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PRELIMINARY STUDIES ON THE INFLUENCE OF DIFFERENT SUBSTRATES ON THE CULTIVATION OF PEPPERS (*CAPSICUM ANNUUM* L.)

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Abstract

The paper presents a summary of scientific and technical findings on the influence of different substrate types used in pepper crops in protected environments. Pepper cultivation has developed a lot over time, due to different factors, so that different possibilities of cultivation have emerged, in the field, in greenhouses, in seedlings, on natural or artificial substrate, in hydroponic systems. The substrate must meet certain requirements: it must have a suitable structure, ensure gas exchange with the atmosphere and be permeable to water and air, and be rich in nutrients. In particular, the paper refers to the use of organic substrate to improve the quality and quantity of pepper fruits. According to the literature cited, the use of organic substrate offers numerous advantages including better control of nutrition and irrigation, adequate aeration and drainage and better conditions for root system development. The aim is to obtain an earlier and higher yield by adapting the pepper cultivation technology in a limited space, by using certain doses and types of fertilizers leading to the optimization of nutrients.

***Key words**: organic substrat, cultivation tecnology, higher yield, protected environments.*

INTRODUCTION

In light of current global trends, which encompass concerns regarding burgeoning population growth, elevating standards of living, and the imperative to augment agricultural productivity, intensified attention is being directed towards the cultivation of agricultural crops, with a particular emphasis on vegetable crops. This necessitates a deliberative exploration of diverse growing media, encompassing both organic and inorganic substrates, to meet the escalating demand for food. Projections by Blok et al. (2021) forecast a substantial fourfold increase in the utilization of varied growing media by 2050, underpinning aspirations for enhanced sustainability, precision in water and nutrient management, and increased resistance against diseases.

A consensus prevails within the scientific community regarding the imperative to discover novel substrates conducive to horticultural and potted plant cultivation (Paradelo et al., 2012). Furthermore, organic materials are increasingly recognized as secure reservoirs of plant nutrients, posing minimal risks to crops or soil integrity (Hasanuzzaman et al., 2010).

Amidst the dynamic landscape of crop management, propositions for novel substrates in soilless production exhibit considerable variability (Papadopoulos, 1994). However, the efficacy of many innovative substrates is often compromised by suboptimal management practices. The selection of a specific substrate is intricately influenced by factors such as local availability, cost considerations, and growers' familiarity with substrate performance. Moreover, decisions regarding substrate choice necessitate a nuanced evaluation of various physical and chemical attributes (Cantliffe et al., 2001; Gruda et al., 2016).

Extant research underscores the profound impact of agricultural management practices on the physical attributes and chemical composition of fruits and vegetables. Variations in elemental concentrations are observed, owing to the interplay between intrinsic genetic factors and extrinsic environmental influences, notably interactions between soil and plants (Barcanu et al., 2020; Soare et al., 2017; Dinu et al., 2018).

Among vegetable crops, sweet peppers (*Capsicum annuum* L.) hold a distinct position, prized for their vibrant hues, delectable flavor profiles, and nutritional richness (Vega-Galvez et al., 2009). Analogous to numerous other vegetables, peppers are amenable to cultivation utilizing conventional substrates such as perlite, sand, rockwool, and other soilless systems, which have substantially supplanted traditional soil-based cultivation methods within greenhouse environments (Zhai et al., 2009).

Thus, a comparative analysis of various substrates utilized in sweet pepper cultivation, elucidating their distinct advantages and applications has been conducted. Through a comprehensive review of literature, substrates including peat, coconut fiber, sheep wool, rockwool, compost, rice hull, organic mulch, vermicompost, and plastic mulch are evaluated based on their unique properties and contributions to plant growth and soil management. Each substrate is examined in terms of its reusability, capacity for air maintenance, nutrient content, weed suppression, and impact on soil quality and microbial activity. The findings provide valuable insights into selecting suitable substrates for optimizing plant productivity while considering environmental sustainability.

MATERIALS AND METHODS

A comprehensive literature search was conducted using prominent academic databases including Google Scholar, Science Direct, and Springer, was conducted to identify relevant studies published within recent years. The search was conducted using a combination of key terms, including "organic substrate", "sweet pepper crop", "greenhouse crop", "hydroponics", and "crop management". Only peer-reviewed articles meeting specific criteria were considered for inclusion in this review. Selected studies were required to have relevance in the vegetable growing field and to present comparative data on the performance of different substrate types in sweet pepper (*Capsicum* sp.) cultivation within protected environments, such as greenhouses or solariums. Initial screening of articles was conducted based on title and abstract to identify potentially relevant studies. Full-text review was then performed to assess eligibility based on the inclusion criteria. A total of 154 papers were initially identified through the literature search, of which 67 studies met the selection criteria and were included in the final review. Data relevant to substrate types, cultivation methods, experimental design, crop performance metrics, and other pertinent variables were extracted from each selected study. Comparative analyses were conducted to evaluate the efficacy of different substrate types in terms of growth parameters, yield, nutrient uptake, disease incidence, and other relevant outcomes. Findings from the selected studies were synthesized to provide insights into the suitability and effectiveness of various substrate options for sweet pepper cultivation in protected environments.

RESULTS AND DISCUSSIONS

The substrate plays a pivotal role in regulating the water balance crucial for plant growth, primarily by its water retention capacity (Kirda et al., 2004). This capacity depends on the physical attributes of the substrate, including particle size, structure, and porosity (Ansorena, 1994; Burés et al., 1996). Substrates comprising particles ranging from 1 to 10 mm exhibit varying water retention capabilities (Sanchez-Molina et al., 2014), with smaller particles (<1mm) demonstrating increased water holding capacity (Ansorena, 1994).

The cultivation of peppers in organic substrates offers numerous advantages over traditional soil-based methods, particularly in terms of overall and early production yields. Soilless cultivation facilitates denser plant growth and balanced supply of air, water, and nutrients, thereby enhancing disease resistance. Moreover, according to Munoz et al. (2010), soilless cultivation minimizes weed growth and allows for the adoption of natural or biological pest control methods, while also facilitating easier elimination of soil-borne pests and diseases.

Hydroponics emerges as a prominent soilless cultivation technique renowned for its productivity, water and land conservation, and environmental sustainability (Savaas, 2003; Barcanu et al., 2018). This method provides precise control over plant nutrition, eliminates soil preparation requirements, and enhances cultivation duration and greenhouse yields. The transition to hydroponics aligns with environmental policies, facilitating reduced fertilizer usage and mitigating nutrient leaching into the environment (Avidan, 2000; Barcanu-Tudor & Draghici, 2018).

A suitable substrate should possess sufficient mechanical properties, high porosity, and the ability to evenly distribute oxygen and water for activity. It should also have a low soluble salt content and a pH between 5.0 and 6.5, as well as being sterile and chemically inert. Soilless substrates are derived from organic materials. Donnan (1998) suggests that materials with health benefits can improve product quality. Growing media serve several functions, including providing aeration and water, supporting maximum root growth, and physically supporting plants.

The physical and chemical properties of growing substrates are crucial factors when used as growing media in soilless culture.

In terms of physical properties, the most important characteristics of growing media are a high content of easily available water combined with adequate air supply. Bilderback et al. (2005) proposed ranges for physical substrate properties, including 0.19-0.70 g, 3 cm for bulk density, 10-30% for air porosity, and 50-85% for total porosity.

The degradation of soil quality due to environmental conditions and improper management practices necessitates a transition to soilless cultivation systems, which provide desirable conditions for crop growth and development and enhance resource use efficiency. One of the factors limiting growth in soilless cultivation systems is the type of growing substrate. The use of more sustainable resources and ecological growth substrates is a challenge that affects the soilless culture industry.

Peat

Peat, derived from the slow decomposition and partial carbonization of accumulated plant material in unaerated bogs, serves as a natural fertilizer renowned for its unique properties.

It emerges as a versatile option, offering reusable properties and economic advantages, especially in regions with abundant resources. Its unique formation under acidic, waterlogged conditions renders it highly productive for soilless cultivation (Kitir et al., 2018; Osvalde et al., 2021).

Following fertilization and liming, Sphagnum peat often stands as the primary constituent of numerous growing media due to its distinct advantages. Its inherently low pH and nutrient content allow for facile adjustment to cater to crop-specific requirements. Moreover, the mode of peat formation ensures its freedom from pests and pathogens, while controlled production processes further eliminate weed seeds (Schmilewski, 2008).

Peat emerges as a quality substrate, exhibiting superior characteristics compared to alternative growing media, thus rendering it the predominant choice in organic substrates. By comparing black and red peat, composted bark and sandy soil, through chemical analysis, biometric measurements and quantity of product, Popescu et al., (1995) highlighted the superiority of the two substrates, obtaining a double yield and a harvest two weeks earlier.

Moreover, the parameters measured on direct seeding on peat substrate, were higher than those obtained from transplanted seedlings such as fresh root mass, dry matter. Among the biometric parameters, plant height was higher in the transplanted plants, but other indices such as hypocotyl length, stem diameter, number of leaves, leaf area were higher in the transplanted plants (Jankauskienė & Laužikė, 2023).

Although peat is the most important constituent of growing media, other organic and mineral-organic materials are being promoted through research and development. It is important to note that the use of these materials should be clearly marked as subjective evaluations. For several years, more funding and effort have been invested in testing alternatives to peat than in peat itself. (Schmilewski, 2008)

The hot pepper plants grown in a big pot system have recorded the highest values for vegetative growth parameters, yield per square

metre, and the percentage of nitrogen and phosphorus in leaves (Metwally, 2016).
Based on the study's findings, it may be advisable to use peat growing media to improve the quality and yield of pepper cultivars (Gungor &Yildirim, 2013)

Coconut fibre

Coconut fiber stands out as a promising and environmentally friendly substrate for soilless cultivation, characterized by its composition of lignin and cellulose particles with varying sizes. This substrate exhibits diverse capabilities, including cation exchange, absorption of gases or ammonia nitrogen, and adjustment of pH levels within the culture medium (Shinohara et al., 1997).
It presents notable attributes such as high air maintenance capacity and re-wettability, enhancing its suitability for hydroponic systems (Abad et al., 2005).
When employed in pepper cultivation within pots, the utilization of coconut substrate has demonstrated the potential to yield high-quality harvests while enhancing economic efficiency (Roşca & Novac, 2010).
Abad et al., (2005) provided regression equations aimed at formulating a coir dust medium with optimal physical characteristics tailored to specific soilless substrate culture systems. The preparation of this medium involves blending appropriate proportions of various particle size fractions. Notably, the particle size distribution of coir dust significantly influences its physical properties, impacting aspects such as water retention, aeration, and relative hydraulic conductivity. These properties, heavily influenced by particle size distribution, play a pivotal role in enhancing irrigation management within containers utilizing coir dust as a substrate.

Sheep wool

Sheep wool, often regarded as a byproduct of sheep farming, has garnered attention as a potential resource for agricultural applications, particularly as a fertilizer or substrate. Although less conventional, it serves as a nitrogen-rich substrate, contributing to plant nutrition and potentially mitigating waste streams (Bradshaw and Hagen, 2022).
Concerns surrounding its safe utilization prompted investigations into its efficacy in enhancing plant growth and yield. In a study conducted by Górecki & Górecki (2010), the impact of washed sheep wool as an amendment to a peat-based growing substrate was evaluated concerning the growth and yield of sweet pepper, tomato, and eggplant. The experimental setup involved spreading a layer of wool on a 5 cm thick stratum of substrate, followed by covering with the same substrate at a rate of 10 g of wool per 1 dm^3 of substrate. The plants were individually cultivated in containers.
Results from the study revealed that the incorporation of wool led to notable enhancements in yield, with increases of up to 33%, particularly evident for tomato and pepper crops. Furthermore, the addition of wool induced alterations in the nutrient content of both the substrate and leaves, signifying its potential as a valuable and environmentally friendly fertilizer.
Bradshaw & Hagen (2022) noted that mulching increases soil temperature, which results in a higher release of nitrogen from sheep’s wool. The performances of wool pellets were very close to those of organic fertilizers, which indicates that wool can be an alternative as a growing medium in ecological agriculture.

Rockwool

Mineral wool products are engineered to possess notable water and air retention capacities, facilitating root growth and nutrient uptake in hydroponic systems. Thus, rockwool stands out for its inertness, sterility, and efficient drainage properties, making it indispensable in hydroponic setups while ensuring disease and pest control. Furthermore, rockwool exhibits a rapid response to fluctuations in liquid feeding electrical conductivity (EC) or pH requirements, enabling precise control over nutrient delivery and maintaining optimal growing conditions (Bussel & Mckennie, 2004). The fibrous structure of mineral wool provides robust mechanical support for plant development. However, the naturally high pH of mineral wool renders it unsuitable for immediate plant growth, necessitating conditioning processes to attain a stable and appropriate pH level. Conditioning typically involves pre-soaking mineral wool in a nutrient solution adjusted to pH 5.5 until bubbling ceases (Alexander et al., 1994).

Water absorbent rockwool is extensively utilized in horticulture as a substrate for propagation and growth. Typically formed into plugs, blocks, or slabs, rockwool serves as an intermediary medium for cultivating crops until they reach transplanting maturity. Various types of blocks and slabs are manufactured, differing in density, fibre orientation, size, and shape. While some are single-use with lower fibre density and shorter lifespan, others are more durable with higher fibre density. The orientation of fibres in rockwool slabs, whether horizontal or vertical, impacts water holding capacity and aeration, with horizontal fibres and dual density slabs exhibiting superior performance (Bussel & Mckennie, 2004).

Water-repellent rockwool is commonly used in horticulture as flock or granulate in coarse, medium, and fine grades. Coarse grade water-repellent rockwool may occasionally be used as a soil conditioner in the greenhouse. The main use of all grades of water-repellent rockwool is in container mixes, which also include water-absorbent rockwool flock or other substrates such as peat, bark, and soil. Nursery, houseplants, hydroponic herbs, and commercial cut flower crops are grown in containers using these mixes. (Bussell & Mckennie, 2004).

Despite its prevalent use in Europe, rockwool as a growing medium presents several drawbacks. It is non-biodegradable, costly to produce due to high energy consumption, non-recyclable, and entails significant storage expenses (Osvalde et al., 2021).

Compost

The utilization of compost in agricultural practices offers a multifaceted array of benefits that contribute to soil health and productivity. As elucidated by Cortellini et al., (1996), the incorporation of compost enriches soil organic matter content, thereby fostering a conducive environment for nutrient cycling and microbial activity. Furthermore, Maynard (1995) highlights the enhancement of soil cation exchange capacity, facilitating improved nutrient retention and availability for plant uptake. Compost's capacity to augment soil water holding capacity, as evidenced by Paino et al. (1996), ensures sustained moisture levels crucial for plant growth and resilience to drought stress.

Moreover, Serria-Wittling et al. (1996) underscore its role in ameliorating soil acidity, thereby promoting optimal pH levels conducive to plant nutrient uptake and microbial activity. Additionally, Rothwell and Hortenstine (1969) demonstrate the stimulatory effect of compost on soil microbial and enzymatic activity, vital for nutrient cycling and soil health maintenance. Finally, Turner et al. (1994) high light its ability to mitigate soil compaction, thereby enhancing soil structure and aeration.

When applied as a mulch to the soil surface, organic compost exhibits a slower decomposition rate compared to when it is incorporated into the soil, allowing for its utilization throughout an entire growing season. This extended presence improves the water holding capacity of the soil and reduces the apparent density in the upper root zone (Wang et al., 2010).

Post-composting, the volume of organic compost decreases while its density increases, as observed in studies such as that by Paun et al. (2021). Despite this, mineralized nitrogen content in compost tends to be low due to inherent processes and nitrogen loss through leaching. To augment mineralized nitrogen levels, effective management of the composting process and utilization of diverse nitrogen sources are recommended (Younis et al., 2022).

Although compost can be integrated into seedling growth mixtures, it is typically not employed as the sole planting substrate due to various factors. These include rapid drying, potential presence of phytotoxins, and nitrogen immobilization by lignin. Consequently, compost is often utilized in mixtures comprising 20-30% for transplanting seedlings, as noted by Morel & Guillemain (2004).

Furthermore, compost application has been linked to enhancing plant immunity against diseases and pests, contributing to overall plant health and vigor (Ahmad et al., 2019).

Vermicompost

Vermicompost, enriched with humic substances and beneficial microorganisms, plays a pivotal role in soil health maintenance, nutrient cycling, and root protection, warranting its consideration in integrated soil management strategies (Lara & Quintero, 2006)

Its physical, chemical, and biological properties, emerges as a substrate conducive to promoting the growth of various vegetable plants within greenhouse environments. This comprehensive attributes enable it to meet the nutritional requirements of these plants effectively.

In the realm of organic chili pepper production, organic fertilizers represent a cost-effective, environmentally friendly, and sustainable alternative to chemical fertilizers (López-Espinosa et al., 2013). By reducing reliance on synthetic inputs, organic fertilizers contribute significantly to the ecological integrity of agricultural systems.

Humus derived from earthworm activity garners widespread acclaim, not only within conventional agriculture but also within the realm of organic farming (Bravo-Lozano et al., 2011).

Rice hull and straw

Rice hull is an agricultural by-product that is often underutilised. According to Okafor & Okonkwo (2009), over 100 million tons of rice hull are generated annually worldwide. Due to the increasing difficulty and expense of collecting and disposing of rice hull, it is often left unused as waste.

It demonstrates multifaceted benefits including weed suppression, improved soil nutrient availability, and control of soil-borne pathogens, making it an environmentally friendly alternative (Dobermann & Fairhurst, 2002)

The management of rice straw disposal presents a notable environmental concern if not handled appropriately, with options including incorporation into soil or field burning, as outlined by Mansaray & Ghaly (1997). Despite its disposal challenges, rice straw possesses favorable properties as a growing medium, characterized by its lightweight nature, inertness regarding nutrient absorption and desorption, good drainage, aeration, and slow decomposition rate (Saparamadu, 2008).

The utilization of rice husk is recommended only after it has been fully immersed in water for a week.

Transplanting pepper plants onto rice straw culture media led to notably higher root fresh weight, number of leaves per plant, number of branches per plant, and plant height when compared to sandy soil (El-Sayed et al.; 2015). Furthermore, sweet pepper plants grown on rice straw exhibited significantly higher early, marketable, and total yields compared to those grown on sand or other media. Analysis of leaf nutrient concentrations revealed that nitrogen and potassium levels were highest in sandy soil, while they were lowest in straw culture. Conversely, phosphorus and calcium concentrations were highest in straw culture, suggesting a significant impact on leaf chlorophyll content and phosphorus levels.

Rice straw could be recommended as a growing substrate to replace naturally infested soil. It can improve the production of pepper plants under greenhouse conditions while saving 35-38% of irrigation water and fertilizers. Additionally, it presents a solution for soil salinity and alkalinity, and avoids the serious pollution resulting from burning rice straw for disposal.

Moreover, the adoption of rice straw substrates holds promise for enhancing the exportation of organic sweet peppers by eliminating the need for soil chemical disinfectants and nematicides typically employed to combat soil-borne pathogens and nematodes.

Wood fibres

Wood fibers are derived from wood and wood waste through mechanical or thermal processes. However, only mechanically treated wood is deemed suitable as raw material for this purpose. Wood subjected to gluing, coating, lacquering, painting, or treatment with organic or inorganic substances is prohibited due to potential adverse effects.

To mitigate the risk of nitrogen immobilization by wood fibers, which can pose challenges in commercial horticulture, the addition of a nitrogen fertilizer to the wood chips prior to extrusion is recommended. This precautionary measure aims to prevent potential cultivation difficulties associated with nitrogen immobilization.

Perlite

Perlite stands as a prevalent growing substrate within vegetable cultivation, notably in the cultivation practices of sweet peppers (*Capsicum annuum*). This lightweight, inert material is derived from volcanic glass and is characterized by its high porosity and excellent drainage properties. Several investigations have indicated that in the initial phases of development (up to 90 days post-transplantation), sweet pepper plants cultivated in a perlite-based medium exhibited a notable reduction in all parameters related to vegetative growth compared to those grown in sandy soil. It should be emphasized that this research specifically targets the early developmental stages. The physical attributes of the perlite utilized in this examination were delineated as follows: a bulk density of 0.13 g/cm, moisture content, water holding capacity of 69.7%, pH level of 7.8, and porosity of 68% (Raviv et al. (2008).

The escalation in bulk density is intricately associated with a diminution in the overall pore volume, primarily impacting growth by constraining free pore space. This discovery corroborates the findings of Abd-El-Baky et al. (2010), whose investigation revealed that plant height, stem diameter, and root fresh weight exhibited noteworthy augmentation in sand-based substrates compared to those in perlite.

Organic mulch

The integration of organic mulch into agricultural and horticultural practices embodies a holistic approach to soil management, offering advantages that encompass both agronomic and environmental considerations. The utilization of organic mulch confers multifaceted benefits, each contributing to the overall enhancement of soil health and productivity (Lalande et al., 1998; Feldman et al., 2000).

Firstly, organic mulch serves as a formidable tool in moisture conservation, effectively mitigating water loss through evaporation and enhancing soil water retention capacity. This attribute is paramount in arid and semi-arid regions where water scarcity poses a significant challenge to agricultural sustainability. Moreover, the ability of organic mulch to reduce soil erosion, as highlighted by Feldman et al. (2000), underscores its role in safeguarding soil integrity and mitigating the detrimental effects of water and wind erosion, thereby preserving soil structure and fertility.

Furthermore, organic mulch serves as a natural barrier against weed proliferation, effectively suppressing weed growth and competition for resources such as water, nutrients, and sunlight. This not only reduces the need for labor-intensive weed management practices but also mitigates the use of synthetic herbicides, aligning with principles of sustainable agriculture and environmental stewardship.

Importantly, the cost-effectiveness of organic mulch, as underscored by Lalande et al. (1998), presents a compelling advantage for resource-limited agricultural systems. Its affordability and accessibility make it a viable option for smallholder farmers and subsistence agriculturalists, facilitating widespread adoption and implementation.

Additionally, the incorporation of organic mulch into soil systems augments soil quality through the gradual decomposition of organic matter, enriching soil with essential nutrients and organic carbon. This process stimulates soil microbial communities, promoting biodiversity and enhancing soil fertility and structure over time.

Plastic mulch

Plastic mulches play a crucial role in vegetable crop cultivation, serving various functions such as modifying soil temperature and moisture, controlling weeds, deterring insects, and impacting plant photobiology.

The prevalent material for plastic film mulching is low-density polyethylene, synthesized through ethylene polymerization under high pressure (Lamont, 2005). Besides these benefits, plastic mulch acts as a protective barrier against soil-borne pathogens and microorganisms, ensuring food safety and quality in agricultural production (Lamont, 2005).

Foremost, the utilization of plastic mulch markedly reduces evaporation of water from the soil, thereby conserving precious moisture resources crucial for plant growth and development. This attribute is particularly advantageous in regions prone to water scarcity, where efficient water management is imperative for ensuring crop viability and resilience to drought stress.

Furthermore, plastic mulch serves as a formidable barrier against weed encroachment, effectively suppressing weed growth and competition for essential resources such as water, nutrients, and sunlight. This not only alleviates the need for labor-intensive weed control measures but also mitigates the reliance on chemical herbicides, thereby fostering environmentally sustainable crop production systems.

Moreover, the implementation of plastic mulch has been consistently associated with increased crop yields, as demonstrated by Narayan et al. (2017). This elevation in yield potential is attributed to several factors, including enhanced soil temperature regulation, optimized moisture retention, and minimized competition from weeds, collectively facilitating optimal conditions for plant growth and productivity.

Additionally, plastic mulch contributes to improved fruit quality, characterized by attributes such as size, color, flavor, and nutritional content. The insulation provided by the mulch maintains consistent soil temperatures, promoting uniform fruit ripening and minimizing physiological disorders, thereby enhancing marketability and consumer appeal.

The expedited maturation afforded by plastic mulch translates into earlier harvests, providing growers with a competitive edge in seasonal markets and optimizing resource utilization. Furthermore, the inhibition of weed growth and reduction in soil compaction associated with plastic mulch contribute to improved soil health and structure, facilitating root development and nutrient uptake efficiency (Bosland & Votava, 1999; Tindall, 2001).

Importantly, plastic mulch serves as a barrier against soil-borne pathogens and microorganisms, safeguarding fruits from contamination and spoilage, thus ensuring food safety and quality assurance. This multifaceted array of benefits underscores the pivotal role of plastic mulch in modern agricultural practices, exemplifying its potential to revolutionize crop management strategies and foster sustainable food production systems for future generations.

The microclimate of a field can be altered by adjusting the surface's radiation budget and reducing soil water evaporation.

This has been demonstrated in studies by Liakatas et al. (1986), Romero-Sierra & Tanner (1974) and Ham et al. (1993).

The study found that the black polythene mulch (double coated 30 micron) had a higher soil moisture content (16.74%) compared to the double coated white polythene (15.22%) and the control group (10.10%). The increase in moisture retention capacity resulting from polythene mulching can be attributed to the reduction in moisture evaporation from the soil. Additionally, the water that evaporated from the soil was trapped beneath the mulches, resulting in vapours that dropped back into the upper soil layer. Wang et al. (1998) reported that all types of polythene mulch increased soil moisture content in a chilli field compared to the control. At the time of crop harvesting, weeds were removed from different plots and dried to obtain their dry weight (g/plot). The results showed that polythene mulches were more effective in reducing weed density compared to organic mulches. In plots with polythene mulch, weeds only emerged through the punch holes and no weeds were found under the plastic. This may be due to the lack of light penetration through the black plastic. The density of weeds was lowest in plots covered with black polythene mulch (74.81 g/plot), followed by those covered with white polythene mulch (32.42 g/plot), and highest in the control group (418 g/plot). Mulch affects the microclimate surrounding the plant through its interaction with water and soil. The use of mulch resulted in a higher number of fruits per plant, a decrease in the number of aborted fruits, and an increase in fruit weight, ultimately leading to higher production per plot (Narayan et al., 2017). When using various types of plastic mulches (black, aluminum, silver, and white), it was observed that the dry weight of the shoots was higher in the mulched soil compared to the control soil. Additionally, a greater quantity of nutrients (N, K, and S) were found in the leaves (Canul-Tun et al., 2017)

The analysis of the optical properties of plastic mulches in shortwave and longwave spectrums demonstrated a wide range of characteristics in modern agricultural plastics. Field experiments revealed that the optical characteristics of the mulch affected the subsoil and surface temperatures of mulched beds.

Ham et al. (1993) conducted their experiments without a crop to maximise solar irradiance on the surface and intensify the effect of mulch optical properties. The shading of the bed by the developing crop canopy would likely moderate differences between mulches, as well as the effect of mulching in general.

The combination of soil plastic mulching and the application of organic amendments shows promise for controlling soilborne pathogens in temperate regions through various mechanisms. These include the accumulation of toxic volatile compounds generated during organic matter decomposition, the creation of anaerobic conditions in the soil, and an increase in soil suppressiveness due to high levels of microbial activity (Gamliel et al., 2000). The use of organic amendments followed by soil plastic mulching may be a viable solution for controlling *Phytophthora* stem and root rot in pepper crops under temperate climates. The decrease in disease incidence observed was attributed, at least in part, to a reduction in oospore viability, an increase in soil microbial activity and functional diversity, and the production of NH_3, which may have resulted in pathogen suppressiveness.

After being warmed up, the root zone temperature in the covered raised bed was approximately 2 degrees Celsius higher than in the uncovered raised bed. The temperature of the environment and soil was influenced by the colour of the mulch and the year, while the air temperature was affected by the covering of the pepper rows. The covered area experienced a higher temperature by 2-5°C (Ham et al., 1993).

The selection of substrates for sweet pepper cultivation should be guided by a thorough understanding of their respective advantages and applications. Integrating diverse substrates into cultivation systems enables growers to address specific requirements while promoting sustainable practices and enhancing overall productivity. Future research endeavors should focus on optimizing substrate combinations and exploring novel materials to further advance horticultural production systems in a resource-efficient and environmentally sustainable manner.

CONCLUSIONS

The selection of suitable substrates for sweet pepper cultivation is crucial for optimizing growth and yield potential. Organic substrates such as peat, coconut fiber, and vermicompost offer distinct advantages in terms of water retention, nutrient availability, and disease suppression, while mineral substrates like rockwool provide precise control over plant nutrition in hydroponic systems. Understanding the attributes and applications of different substrates is essential for tailoring cultivation practices to specific crop requirements and environmental conditions.

Soilless cultivation systems, including hydroponics and organic substrate-based methods, offer viable alternatives to traditional soil-based approaches, particularly in regions with limited arable land or soilborne disease pressures. The adoption of soilless cultivation facilitates resource-efficient crop production, enhances disease resistance, and promotes sustainable agriculture practices by minimizing water and nutrient wastage while maximizing yields.

The integration of organic mulches into agricultural systems presents numerous agronomic and environmental benefits, including moisture conservation, weed suppression, soil erosion control, and enhancement of soil health. Organic mulches contribute to sustainable soil management practices by improving soil structure, fertility, and microbial activity, thereby supporting long-term agricultural productivity and ecosystem resilience.

Future research efforts should focus on optimizing substrate formulations, exploring alternative materials, and assessing the long-term impacts of soilless cultivation systems on crop productivity, soil health, and environmental sustainability. By advancing our understanding of substrate-plant interactions and cultivation practices, we can develop innovative solutions to address emerging challenges in horticultural production and promote the adoption of sustainable agricultural practices on a global scale.

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