**Synergistic Impact of Humic Acid and Biofertilizers on the Growth and Yield of Strawberry (*Fragaria × ananassa* Duch): A Review**

**Abstract**

Strawberries (*Fragaria × ananassa*) are a highly valued fruit crop globally, with increasing demand for sustainable agricultural practices that enhance both yield and quality. This review examines the role of humic acid and biofertilizers in improving strawberry vegetative growth and yield. Humic acid, an organic compound derived from the decomposition of plant and animal matter, enhances soil structure, nutrient availability, and microbial activity. It stimulates root growth, increases nutrient uptake, and improves plant resilience against abiotic stress, contributing to higher strawberry yields and better fruit quality. Biofertilizers, which contain living microorganisms, complement the effects of humic acid by promoting nutrient cycling, nitrogen fixation, and phosphate solubilization. The synergistic effect of humic acid and biofertilizers creates an optimal environment for strawberry plants, leading to enhanced vegetative growth, flowering, and fruiting. Studies have shown that the combined application of humic acid and biofertilizers significantly increases strawberry yield, improves fruit size, sugar content, and overall marketability. Furthermore, the use of these organic amendments aligns with sustainable farming practices, reducing the reliance on chemical fertilizers and minimizing environmental impact. The review highlights the potential of integrating humic acid and biofertilizers into strawberry cultivation as a sustainable strategy to meet the growing demand for high-quality strawberries.

**Keywords:** Strawberry, biofertilizer, humic acids, microorganisms, growth, yield

**Introduction**

The hybrid strawberry, *Fragaria × ananassa* Duch., is a hybrid of *Fragaria virginiana* (L.) Duch. and *Fragaria chiloensis* (L.) Duch. *F. × ananassa* requires a lot of water because of its shallow root structure, huge leaf area, and high-water content in its fruits. In nature, all cultivated strawberry cultivars are octaploid (2n = 8x = 56) (Klamkowski and Treder, 2006). This herbaceous crop grows prostrate and functions as an annual in subtropical climates and as a perennial in those where temperature is sensitive (Singh *et al*., 2009; Sran *et al*., 2023). Strawberries are cultivated commercially on raised beds with impermeable polythene mulch covering them. The plants only receive water by trickle watering beneath the polythene. Withholding water from strawberries growing in pots has been observed to rapidly lower their leaf water potential. Low soil water levels have been associated with lower yields in field investigations (Liu *et al*., 2007; Singh, 2020). Variations in cultivar responses to salt stress have been studied (Gulen *et al*., 2006; Turhan and Eriş, 2007), but little research has been done on cultivar variation in response to low water supply. Differences in yield and root development during drought stress between three cultivars of *F. × ananass*a, which suggests that diversity within the species may have resulted from varying responses to water deficits in progenitors of the commercial strawberry (Zhang and Archbold, 1993a; Zhang and Archbold, 1993b).

**Morphological description:** Herbs with a short, thick underground stoloniferous organ. Leaves thick, coriaceous or sub-coriaceous, petioles 5-20 cm, hairy; leaflets 3-6 × 3-6 cm, ovate to rhombic or obovate, the upper surface dark green, glossy, glabrescent, the lower surface scattered to densely hairy, sericeous along the veins, the veins prominent, the base cuneate or the lateral leaflets oblique, the margins coarsely serrated-toothed, the apex rounded to broadly acute; petioles 2-7 mm; Stipules 1-2 cm, adnate basally, the apex free, acuminate, simple or 1-2-lobed. Inflorescences 10-20 cm, erect or porrect, arranged below or just above the leaves, with 3-10 flowers. Flowers perfect or rarely pistillate; pedicels 3-10 cm, hairy; bracteoles and sepals subequal or bracteoles scarcely narrower, 6-10 × 2-4 mm, lanceolate or elliptic, evenly hairy or glabrescent distally, the margins entire, or 1-3-dentate, the apex acute to acuminate; sepals 5-9; Petals 5-9, 10-15 mm, broadly ovate. Fruit 2-6 cm diameter, globose or conical, red to yellow or white; bracteoles and sepals clasping; achenes embedded in the receptacle. (Parent species native to North and South America; cultivated worldwide. (WFO, 2024; Singh, 2020; Sran *et al*., 2023; Kumar *et al*., 2019; Kumar *et al*., 2020; Mishra *et al*., 2015)

One of the most well-liked and nutritious fruits, strawberries, has drawn a lot of interest in agricultural research due to its production. Strawberries are popular in processed forms such jams, jellies, and juices, and are also eaten fresh due to their high vitamin, antioxidant, and other bioactive chemical content (Singh, 2020). The agriculture industry is investigating novel approaches to improve the growth and quality of strawberry fruit due to the growing consumer demand for premium strawberries. Among these tactics, the use of biofertilizers and additions like humic acid has shown to be a viable method for producing strawberries in a sustainable manner. Microorganisms break down plant and animal materials to produce humic acid, which is a complex mixture of different organic compounds. It is a major component of humic substances, which are found in soil, peat, coal, and other organic-rich environments. Humic acid plays a crucial role in improving soil fertility, structure, and microbial activity, thereby enhancing plant growth and development. It has been reported to stimulate root growth, increase nutrient uptake, and improve the overall health of plants. The application of humic acid in agriculture has gained popularity due to its potential to enhance crop yields and improve soil health, making it an essential tool in sustainable farming practices (Arancon *et al*., 2006; Neri *et al*., 2002; Mareguddikar *et al*., 2023; Singh, 2006; Kumar *et al*., 2015; Kumar *et al*., 2019; Umar *et al*., 2009; Ahmad *et al*., 2010; Bhagat *et al*., 2020).

Biofertilizers, on the other hand, are preparations containing living microorganisms that promote plant growth by increasing the availability of nutrients in the soil. These microorganisms, which include bacteria, fungi, and algae, colonize the rhizosphere—the region of soil surrounding plant roots and facilitate nutrient absorption by converting insoluble forms of nutrients into forms that are more readily available to plants. Biofertilizers are increasingly being recognized as a sustainable alternative to chemical fertilizers, as they help reduce the environmental impact of agriculture by minimizing the need for synthetic inputs. In strawberry cultivation, biofertilizers have been shown to enhance plant growth, improve fruit quality, and increase resistance to diseases (Hazarika *et al*., 2007; Kumar *et al*., 2015; Rueda *et al*., 2016; Singh *et al*., 2023; Antoun, 2015; Deshmukh *et al.,* 2016).

According to Sood *et al*. (2018), using biofertilizers and humic acid together is a synergistic way to increase strawberry yield and growth. Biofertilizers help with the biological fixation of important elements, such phosphorus and nitrogen, which guarantees a consistent supply of these nutrients to the plants. Humic acid, on the other hand, improves soil structure and increases nutrient availability. This combination not only supports the growth and development of strawberry plants but also contributes to the sustainability of the production system by reducing the reliance on chemical fertilizers and promoting soil health.

**Humic acid**

One natural resource that can be utilized in place of inorganic fertilizers is humic acid. According to Sharif *et al*. (2002), humic acid is a naturally occurring polymeric organic chemical that is converted as a result of organic matter decomposing and is first found in lignite, peat, and humus. According to Piccolo (2012), humic acid is made up of a mixture of organic acids that are aromatic in nature and have a variety of heterogeneous functional groups that do not interact with different metallic ions like Mg, Zn, Ca, and Cu. It is possible to apply humic acid both foliarly and in the soil. Humic acid is a soil addition that provides nutritional supplementation along with a soft, pulverized, and well-aerated soil. Conversely, using humic acid as a foliar spray guarantees enhanced photosynthetic rate, permeability, and nutrient absorption. Vermiwash is another one of these biostimulants; it is mostly used topically. According to Anonymous (2007), it has the following contents: N 0.29 %, P 0.042 %, K 0.143 %, Ca 0.186 %, Mg 0.11 %, S 0.058 %, Fe 0.466 ppm, Mn 0.406 ppm, Zn 0.11 ppm, and Cu 0.18 ppm.

Data on the growth and fruit output of strawberries at different stages were recorded. The results of the analysis revealed that titratable acidity was not significant, but there were more fruits plant-1, total carotenoids, and total lycopene content observed at 3mlL-1 humic acid. The least amount of fruit waste, however, was observed at 4.5mlL-1 humic acid. The agroclimatic conditions of Peshawar led to the conclusion that the strawberry cultivar Chandler might benefit from a 3.0 mlL-1 humic acid spray for improved development and high-quality fruit output (Ullah *et al*., 2017). The plant treatment T9, which included seaweed extract at 8000 ppm and humic acid at 3 g/L, likewise had the earliest fruiting and blooming. Fruit diameter (4.05 cm), length (5.84 cm), and weight (30.84 g) were determined to be better, followed by T8 (SWE @ 7000 ppm + humic acid @ 3.0 g/L). T9 showed a larger yield (343.52g) and more fruits per pant (20.66), but T1 (control) showed a lower yield and fewer fruits per plant. Fruit quality characteristics showed that T9 was superior to T8 in terms of TSS (11.13ᴼB), acidity (0.58%), and ascorbic acid content (60.16 mg/100 g). Higher amounts of humic acid and seaweed extract have been shown to significantly improve strawberry yield quality, indicating their superiority in raising crop production (Rishitha *et al*., 2023).

**Biofertilizers**

Although synthetic manures are essential for fulfilling supplement requirements, they shouldn't be used excessively or insufficiently. This can deplete the real and synthetic qualities of the soil, harm people's health and the environment, and ultimately result in low harvest yields. Table 1 illustrates the application of various biofertilizers in strawberry cultivation. Certain types of biomanure, such those that contain Azotobacter, PSB, and Azospirillum, among others, can fix atmospheric nitrogen and solubilize phosphorus in the soil, enhancing the mobility and richness of nutrients in the soil. Nature's ability to create biofertilizers, which can take the place of chemical fertilizers, is one of the greatest gifts to agricultural science. The microorganisms in biofertilizer ensure that the host plants' physiology is correctly controlled, growing, and developing, and they also assist the plants in receiving the right amount of nutrients (Kumar *et al*., 2018; Thakur *et al*., 2018).

Strawberries were also improved in quality by using bio-fertilizers. In the Rueda *et al*., 2016 study, three nitrogen levels were combined with the inoculation and co-inoculation of bacterial cultures of *Azotobacter spp*. and *Azospirillum spp*., and it was discovered that this combination demonstrated a considerable improvement in strawberry growth and yield. In a study, strawberries treated with a mixture of wood ash, PSB, chicken manure, Azotobacter and oil cake showed the maximum values of growth perameter, including the earliest blooming, height of plant, runners per plant, plant spread and yield. Fruit quality indices as TSS, ascorbic acid, sugars, and color may rise in plants that get PSB and AMF inoculations, according to Lingua *et al*. (2013). This might be as a result of zinc and phosphate solubilization, which improves nutrient availability and uptake in strawberry plants. In their experiment, Sood *et al*. (2018) used three different concentrations of biofertilizer and plant growth regulators on strawberries. The treatment with phosphate solubilizing bacteria (6 kg/ha) and gibberellic acid (100 ppm) was suitable for plant growth and took the shortest amount of time (57 days) to produce the first flower when compared to the control.

A different set of results was examined to see how the strawberry responded to photoperiod. They examined how three-day neutral (DN) cultivars of strawberries (Aptos, Brighton, and Hecker) and two short day (SD, June bearing) cultivars (Redgauntlet and Torrey) responded to different temperature and day length regimes. They found that at the commencement of inflorescence, the day/night temperature regime (18/13, 21/16, or 30/258C) and day length (9 or 15.h) had a significant impact on the yield metrics in the short-day cultivars. When compared to flowers begun under short-day circumstances, floral initiation was suppressed during long days, resulting in poor fruit set and growth (Manakasem *et al*., 2001). By applying Azotobacter + PSB + AM + Vermicompost, Singh *et al*. (2015) found that plant height, plant spread, number of leaves, and leaf area plant-1 were all at their highest; in contrast, all growth features were found to be at their lowest in the control group.

The experimental results reported by Kumar *et al*. (2020) indicate that "the plant height and leaf size were significantly influenced by the sole inoculation of Azospirillium and Azotobacter and in combination with PSB compared to control and 100% RDF treatment." The use of biofertilizer has resulted in a significant increase in the fruiting period and the yield per hector area compared to control. The longest harvesting time of seventy days was observed when 75% RDF + Azospirillium @ 2g/plant + PSB @ 2g/plant + 25% K topdressing was combined. (Dubey & Associates, 2016). The highest harvesting period with 75% RDF + Azospirillium @ 2g/plant + PSB @ 2g/plant + 25% K topdressing was noted (70 days). (Dubey *et al*., 2016). The best results for strawberry plant growth parameters, such as height of plant, plant spreading in North-South and East-West directions, and number of leaves, were observed in treatment T5 RDF + Azospirillum (@7 kg / ha) + Phosphate Solubilizing Bacteria (@6 kg / ha). In contrast, treatment T0: RDF (Control) showed the lowest value for the same parameters. Treatment T11, which included RDF + Azospirillum (@7 kg/ha) + Phosphate Solublizing Bacteria (@ 6 kg/ha + VAM @ 10 kg/ha), produced the early flowering, fruit maturity and fruiting. The treatment T11 (RDF + Azospirillum (@7 kg / ha) + Phosphate Solubilizing Bacteria (@6 kg / ha) + VAM (@10 kg / ha) had a significant impact on flowering, fruiting, growth and physical parameters, such as the number of flowers, number of fruits, fruit length, fruit diameter, fruit volume and weight; in contrast, the control group (T0) showed the lowest value for the same. In terms of yield, the treatment T11 (RDF + Azospirillum (@7 kg / ha) + Phosphate Solubilizing Bacteria (@6 kg / ha) + VAM (@10 kg / ha) produced the best yield (355.84 q/ha) compared to the other treatments. Additionally, the control had the lowest yield (Bhagat *et al*., 2020).

In comparison to other treatments, measurements throughout the early stages of plant growth were highest in T5 (Azotobacter 2g/plant + GA3 5ppm). In terms of strawberry fruit crop growth characteristics (such as plant spreading, height of plant, stem girth and leaves number), T5 had greater yield and flowering characteristics (Azotobacter 2g/plant + GA3 5ppm). When it comes to Strawberry Cv. Camarosa in the Punjab area of India, the dose indicated combination Azotobacter 2g/plant + GA3 @5ppm shows considerable effects (Marwaha *et al*., 2023).

**Table 1:** Bio-fertilizer effect in farming of strawberry

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| --- | --- | --- | --- |
| **S. No.** | **Bio fertilizer Name** | **Effect** | **Source** |
| 1 | Azotobacter | vegetative growth increased | Singh *et al.* (2009) |
| 2 | Azospirillum | More vegetative growth. | Singh *et al.* (2009) |
| 3 | Azotobacter | fruit size and weight increased | Mishra *et al.* (2015) |
| 4 | PSB | Height of plant and improved berry size. | Mishra *et al.* (2015) |
| 5 | Azotobacter | Vegetative growth and yield | Singh *et al*. (2015) |
| 6 | PSB | Boost phosphorus availability and biological nitrogen fixation—both essential for healthy vegetative growth. | Deshmukh *et al.* (2016) |
| 7 | PSB | Increased root growth and development. | Prasad *et al.* (2022) |
| 9 | Azotobacter | Numbers of runners, leaves number increased, and plant height improved | Kumar *et al.* (2020) |
| 10 | Azospirillum | Increase plant height, biological activity, and soil fertility. | Kumar *et al.* (2020) |

Using PGPB strains (Pseudomonas BA-8, Bacillus OSU-142, and Bacillus M-3) alone and in combination, Ahmad *et al*. (2010) observed that treating plants with M3 + BA-8 (91.73) and M3 (81.58) resulted in a significant increase in the number of fruits per plant. According to Cacatto *et al*. (2016), anthocyanin and TSS percentage increased dramatically while fruit acidity was significantly reduced by an arbuscular mycorrhizal inoculation (3 kg ha-1). As per the findings of Kumar *et al*. (2019), the plant height and leaf size were found to be considerably impacted by the exclusive inoculation of Azospirillium and Azotobacter, as well as their combination with PSB, compared to the control and 100% RDF treatment.

**Conclusion**

In conclusion, the impact of humic acid and biofertilizers on the vegetative growth and yield of strawberries represents a critical area of research with significant implications for sustainable agriculture. By improving soil health, enhancing nutrient availability, and promoting plant growth, these organic amendments have the potential to transform strawberry cultivation, making it more sustainable, productive, and environmentally friendly. This review aims to provide a comprehensive overview of the current knowledge on the effects of humic acid and biofertilizers on strawberry production, with a focus on their role in enhancing growth, yield, and fruit quality.

**Disclaimer (Artificial intelligence)**

Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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