potassium fertilizer solution, at three-day intervals. After four weeks, the secondary hardening and field transfer were completed. The plantlets were transported to the net-house on plastic bags filled with garden soil for acclimatization and hardening before being transplanted into fields (Dhukate *et al.*, 2021).

Advantages of this technique

Strawberries may be micropropagated, which has various advantages, especially for large-scale production. It enables the fast growth of disease-free, genetically homogeneous plants in a controlled setting, resulting in high-quality planting material (Mir *et al.*, 2010). This approach is good for propagating elite cultivars since it generates a high number of plants in a short period of time. Micropropagation allows for year-round production, regardless of seasonal limits, and aids in the conservation of precious germplasm. Furthermore, the approach provides steady growth and yield, which improves commercial profitability. Micropropagation speeds up strawberry plantation development and helps to fulfill the global need for healthy, productive crops by minimizing reliance on traditional propagation methods (Bhojwani *et al.*, 2013).

Disadvantages of this technique

Micropropagation of strawberries, while incredibly effective for bulk production has some drawbacks. The procedure is labor-intensive, necessitating expert workers and exact laboratory conditions, which may raise expenses. Contamination hazards are substantial because to the sterile environment required and any microbial infection might result in severe losses. Somaclonal mutations can cause genetic heterogeneity and inconsistency in plant quality. Furthermore, plants produced in vitro may be poorly adapted to outdoor circumstances, resulting in significant death rates following transplanting. Micropropagation is less accessible to small-scale farmers due to the high initial setup costs. Overall, these constraints can stymie wider adoption, despite the benefits.

Potting media for Soilless Cultivation

Soilless growth media, which are devoid of soil-borne illnesses, pests, and nematodes (Tehranifar *et al.*, 2007; Thakur, 2018) are more popular for eliminating pests and diseases (Adak, 2015). Soilless horticulture artificially supports plants and stores nutrients and water (Raja *et al.*, 2018). Soilless medium is gaining popularity since it is devoid of soil-borne pests, illnesses, and nematodes. (Tehranifar *et al.*, 2007) address inadequate drainage, structure, soil fumigation and salt accumulation to improve vegetative growth, fruit output, and strawberry quality (Shylla *et al.*, 2018). Strawberries often grow in soilless medium such as peat moss, rockwool, perlite, cocopeat, vermicompost and other blends. Growing media qualities impact plant growth and production, both directly and indirectly (Taylor, 2013). Growing demand for high-quality off-season varieties has led to tremendous growth in greenhouse production. Soilless mediums are commonly used in greenhouse crop production to prevent soil-borne illnesses, minimize labor costs, and increase crop yields annually. Effective fertilizer management is crucial for successful hydroponic systems. Crop output and quality are heavily influenced by how well plant nutrients are absorbed from the solution (Sumit, 2023).

Characteristics : Soilless substances are lightweight, highly porous, free or low in harmful chemicals and phytopathogenic microorganisms, easy to sterilize and fertilize as per crop demands, possess unique water-holding and moisture retention capacities and release mineral elements upon decomposition.

Types of soilless media for strawberry cultivation

Peat and peat like material : Sphagnum moss is a desired type of organic matter. It is commonly accessible and affordable. It improves drainage and aeration in heavy soils. It can absorb 10-20 times more water than its weight in water-holding cells. Hypnaceous moss decomposes faster than certain other peat kinds. Thus, it is appropriate for media usage. According to Lee *et al.* (2013), peat moss and other organic substrates, such as rice husk and vermicompost, are commonly employed for early plant acclimatization in vitro. Peat moss provides moisture and nutrients to plants during their early development phases.

Oberpaur *et al.* (2010) found that combining peat moss with soil creates the most efficient and cost-effective potting media for banana plantlets in a screen house, despite its high cost.

Cocopeat : Cocopeat is a widely used substrate in India. Coco peat is a by-product of the coconut is a popular substrate due to its cost, aeration, drainage and longevity. It is available in both loose form and compacted bricks, making transportation cost-effective. These bricks, weighing roughly 4-5 kg, may expand to 4-5 times their capacity when loosening with water. Before using coco peat, it is recommended to sterilize it using steam or another means. Compostable material from the coconut industry is a cost-effective, porous, draining and durable substrate option (Akshay *et al.*, 2023).

Vermicompost : Vermicompost is composed of transportable plant nutrients and components produced during organic matter decomposition, including nitrogen, exchangeable phosphorus, potassium, calcium, and magnesium. Arancon *et al.* (2004) found that using vermicompost in soilless culture increased strawberry growth and production.

Plant residues : Leaf mold enhances potting soil aeration, drainage, and water retention. Excessive usage of sawdust may limit plant development due to its high cellulose and lignin content. Sawdust from phytotoxic tree species should not be used in potting medium. Bagasse is a waste byproduct from the sugar industry. It improves the aeration and drainage of container medium and is available in low-cost. Rice hulls significantly improve drainage in potting medium.

Farmyard manure : Farmyard manure (FYM) is a nutrient-dense organic fertilizer made from digested animal excrement and plant leftovers. It improves soil fertility by delivering vital minerals including nitrogen, phosphorus, and potassium, which promote healthy plant development. FYM enhances soil structure and water retention, lowering erosion and enhancing drought resilience. FYM coupled with perlite was shown to be the optimal media for strawberry growing, leading to healthier plants, increased fruit output and improved runner development (Shylla *et al.*, 2018).

Clay particles/ balls : These are mainly use in vertical system of strawberry plantation. It promotes aeration and drainage. It tends to float and is reasonably priced. When used as a top layer mulch, clay balls can aid to retain soil moisture, reduce weed development, and regulate soil temperature. In hydroponic systems, clay balls are frequently utilized as a strawberry growth media. They are light, reusable and have good water holding capabilities.

Perlite/Vermiculite : Perlite is a white porous substance made from crushed volcanic rock that expands when heated. Perlite is a sterile, neutral pH material that improves air space and water drainage in nursery environments. Using perlite keeps the medium lightweight compared to dirt. Perlite and its combinations can stimulate root growth by improving aeration and promoting shoot nutrient absorption, resulting in higher berry output (Shylla *et al.*, 2018). Vermiculite is a naturally occurring mineral that appears in the shape of shiny flakes ranging in color from dark gray to sandy brown. Garden vermiculite will always be exfoliated. It provides a variety of beneficial properties for both soil and plants. It aerates, retains moisture and nutrients, is lightweight, non-toxic, sterile does not decay or mold and has a neutral pH.

The impact of Potting Media on Strawberry growth, Yield and Quality

According to Jafarnia *et al*. (2010), strawberries grown in 60% perlite + 40% peat moss, 100% perlite, and 80% perlite + 20% peat moss produced the most fruits, dry weight, leaves and flowers per plant in the Frenso, Selva and Kordestan cultivars. Thakur and Shylla (2018) found that using perlite + FYM (1:1) media improved plant height, flowering, leaf area, crowns, root length, runners and yield in Chandler under protected conditions. Growing media composed of vermicompost, perlite, and cocopeat in a 5:45:50 ratio. The strawberry cv. showed considerable improvement in leaf count, leaf area, petiole length, runner count, crown count and fruit output (Ameri *et al*., 2012). Sharma *et al*. (2002) investigated the impact of growing media on strawberry (*Fragaria* × *ananassa* Duch.) growth, yield and quality. Three media ratios were used: 1:1:1, 2:1:1, 3:1:1, 4:0:1, 4:1:0 and 4:1:1 respectively, with a control of soil, sand and FYM in a 1:1:1 ratio. Plants grown with a 3:1:1 ratio of cocopeat, perlite, and vermicompost (C2T3) showed increased height, growth, and flowering/fruiting. Ameri *et al.* (2012) found that a mixture of 50% cocopeat, 50% perlite and 5% vermicompost resulted in the highest plant spread. Camarosa contains 45% perlite and 50% cocopeat. According to Yeganeh *et al.* (2024), the highest number of leaves was 10.3. Camarosa cultivar performed well in a 50% perlite/50% peat moss growing medium. Hesami *et al.* (2012) found that soilless potting media with varying ratios of cocopeat, perlite, pumice and vermicompost substantially affected strawberry output.

Conclusion

In conclusion, it is now essential to cultivate strawberries using innovative approaches and techniques. Due to the fact that strawberries are a nutritional fruit, their significance in human nutrition is dependent on their pleasant flavor and scent as well as the rising demand and supply in the global strawberry market and production. Researchers and producers have been looking for new alternative production models in strawberry production due to the mismanagement of cultivated soils and water resources used in strawberry cultivation worldwide, the decline in these production areas, soil pollution from excessive use, and the sharp rise in labor and input costs. Farmers are better equipped to meet the growing global demand for strawberries by incorporating advanced strategies such as hydroponics, vertical farming, micropropagation and soilless media. Hydroponic systems, which provide nutrients directly to plant roots, have been shown to considerably increase production and water efficiency when compared to standard soil-based approaches. Meanwhile, vertical farming saves space by stacking crops in controlled surroundings, allowing strawberries to be grown all year, even in cities.

In-vitro micropropagation techniques have been demonstrated to be a viable alternative to traditional runner generation for bulk propagation. It's also well knowledge that tissue cultured strawberry plants yield more fruit than traditionally cultivated plants. This page also covers the fundamentals of in vitro micropropagation in strawberries, including its history, benefits, and drawbacks. The micropropagation technique is the most widely used method for producing strawberry plantlets on a commercial basis (Capocasa *et al*., 2019). Farmers employing these modern approaches can increase yields while also contributing to a more sustainable and efficient agricultural future. As technology and research advance, the potential for future development in strawberry production remains enormous. This manual provides a foundation for producers looking to embrace innovation and implement innovative solutions that will impact the future of strawberry farming. Finally, the strategies given here enable farmers to increase production, profitability, and environmental stewardship, assuring strawberries' continued success as a worldwide valued commodity.

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