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Role of bio-agents and bio-fertilizers in strawberry production: A review

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Abstract
Today, organic foods are renowned for being healthy for all people worldwide. A trend in consumer consumption for variety of organic products has been observed. Fruit culture in an organic way is also gaining momentum. Producing organic fruit has expanded quickly over the past ten years in response to the high demand for it on both the domestic and international markets, which has helped prevent health problems brought on by pesticides and dangerous chemicals. Organic farming improves soil health, soil moisture content, soil organic carbon, and production. Earthworm population, microbiological activity, and enzymatic activity in the fruit plant application of various Combinations and cumulative use of organics can meet the nutrient needs of fruit crops to improve yield and quality sustainability. Using chemical fertilizers too frequently and pesticides in particular on crops like strawberries that can be consumed without removing the peel fruit, are unhealthy for people. This review summarizes the different methods of cultivation of strawberry using biofertilizers and bio agents and their impact of plant growth, yield and quality.

Keywords: Bioagents, biofertilizers, fruits, strawberry, fruit cultivation

Introduction

Growing plants naturally without the use of artificial pesticides, herbicides, fertilizers, or pgr is known as organic farming. The practice of growing crops organically has grown in acceptance in recent years (Kumar *et al*. 2020) [13]. Organically grown food is now the best choice, for both consumers and farmers. In today' s there has been an increase in demand for foods that have been grown organically due to purported health benefits and worries about food safety. Additionally, more environmentally friendly and having a greater socioeconomic impact on a nation is organic farming. India's population is expanding exponentially, therefore, food security is now a top priority. For agricultural produce to develop more quickly, excessive use of pesticides, fertilizers, and plant growth inhibitors is damaging to both human health and the environment. Foods grown organically are a crucial component of leading a healthy lifestyle. Growing crops organically does not imply reverting to outdated techniques, but rather choosing sustainable practices that serve the objectives of sustainable agriculture. The 1940 book "Look to the Land," which emphasizes that the farm should contain all biological wholeness, is where the idea of organic farming originated. Essentially no synthetic input, antibiotics, growth hormones, genetic alteration methods (such as those used in genetically modified crops), sewage sludge, or chemical fertilizers are used in the cultivation of organic products (Sahani *et al*. 2020). Investigations are conducted into the value of organic farming, its guiding principles, its impact on rural economies, consumption trends, and the export of organically produced goods from India. Its foundation is the notion that organic farms should not use any synthetic inputs because the soil is a living system (Chandrashekar, 2010). Crop rotation, animal manures, crop residues, green manures, and biological pest and disease control are the foundations of organic farming, which aims to preserve the health and productivity of the soil. Crops grown using organic methods are far more valuable than those grown using conventional ones and they are increasingly being produced. According to the International Federation of Organic Agriculture Movements' (IFOAM) standards, organic farming practices and principles are based on the values of environment, justice, care and health. Ecology principle: Using living processes and cycles as a foundation, organic farming should imitate as well as work with them. Principle of Care: Organic farming should be run in a way that protects everyone's health and wellbeing. The fairness principle states that organic farming should be based on partnerships that guarantee environmental fairness. Organic farming should uphold and enhance the health of the earth, humans, animals, plants and soil (Das *et al*. 2020) [8].

Benefits of organic farming

Environmental impact

Environmental protection benefits from organic farming. The consequences of conventional and organic agriculture on the environment have been well studied. Organic farming is thought to be less destructive to the environment because synthetic pesticides, causes toxicity to water, soil, and nearby terrestrial and aquatic wildlife, are not allowed. Furthermore, because organic farms practice crop rotation, they are more effective at protective biodiversity than conventional farms. As compared to conventional farming, organic farming improves soil physio-biological characteristics such as organic matter, biomass, enzyme, improved soil stability, enhanced water percolation, water holding capacity, reduced soil and wind erosion and more.

Nutritional and health benefits

Consumer and producer demands for the nutritional content of foods cultivated organically and conventionally has increased as a result of the rising demand for fresh organically produced commodities. According to an AFSSA (2003) study, meals grown organically have more dry matter than meals grown conventionally, especially green vegetables and tubers. Compared to conventional cereals, organic cereals and commodities have less protein, but their proteins are of higher quality and have higher amino acid scores. Between 25% and 30% more lysine can be found in organic wheat than in conventional wheat. The cows who grazed organic matter and sheep have less fat and leaner meat than conventionally grazed cows and animals. A vitamin with potential cardioprotective properties, linoleic acid, is four times more abundant in the muscle of cows fed organically. An organically grazed cow's flesh was discovered to be rich in polyunsaturated fatty acids. The milk from the organic farm contains more vitamin E and polyunsaturated fatty acids than regular milk. Vitamin E and carotenoids are present in organic milk at levels that are biologically advantageous. Oleic acid level is higher in virgin olive oil that is organic. Organic plants have substantially larger concentrations of magnesium, iron, and phosphorus. Along with trace elements including manganese, iodine, chromium, molybdenum, selenium, boron, copper, vanadium and zinc, they also have higher concentrations of calcium, sodium and potassium (Yadav *et al*. 2015) [40].

Organic foods are healthier, according to a study conducted in the United States on the nutritional qualities of both organic and conventional foods. Apples, pears, potatoes, corn, wheat, and infant meals were all tested for 'bad' elements like aluminum, calcium, iron, magnesium, selenium, and zinc, as well as 'good' elements like boron, calcium, iron, magnesium, selenium, and zinc. In general, organic food included more than 20% less harmful elements and approximately 100% more beneficial nutrients. (Willer *et al*. 2015).

Bio-agents: their role in organic cultivation of strawberry

Trichoderma spp. is very effective at controlling soil-borne diseases. Because of their ability to act as biocontrol agents with direct antagonistic activities against phytopathogens and as bio-stimulants able of promoting plant growth, many *Trichoderma* spp. are successful plant beneficial microbial inoculants. Application of *Trichoderma* increased fruit yield, growth, improved anthocyanin. *Trichoderma harzianum* in combination with organic manures like by combating drought, salt and some pathogen challenges, decreasing applied fertilizers and improving the availability of most macro and microelements, vermicompost encourages production, especially in reclaimed soils (Kumar *et al*. 2020) [13]. Arbuscular mycorrhizal fungi infiltrate plant roots and establish symbiotic relationships there. By altering the morphology or anatomical structure of plant roots, enhancing the rhizosphere's chemical and physical qualities, and turning on disease resistance and defense mechanisms in plants, it can control the creation of secondary metabolites in host plants (Prasad *et al*. 2016). Rhizobium plant growth-promoters act as root colonizers (Jose *et al*. 2015). The most well-known species of a class of bacteria that serves as the main symbiotic nitrogen fixer is Rhizobium. Leguminous plants are susceptible to infection by these bacteria, which can result in the development of lumps or nodules where nitrogen fixation occurs. Using the bacterium's enzyme system, reduced nitrogen is continuously provided to the host plant, which provides nutrients and energy for the bacterium's activity. 90% of legumes can be get nondilated. The bacteria in the soil are mobile and free-living, feasting on the leftovers of deceased species live rhizobia. They differ from the bacteria found in root nodules in that they cannot fix nitrogen and have a distinct morphology. Leghemoglobin helps Rhizobium to regulate the oxygen levels in the nodule. Comparable to hemoglobin, this crimson, iron-containing protein binds to oxygen and has a similar purpose. This ensures that the bacteroids have access to enough oxygen for metabolic needs while preventing the buildup of free oxygen, which would inhibit nitrogenase action. It is thought that since neither the plant nor the rhizobia can make it alone, leghemoglobin is created as a result of their interaction (Anonymous 2002) [3]. They are common in a straight rod-like structure; in *Bacillus* plant growth promoting and shows effect against soil borne pathogens (Fikki *et al*. 2008). *Ascophyllum nodosum* increase berry size and yield (Zahidul *et al*. 2012).

Physiological aspects of bio agent action

The host plant releases a range of compounds at the first encounter with free-living rhizobia roots that penetrate the soil. Some of these promote bacterial population expansion in the vicinity of the roots (rhizosphere). Rhizobia adhere to the root hairs after identifying their intended host plant. The bacteria's nod genes are activated, which causes nodule formation (Anonymous (2002) [3]. The entire nodulation procedure is controlled through incredibly intricate chemical interactions between the bacterium and the plant. The bacteria release nod factors after becoming attached to the root hair. These encourage curling of the hair. Rhizobia then enter the root through the hair tip, where they cause an infection thread to develop. Only in response to infection does this thread form and it is made by the root cells, not the bacteria. The root is penetrated by the thread of infection. With frequent branching of the thread, the thread enters surrounding hair cells and other nearby root cells (Thoudam *et al*. 2022) [35]. The bacteria proliferate in the increasing tube network, ongoing production of nod factors that encourage the root cells to proliferate and finally establishing a root nodule. Small nodules become evident to the naked eye one week after the infection. All root nodules are thousands of living Rhizobium bacteria, the majority of which are in the distorted form known as bacteroids, are densely packed within plant cell membrane fragments are encircled by the bacteria. The nitrogen is fixed in these symbiosome-like structures, which can have one or more bacteroids inside (Cornejo *et al*., 2017). Trichoderma adheres to the pathogen by using cell-wall carbohydrates that interact with the lectins on the pathogen, coils around it to create the aspersoria. Through the parasitization of a variety of fungus, detection of other fungi, and growth toward them, *Trichoderma* spp. may directly biocontrol an organism (Sarma *et al*., 2014) [26]. The sequential expression of CWDEs, primarily chitinases, glucanases, and proteases, is a contributing factor in remote sensing. Different induction patterns exist from one strain of Trichoderma to another. It is thought that exo-chitinases are naturally secreted at low amounts by fungus. Fungal cell walls are broken down by chitinases, releasing Exochitinases are induced by oligomers and the attack starts (Benitez *et al*. 2004).

Role of bio-fertilizer

Chemical fertilizers are crucial for meeting nutrient needs, but frequent, excessive, and unbalanced use can pose health and environmental dangers, deplete the soil's chemical and physical properties and eventually lead to low crop yields. Alternative sources of safe fertilizers that can increase agricultural output without degrading soil quality must be taken into account. Therefore, the utilization of bio fertilizers provides some hope in this area. Biofertilizers have long been viewed as an economical and ethical way to improve soil fertility. N-fixing bacteria can fix nitrogen from the atmosphere either independently, symbiotically, or non-symbiotically, or they can employ a biological process to transform non-useful soil nutrients into usable forms (Prasad *et al*. 2016). Biofertilizers are organic substances that are formed by the roots of cultivated soil and contain living microorganisms. They have no harmful effects on plants, the health of the soil, or the environment. These plants help to stimulate plant growth hormones in addition to their function in fixing nitrogen and phosphorus. A form of fertilizer known as a "bio-fertilizer" (Azotobacter, PSB and Azospirillum, among others) may fix nitrogen from the atmosphere and solubilize phosphorus in the soil, boosting soil fertility and biological activity. Azotobacter is a gram-negative, nitrogen-fixing, free-living organism that is a member of the Azotbacteriaceae family. In order to increase biological nitrogen fixation and phosphorus availability, both of which are essential for healthy vegetative development, bio-fertilizers like PSB are utilized. This encourages root growth (Willer *et al*., 2019) [39]. Auxins, cytokinin, and other growth-promoting compounds are promoted by Azotobacter and Azospirillum, improving the tolerance to biotic and abiotic stress (Yadav *et al*., 2017) [41]. Some Pseudomonas species are the most effective against bacteria that colonize roots and soil-borne pathogens (Negi *et al*., 2021). Phosphorus-dissolving microbes may be essential for providing plants with soluble phosphorus (Khan *et al*., 2010). PSB plays the majority of the function in resolving inorganic P, despite the fact that fungus can also solubilize P. According to a process known as pH lowering of the soil brought on by microbial activity, the release of protons, or organic acid mineralization through acid generation phosphatase, finally leading to soil P availability, phosphorus is soluble in soil. The majority of the phosphates in soil are phosphatic. Fertilizers are fixed as phosphates, which are insoluble in water, in an alkaline environment (Satyaprakash *et al*., 2017) [27]

Physiological aspects of bio fertilizer action

Azotobacter is an aerobic heterotrophic bacterium that fixes nitrogen in the rhizosphere and gives it to the plants. These bacteria use nitrogen to make vitamins like biotin and folic acid. Ferredoxin, hydrogenase, and nitrogenase, three crucial enzymes required for nitrogen fixation, are all present in Azotobacter. Adenosine triphosphate, a type of energy, is important for the nitrogen fixation process (ATP). Due to the great sensitivity of nitrogen fixation to oxygen, Azotobacter adapted a unique defence mechanism against oxygen. This defense mechanism involves a major increase of metabolism that decreases the amount of oxygen in the cells. Additionally, there is a unique protein called shethna that guards nitrogenase and is important in shielding cells from oxygen. In the absence of a nitrogen supply in the medium, oxygen is used during nitrogen fixation to kill mutants that do not produce this protein. Ions of homocitrate have a specific function in the processes of nitrogen fixation (Anonymous, 2022) [4]. Azotobacter species can directly affect plant development by creating plant growth regulators such gibberellins, indole acetic acid (IAA) and cytokinins. These hormones can improve plant growth, development, nutrient uptake besides providing indirect protection to host plants from phytopathogens and encourage further helpful microorganisms in the rhizosphere (Aasfar *et al*., 2021) [1]. Azospirilla are nitrogen-fixing, Gram-negative, free-living rhizosphere bacteria. They exhibit a flexible C-and N metabolism, which makes them well suited to thrive in the rhizosphere's competitive environment. Amino acids, molecular nitrogen, nitrate, nitrite, and ammonium can act as sources for N. Under unfavourable circumstances, nutritional deficiency and desiccation, azospirillum can develop into forms that are expanded cystic in nature. The development of morphological change goes hand in hand with a polysaccharide-coated exterior and the buildup of many poly-L-hydroxybutyrate granules, which can function as a C-energy source (Steenhoudt *et al*., 2000).

Role of bio-agents and bio-fertilizers in organic strawberry cultivation

Applying bio-fertilizer could significantly enhance strawberry quality, including the fruit's sugar/acid ratio and soluble fibre content. Application of biofertilizer has a significant impact on strawberry sugar/acid ratio, soluble solids and vitamin C content. The number of leaves per plant, length of leaves, plant spread, breadth of leaves, length of petioles, height of plants, total number of fruits, runners, weight of fruit per plant, weight of fruit per berry, T.S.S. content of fruits, as well as maximum ascorbic acid of fruits and maximum acid content are all significantly increased in strawberries when organic manure and bio-fertilizers are applied together (Kumar *et al*. 2020) [13].

In the meristematic region of plants, cell elongation and cell division are also benefited by PSB, according to research on the behaviour of biofertilizers. The biological soil fixation of nitrogen and the availability of phosphorus, which are necessary for healthy vegetative growth, are increased when biofertilizers like PSB are used. The application of PSB in trials on banana and strawberry plants has increased the nitrogen availability in the soil and increased the value of plant growth characteristics, including the maximum and minimum values for plant height, spread, the number of leaves per plant and leaf area. The cation and anion content of strawberry fruit is also impacted by the use of biofertilizers. The overall plant growth, flowering, fruit ion content, fruit production, and fruit quality may be considerably enhanced by a suitable combination of bio-fertilizer and PGRs. (Sood *et al*. 2018) [32].

Conjugation of PSB with Azotobacter using various doses can increase the number of crowns and runners per plant. This in turn affects the overall yield attributable to more fruits being produced per plant, larger and heavier berries, and/or increased nitrogen and phosphorus availability in plants as well as increased nitrogen and phosphorous transfers from root to flower through plant foliage due to nitrogen fixers and phosphorous solubilizers (Mishra *et al*. 2011).

Vermicompost application improves the physio-chemical characteristics of the soil, which in turn increase enzyme activity, microbial population, and plant growth hormones. Composts include nitrogen and phosphate, which promote vegetative development and the commencement of floral buds (Kumar *et al*. 2015) [12].

Azotobacter application may be preferable which results in more flowers and fruits set per plant, more crowns and inflorescences per plant and faster N_2 fixation are all impacted by the use of additional bio-fertilizer. TSS and total sugars contents of berries significantly increase with different treatments of Azotobacter, Azospirillum and PSB (Tripathi *et al*. 2016) [38]. Mulching combined with application of Azotobacter, Azospirillum and PSB at different concentrations resulted in highest number of runners and crowns/plant. Application of azotobacter also raises endogenous auxin levels and is crucial for nitrogen fixation. It is believed that Azotobacter will accelerate plant growth, which could help to increase fruit production and reduce weed growth brought on by black polythene (Tripathi *et al*. 2017) [37].

Use of biofertilizers and organic manures also enhances the soil capability to hold nutrients and organic matter. More nutrients and minerals are absorbed by the plants, which results in a rise in the number of leaves and plant development. By engaging in greater photosynthetic activity, a plant with more leaves produces more carbohydrates, which are then used for fruit development (Thoudam and Kotiyal 2022) [35].

Use of phosphorus-based biofertilizers for vigorous vegetative development, soluble bacteria contribute to an increase in biological nitrogen fixation and phosphorus availabilities. Different organic nutrition sources and bio-fertilizers had a substantial impact on the quantity of runners per plant and crowns per plant. Composts had nitrogen and phosphate, which promoted commencement of floral buds and vegetative development (Srivastav *et al*. 2018) [34].

Table 1: List of biofertilizer used in cultivation of strawberry

S. No.	Name of biofertilizer	Effect	Source
1.	*Pseudomonas*	Effective root colonizing bacteria.	Fikki *et al*. (2008)
2.	*Azotobacter*	Increased vegetative growth.	Singh *et al*. (2009) [28]
3.	*Azospirillum*	Fix atmospheric nitrogen, solubilize phosphorus, and promote soil fertility, biological activity and plant height. more vegetative growth.	Singh *et al*. (2009) [28]
4.	*Azotobacter*	TSS increased, fruit size, weight and volume.	Mishra *et al*. (2010)
5.	Phosphorus Solublizing Bacteria	Plant height, development of inflorescence, increased berry size.	Mishra *et al*. (2010)
6.	Phosphorus Solubilizing Bacteria	Increase biological nitrogen fixation and phosphorus availability, which are necessary for robust vegetative development.	Deshmukh *et al*. (2014)
7.	Phosphorus Solublizing Bacteria	Promote root growth.	Prasad *et al*. (2016)
8.	*Azotobacter*	Enhanced yield and growth of strawberry.	Soni *et al*. (2018)
9.	*Azospirillum*	Fix atmospheric nitrogen, solubilize phosphorus and promote soil fertility, biological activity, and plant height. more vegetative growth.	Kumar *et al*. (2020) [13]
10.	*Azotobacter*	Increased number of leaves, numbers of runners and plant height.	Kumar *et al*. (2020) [13]
11.	*Pseudomonas*	Increased plant height and induced early flowering.	Negi *et al*. (2021)

Table 2: List of bio-agents used in cultivation of strawberry

S. No.	Name of bio-agents	Effect	Source
1.	*Trichoderma harzianum*	Effective against soil borne pathogens.	Fikki *et al*. (2008)
2.	*Bacillus* spp.	Plant growth promoting effect, Effect against soil borne pathogens.	Fiki *et al*. (2008)
3.	*Arbuscular mycorrhiza*	Increased the nitrogen nutrition produced maximum plant height, plant spread, number of leaves, leaf area and yield.	Tahat *et al*. (2010)
4.	*Ascophyllum nodosum*	Increase berry size and yield, Drought tolerance.	Zahidul *et al*. (2012)
5.	*Rhizobium* spp.	plant growth-promoters act as root colonizers.	Jose *et al*. (2015)
6.	*Arbuscular mycorrhiza*	Increased the nitrogen nutrition produced maximum plant height, plant spread, number of leaves, leaf area and yield.	Prasad *et al*. (2016)
7.	*Trichoderma harzianum*	Increased fruit production and enhance nutritional properties.	Lombardi *et al*. (2020) [16]

Table 3: Organic inputs used in the cultivation of strawberry

S. No.	Organic inputs	Observations	Source
1.	Azotobacter, FYM, Vermicompost	Enhance the yield and growth of strawberry.	Soni *et al*. (2018)
2.	Azotobacter, FYM	Increased number of leaves, numbers of runners and plant height.	Kumar *et al*. (2020) [13]
3.	Vermicompost	Increase nutrients N, P, K.	Hoehne *et al*. (2020)
4.	FYM, Poultry manure	Low yield as compared to conventional.	Kahu *et al*. (2010)
5.	Pseudomonas, Vermicompost	Plant height and induced early flowering, Effective root colonizing bacteria.	Negi *et al*. (2021)
6..	FYM, Vermicompost	Increase fruit weight, increase yield.	Saygi *et al*. (2022)

Conclusion

This review aims at exploring the possibilities of organic sources of plant nutrients and bioagents that are at par with the conventional methods of strawberry cultivation. Although farm yard manure is the most commonly used organic input provided to the strawberry plants, yet incorporation of other organic sources of nutrients along with inoculation of rhizosphere with bio agents can lead to profitable production and substantial plant growth and development.

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