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RESEARCH ARTICLE

Effects of biostimulants on growth, yield, and quality of chili intercropped with palmyrah

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Abstract

A field experiment was conducted to investigate the impact of biostimulants on the growth and yield of chili (var. KKM Ch-1) as an intercrop under palmyrah plantation at the College Orchard of the Department of Horticulture, VOC Agricultural College and Research Institute, Killikulam, Thoothukudi district of Tamil Nadu during 2023-24. Four treatments, including potassium chloride (KCl) 1%, pink-pigmented facultative methylotrophs (PPFM) 1%, panchagavya 3%, and water as a control, were applied in a randomized block design with five replications. Observations were recorded on plant height (cm), number of branches at 30, 60 and 90 days after transplanting, along with yield attributing characters *viz.,* days to 1% flowering, 50% flowering, no. of red ripened fruits per plant, individual fruit weight (g), yield per plant (g), yield per ha (tons), dry yield per plant (g), dry yield per hectare (ton), ascorbic acid content (mg per 100g), capsaicin (%), capsanthin (%) and oleoresin (%). The maximum plant height at 30 (25.48 cm), 60 (56.79 cm), and 90 days after transplanting (70.75 cm), number of branches at 30 days after transplanting (2.80), 60 days after transplanting (8.80) and 90 days after transplanting (11.40), early flowering (38.40 days), 50% flowering (46.40 days), individual fruit weight (2.18 g), number of fruits per plant (78.20), yield of red ripen fruits per plant (170.31 g), yield per ha (6.30 ton per ha), leaf area index (LAI) (0.84), chlorophyll a (1.42 mg per g), chlorophyll b (1.77 mg per g), total chlorophyll (3.28 mg per g), proline content (251.85 mg per g), dry yield per plant (65.67 g), dry yield per hectare (2.43 ton per ha), ascorbic acid content (12.27 mg per 100g), capsaicin (0.53%), capsanthin (44.04) and oleoresin (14.51%) was recorded in (the 3%) panchagavya spray treatment. The salient findings revealed that among the different treatments, 3% panchagavya spray exhibited superiority in promoting growth and yield in chilli as an intercrop under palmyrah in dryland conditions of the Thothukudi district.

Keywords

chili; intercrop; palmyrah; panchagavya; potassium chloride; PPFM

Introduction

Palmyrah (*Borrassus flabellifer* L.) is a versatile and resilient palm species, long esteemed for its diverse uses, including food, medicinal applications, and construction materials. It is a hardy tree native to tropical Africa and found in the drier parts of India, Sri Lanka, Thailand, Malaysia, Vietnam, and

Indonesia. Palmyrah is often referred to as Karpagathara (tree of life), highlighting its importance to humankind, with over 800 reported uses from crown to root of the tree (1). It has been designated as the state tree of Tamil Nadu since 1978. Around 103 million palms are estimated to exist in India, with Tamil Nadu retaining half of the total number (2). Among the 51.6 million palm trees in Tamil Nadu, more than half are located in the southern districts of Virudhunagar, Thoothukudi, Tirunelveli, and Ramnad. Thoothukudi district alone is home to approximately 10 million palm trees (3).

The palmyrah tree can grow up to a height of 13-14 meters, sometimes, even reaching 90 meters in height. It is a slow-growing plant and takes approximately five months to produce its first frond (4). The species offers significant opportunities for intercropping by providing both horizontal and vertical space for, additional income generation (1). Restoring diversity in agricultural ecosystems and effectively managing it are two crucial aspects of sustainable agriculture (5). This approach can be utilized to optimize the utilization of available resources, boost yield, and enhance profitability per unit area (6). Vegetable crops, renowned for their shorter life cycles and high market value, demonstrate superior performance as intercrops.

Chili (*Capisicum annuum* L.) is a widely grown spice cum vegetable crop. It is the fourth major crop cultivated globally and belongs to the Solanaceae family, with a chromosome number of 2n=2x=24, and originated in South Central America (7). India is the world's biggest producer, importer, and user of chili after China followed by Thailand, Ethiopia, and Indonesia. Approximately 75% of India's total area used for chili farming is located in the country's central to southern states, including Tamil Nadu, Andhra Pradesh, Karnataka, and Maharashtra (8). Chilies thrive in tropical climates with warm, humid conditions and temperatures ranging from 18 to 30°C. In addition to its culinary uses, this ingredient is also employed in industrial processing for its robust flavor and color, as well as in pharmaceuticals for both Allopathic and Ayurvedic medical purposes (9). Chili is a drought-tolerant crop and can produce high yield even under drought stress.

Stress impacts crops at morphophysiological, biochemical, and molecular levels, leading to growth inhibition, accumulation of compatible organic solutes, and alterations in endogenous phytohormone levels. In agricultural practices, fertilizer is a crucial input for increasing crop yields. Meanwhile foliar application of organic and inorganic fertilizer during appropriate intervals facilitates quick and easy absorption with enhanced crop growth and yielding up to 15 to 25% (10). Foliar applied fertilizers (nitrogenous fertilizer, phosphatic fertilizer, potassic fertilizer, humic acid, panchagavya, salicylic acid, jeevamirutham, *Azospirillum,* PPFM, phosphobacteria, etc.) are more effective than soil applied fertilizers.

During drought, the lack of water significantly affects crop production. External application of potassium (K) has been shown to mitigate the adverse effects of water stress. Under mild or severe water stress, K uptake by crops can be reduced by 67% and 82%, respectively. Lower K concentration in the plants leads to decreased resistance to drought stress, as well as reduced size, yield, quality, and reduced photosynthetic pigments (11). Spraying K under drought conditions enhances crop tolerance to various abiotic stresses, improves growth and yield, and regulates physiological processes such as turgor pressure, photosynthesis, and enzyme activation (12).

Methylobacterium, a PPFM, is well-studied for its ability to enhance plant growth and induce defense mechanisms. In addition, PPFM treatment enhanced antioxidant enzyme activity, particularly catalase, suggesting its role in mitigating oxidative stress under drought conditions (13).

Panchagavya serves as a nutrient source that enhances crop growth. Plants treated with panchagavya exhibit accelerated growth, increased yield, higher production of secondary metabolites, and enhanced chlorophyll content under drought conditions. This beneficial effect is attributed to increased stomatal count, sponge parenchyma development, and enhanced thylakoid development (14).

Furthermore, intercropping with groundnut significantly enhanced post-harvest soil nutrient status, particularly increasing nitrogen (N), phosphorus pentoxide (P_2O_5), and potassium oxide (K_2O) levels (1). Intercropping with vegetables under palmyrah plantations is understudied to establish optimal palmyrah vegetable intercropping systems to enhance income generation, while also examining crop performance, economic viability, environmental sustainability, and associated challenges. Thothukudi district is a dry land tract of the southern part of Tamil Nadu and palmyrah farmers were often traditionally reported to intercropping under palmyrah with crops like grains and pulses alone meeting less income per unit area. Vegetable farming even though has bought a kind of intensive cultivation in recent days for the farming community with more income per unit area. The present study aimed to investigate the impact of various biostimulants on the growth and yield of chili under the palmyrah plantation as intercrop.

Materials and Methods

The field experiment was conducted during the kharif season at College Orchard, Department of Horticultural, VOC Agricultural College and Research Institute, Killikulam, Thoothukudi district of Tamil Nadu during 2023-24. The experimental site was situated at 8°70' N latitude and 77°86' E longitude at an elevation of 41.73 m above mean sea level. The experimental plot had uniform topography and was divided into small plots, ridges and furrows were formed. The irrigation was provided through the furrow irrigation method.

Under open field conditions, the maximum temperature varied between 32°C to 38°C with an average of 35°C, and the minimum temperature varied between 22°C to 28°C with an average of 25.4°C. The annual rainfall was 668 mm and relative humidity varies between 60 to 91 percent with an average of 76 percent. The experimental plot consisted of red soil with a pH value of 7.40. Soil profiling revealed available NPK at 253 :23 :110 kg/ha. The field consisted of a palmyrah plantation with 25 years of old trees planted at 3 m x 3 m spacing.

The chili variety KKM- Ch-1 was raised in the nursery after 25 days transplanted the seedlings within the main field as intercrop. The plot size was 3.75 $m^2$with a plant spacing of 60 cm X 45 cm. In this experiment randomized block design with four treatments KCl (1%), PPFM (1%), panchagavya (3%), and plain water as control) and five replications. The foliar spray was given 25 days after planting in a frequent interval of 15 days interval (4 sprays). The recommended amount of fertilizer (NPK: 120 : 80 : 80 kg per ha), from this 30 : 60 : 30 kg per ha of NPK, was applied as basal dose to the field using uniform cultural practices.

Measurements of plant height and branch count were taken at 30, 60, and 90-days post-transplantation. Additionally, LAI, chlorophyll a, b, and total chlorophyll, proline content, the duration to 1% and 50% flowering, individual fruit weight, number of fruits, yield per plant, and per hectare (tons), dry yield per plant and per hectare, ascorbic acid, oleoresin, capsanthin, and capsaicin were documented.

Leaf area index

The leaf area was calculated using the standardized method (15). The leaf area was measured using a leaf area meter. The total leaf area measured was then divided by the entire ground area occupied by each plant to calculate the LAI according to the following formula:

$$\text{LAI} = \frac{\text{Total leaf area of the plant}}{\text{Ground area occupied by the plant}}$$

......(Eqn. 1)

Chlorophyll content

Chlorophyll content in the fresh leaves was measured by the standardized method (16). Leaf tissue (0.25g) was macerated with 10 mL of acetone. The mixture was then centrifuged at 3000 rpm for 10 minutes then the supernatant was collected. The volume was made up to 25 mL using 80% acetone. Finally, the optical density was measured at 663 nm, 645 nm, and 652 nm using a spectrophotometer.

$$Chlorophylla = (12.7 * ODat\ 663) - (2.69 * ODat\ 645) * \frac{V}{1000 * W}$$

......(Eqn. 2)

$$Chlorophyllb = (22.9 * ODat\ 645) - (4.68 * ODat\ 663) * V/(1000 * W)$$

......(Eqn. 3)

$$TotalChlorophyll = (ODat\ 652 * V)/(34.5 * W)$$

.....(Eqn. 4)

Proline content

The proline content of the fully opened leaves was estimated according to the standardized protocol (17). After homogenizing 0.5 g of leaf material with 10 mL of 3% aqueous sulphosalicylic acid, the mixture was centrifuged for 10 minutes at 3000 rpm. Then, 2 mL of aliquot, 2 mL of acid ninhydrin, and 2 mL of glacial acetic acid were combined. The mixture was immediately transferred to cool water to terminate the reaction after an hour of incubation at 100˚C in a hot water bath. Subsequently, 4 mL of toluene was added and vigorously mixed. The colorless layer was removed, and the colored complex was collected. The optical density at 520 nm. The value was given as μg g^{-1}.

$$\text{Proline} = \frac{\mu g\,\frac{\text{proline}}{\text{mL}} * \text{mL toluene}}{115.5} * \frac{5}{\text{g sample}}$$

.....(Eqn. 5)

Capsaicin content

The spectrophotometric approach was used to analyze the content of capsaicin (18). Red chili was used to extract capsaicin using ethyl acetate, which was subsequently combined with a vanadium oxytricloride ($VOCl_3$). After that, the mixture was transferred to a 100 mL volumetric flask and sieved through a No. 40 sieve (0.42 mm). To facilitate extraction, it was further diluted with ethyl acetate to a level of 10 mL and let to stand for 24 hours.

Just before taking a reading, the solution was prepared by diluting 1 mL of the extract with 5 mL of ethyl acetate. After that, 0.5 mL of the $VOCl_3$ solution (0.5% $VOCl_3$ in ethyl acetate) was added and shaken well. After adding 0.5 mL of ($VOCl_3$) to ethyl acetate and subtracting the reading, the absorbance was measured at 720 nm. The results were then compared to a standard curve made from a pure capsaicin solution that included 50, 100, 150, 200, and 250 μg of capsaicin, respectively.

$$\%\ Capsaicin = (mg\ capsaicin)/(1000 * 1000) * 100 * 100/2$$

......(Eqn. 6)

Capsanthin content

The capsanthin was quantified according to a standardized protocol (19). Dried fruits were passed through a sieve. After weighing, a 100 mg sample was moved to a 100 mL volumetric flask. The appropriate amount of acetone was applied and sealed. After giving the flask a good shake, it was left to stand at room temperature for 16 hours in the dark. After giving the flask a vigorous shake, the particles were allowed to settle for two minutes. The absorbance (A) at 465 nm was measured using a blank of acetone. At 465 nm, the glass filter absorbance was measured.

$$\text{Instrument correction factor} = (\text{NBS @ 465 nm})/(\text{Lab A value @ 465 nm})$$

......(Eqn. 7)

$$ExtractableASTAcolour = \frac{Aofacetoneblank * 16.4 * IF}{weightinmg}$$

......(Eqn. 8)

(NSB-National Bureau of Standards reference value at 465 nm; IF- Instrument correction factor)

Oleoresin content

The oleoresin was determined following a previously outlined method (19). Accurately, 100 mg of ground chili powder was added to a 100 mL volumetric flask. The contents were thoroughly shaken, diluted to 100 mL with acetone, and then left to stand for two minutes. After that 10 mL of the extract was pipette out, diluted with 100 mL of acetone in a volumetric flask, and thoroughly mixed. Next, a UV-visible spectrophotometer was used to measure the sample absorbance at 460 nm. Next, using the procedure, the oleoresin extractable color was calculated, and expressed in American Spice Trade Association units:

$$ASTA\ oleoresinextractablecolor = \frac{Absorbanceat\ 460\ nm * 164}{sampleweight\ (g)}$$

.....(Eqn. 9)

Ascorbic acid content

Grounded samples were treated with 4% oxalic acid, adjusted to a 100 mL solution, and centrifuged at 5000 rpm for thirty minutes. After that, 100 mL of 4% oxalic acid was mixed with 5 mL of the supernatant that had been extracted. This mixture was then titrated against a dye solution that was prepared up to 200 mL and comprised 42 mg of sodium bicarbonate and 52 mg of 2, 6- dichlorophenolindophenol. The achieved titer value was identified as V_2. After the standard was created using the specified procedure, the titer value was recorded as V_1 mL (20).

$$\text{Ascorbic acid (mg } 100g^{-1}) = \frac{(0.5 \times V_2 \times 100)}{(V_1 \times 5 \times \text{Weight of the sam-}} \times 100$$

......(Eqn. 10)

Statistical analysis

The days following transplantation were statistically examined across different parameters. Using SPSS software version 16.0 the mean, standard error (SE), and critical difference (CD) were calculated and significance was determined at the five percent probability level. SE is computed by taking the square root of the number of observations and dividing it by the standard deviation.

Results

Statistical analysis was done for the yield attributing parameter of chili under palmyrah plantation with the effect of foliar application and differences among the treatments were seen as highly significant.

Morphological parameters

Regarding morphological characters, plant height and number of branches were recorded at 30, 60, and 90 days after transplanting. The highest plant height was seen in panchagavya (3%) at 70.75 cm, followed by PPFM (1%) at 67.81 cm, both measured 90 days post-transplanting. The lowest plant height was recorded in the control group at 17.75 cm, measured 30 days post-transplanting (Fig. 1). The number of branches showed significant variations among the different treatments. The maximum number of branches was observed in panchagavya (3%) with 11.4 at 90 days after transplanting followed by PPFM (1%) with 10.2 at 90 days after transplanting and the minimum number of branches was seen in control with 1.80 followed by KCl (%) with 2 was on par with PPFM (1%) (Fig. 2).

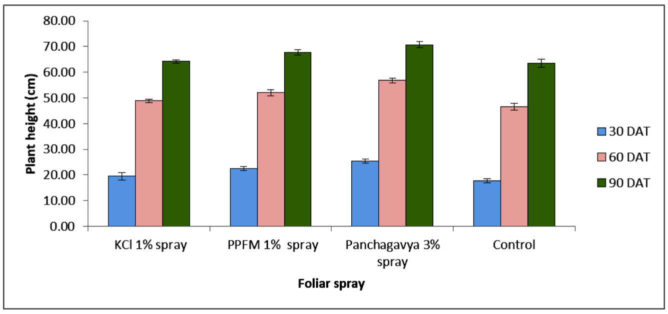

Fig. 1. Effect of biostimulants on chili plant height at 30, 60, and 90 DAT under palmyrah.

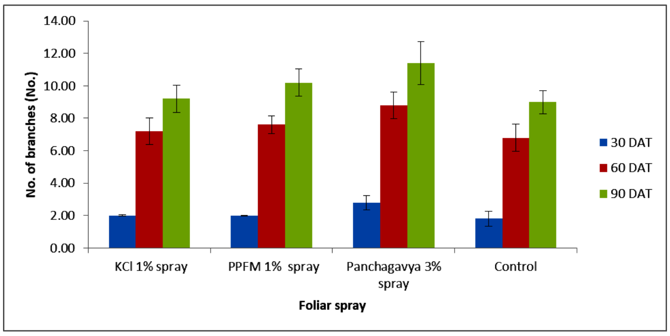

Fig. 2. Effects of biostimulants on the number of branches of chili at 30, 60, and 90 DAT under palmyrah.

The LAI of chili as an intercrop was greatly impacted by various treatments, ranging from 0.74, and 0.84. The highest LAI was registered in panchagavya (3%) with 0.84, followed by PPFM (1%) with 0.79. The lowest LAI was recorded in control with 0.74 followed by KCl (1%) with 0.75 (Fig. 3).

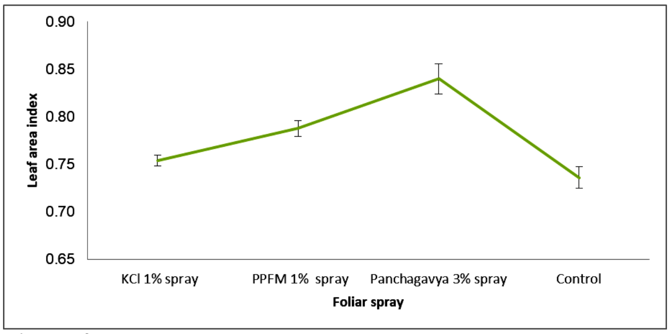

Fig. 3. Effects of biostimulants on LAI of chili under palmyrah.

Biochemical parameters

The application of different biostimulants significantly affected the biochemical characteristics of chili plants, particularly in terms of proline and chlorophyll levels. There were significant variations observed among the different treatments. The panchagavya (3%) spray recorded the highest chlorophyll a, chlorophyll b, and total chlorophyll with 1.42 mg per g, 1.77 mg per g, and 3.28 mg per g respectively followed by PPFM (1%) spray with chlorophyll a (1.36 mg per g), chlorophyll b (1.71 mg per g) and total chlorophyll (3.21 mg per g) and control recorded the lowest amount of chlorophyll a, chlorophyll b and total chlorophyll with 1.25 mg per g, 1.44 mg per g and 3.13 mg per g respectively followed by KCl (1%) spray with chlorophyll a (1.33 mg per g), chlorophyll b (1.68 mg per g) and total

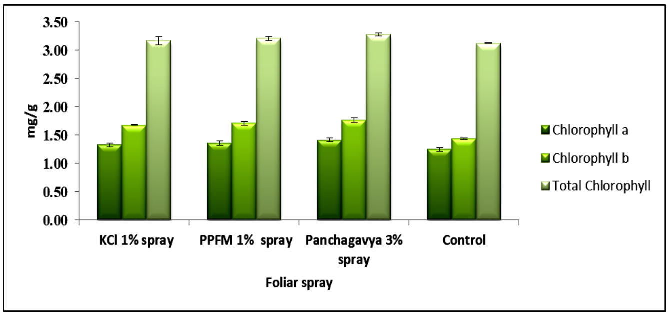

Fig. 4. Effects of biostimulants on chlorophyll a, b and total chlorophyll of chili under palmyrah.

chlorophyll (3.17 mg per g) (Fig. 4).

From the current study, proline accumulation recorded a significant difference among the different treatments ranging from 249.09 to 251.85 mg per g. The maximum accumulation of proline was seen in panchagavya (3%) with 251.85 mg per g followed by PPFM (1%) spray with 259.03 mg per g and minimum accumulation was rec-

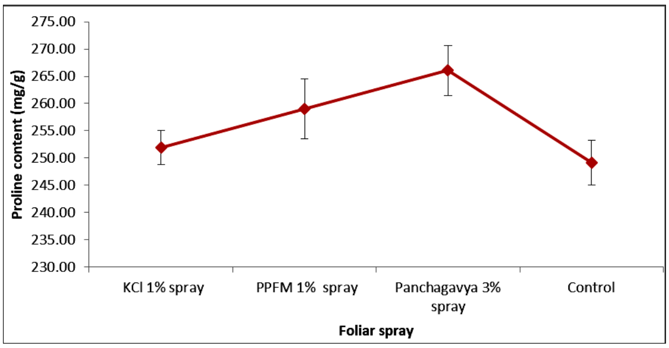

Fig. 5. Effects of biostimulants on proline content of chili under palmyrah.

orded in control with 249.09 mg per g followed by KCl (1%) spray with 251.85 mg per g (Fig. 5).

Yield characters

The impact of various treatments on the yield characteristics of chili as an intercrop was significant. The yield characteristics like 1% flowering range from 38.40 to 44.80 days. The earliest flowering occurred in panchagavya (3%) at 38.40 days, followed by PPFM (1%) at 41.60 days. The

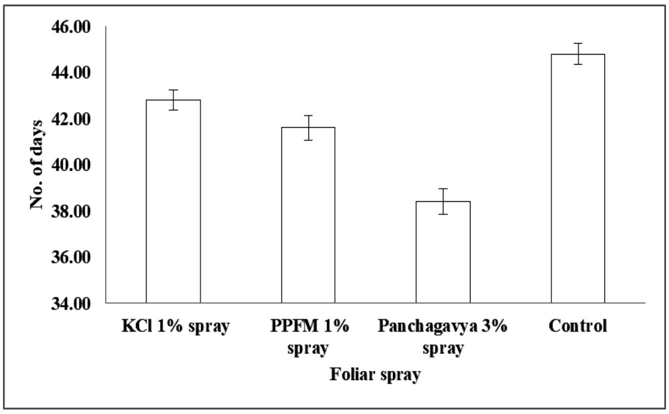

Fig. 6. Effects of biostimulants on days to 1st flowering in chili under palmyrah.

control exhibited delayed flowering at 44.80 days, with KCl (1%) at 42.80 days (Fig. 6).

The number of days to 50% flowering ranged from 46.40 to 53.80 days, with the shortest time in panchagavya (3%) spray at 46.40 days followed by PPFM (1%) at 48.60 days. More days to 50% flowering was registered in control

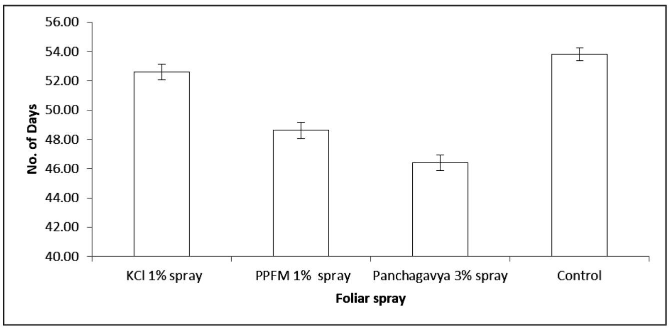

Fig. 7. Effects of biostimulants on days to 50% flowering in chili under palmyrah.

at 53.80 days which was followed by KCl (1%) at 52.60 days (Fig. 7).

The number of fruits per plant also varied significantly, ranging from 56.6 to 78.2. The maximum number of fruits was recorded in panchagavya (3%) with 78.2 which was followed by PPFM (1%) with 67.2 whereas the mini-

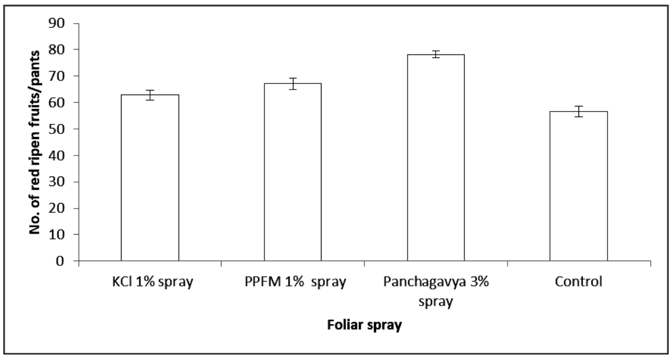

Fig. 8. Effects of biostimulants on the number of fruits per plant in chili under palmyrah.

mum number of fruits was obtained in control with 56.6 which was followed by KCl (1%) with 62.8 (Fig. 8).

Individual fruit weight of chili as intercrop varied significantly among the different treatments ranging from 1.75 g to 2.18 g. The highest weight was registered in panchagavya (3%) with 2.18 g which was followed by PPFM

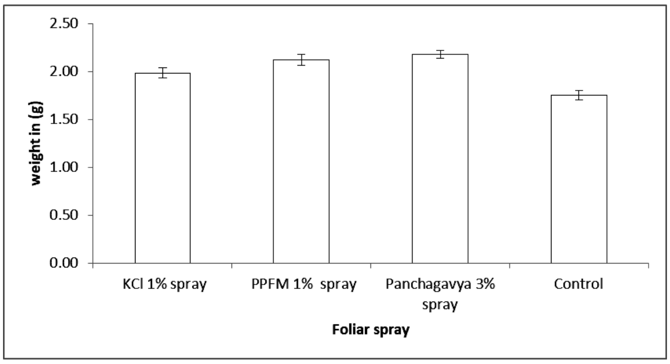

Fig. 9. Effects of biostimulants on individual fruit weight in chili under palmyrah.

(1%) at 2.12 g. Minimum weight was seen in control with 1.75 g followed by KCl (1%) with 1.98 g (Fig. 9).

Yield per plant varied greatly among the three treatments, ranging from 99.03 g to 170.31 g. Maximum yield per plant was registered in panchagavya (3%) with 170.31 g per plant which was followed by PPFM (1%) with 142.45 g per plant whereas minimum yield was recorded in control with 99.03 g per plant which was followed by KCl (1%) 124.59 g per plant.

Among the different treatments of chili, intercrop yield per hectare significantly varied ranging from 3.66 tons per ha to 6.30 tons per ha. panchagavya (3%) spray had the highest yield of 6.30 tons per ha which was followed by PPFM (1%) with 5.27 tons per ha and minimum yield was recorded in control with 3.66 tons per ha which

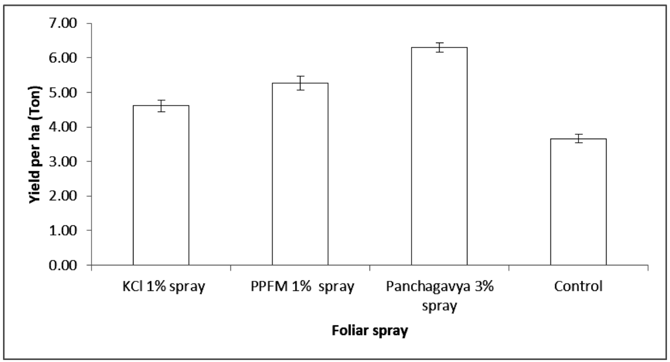

Fig. 10. Effects of biostimulants on yield per ha in chili under palmyrah.

was followed by KCl (1%) with 4.61 ton per ha (Fig. 10).

Dry yield per plant and yield per hectare also varied significantly among the treatments, ranging from 32.25 g to 65.67 g and 1.32 tons per ha to 2.43 tons per ha respectively. The maximum dry weight of fruits per plant and hectare was noticed in panchagavya (3%) with 65.67 g and 2.43 tons per ha which was followed by PPFM (1%) with 58.25 g per plant and 2.15 tons per ha and the least dry weight per plant (32.25 g) and yield per ton (1.32 ton per

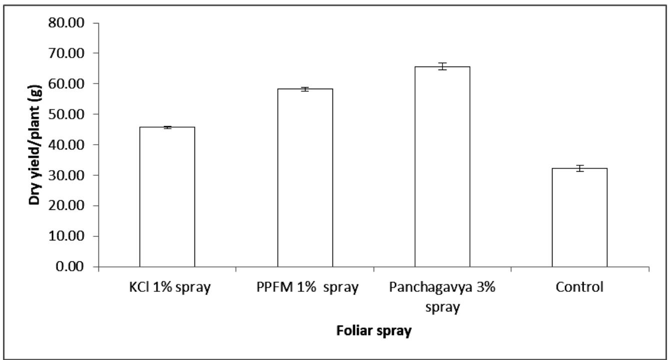

Fig. 11. Effects of biostimulants on dry yield per plant of chili under palmyrah.

ha) was seen in control which was followed by KCl (1%) with 45.67g per plant and 1.68 ton per ha (Fig. 11).

Quality characters

One of the most important vitamins that are present in fruits and vegetables, vitamin C accounts for 90% of the ascorbic acid content in the human diet. The use of biostimulants significantly influenced ascorbic acid content, which ranged from 116.29 mg per 100 g to 121.27 mg per 100 g. The maximum value of ascorbic concentration was estimated in panchagavya (3%) at 12.27 mg per 100 g which was followed by PPFM (1%) with 118.77 mg per 100 g and the lowest ascorbic acid concentration was obtained in control with 116.29 mg per 100 g followed by KCl (1%) with 117.25 mg per 100 g (Table 1).

The days following the transplantation of chili as an intercrop exhibited significant variation in oleoresin concentration across different treatments, ranging from 12.43% to 14.51%. The plant administered with panchagavya (3%) recorded the highest oleoresin content with 14.51% which was followed by PPFM (1%) with 13.76% whereas lower oleoresin content was seen in control with 12.43% which was followed by KCl (1%) with 13.52% (Table 1).

Table 1. Influence of bio stimulants on ascorbic acid content, oleoresin, capsanthin and capsaicin of chili under palmyrah

Treatments	Ascorbic acid content (mg $100g^{-1}$)	Oleoresin content (%)	Capsanthin (ATSA)	Capsaicin (%)
T_1	117.25	13.52	41.05	0.49
T_2	118.77	13.76	42.25	0.51
T_3	121.27	14.51	44.04	0.53
T_4	116.29	12.43	38.50	0.47
S.E. (m)	0.38	0.06	0.26	0.01
S.E. (d)	0.53	0.09	0.37	0.01
C.D.	1.16	0.20	0.81	0.02
C.V. (%)	0.71	1.06	1.42	2.90

Columns show mean values of five replicates with standard error of means.

Capsaicin was responsible for pungency one of the important quality parameters in chili. The capsaicin content in chili as an intercrop, ranging from 0.47% to 0.53%, exhibited substantial variation among the different treatments. Maximum capsaicin was recorded in panchagavya (3%) with 0.53% which was followed by PPFM (1%) with 0.51% when minimum capsaicin (0.47%) was found in control which was followed by KCl (1%) with 0.49% (Table 1).

Among the various treatments capsanthin content in chili as intercrop varied significantly values ranged from 38.50 to 44.04. Maximum capsanthin content was recorded in the panchagavya (3%) at 44.04 which was followed by PPFM (1%) at 42.25 and minimum capsanthin content was obtained in control at 38.50 which was followed by 41.05 (Table 1).

Discussion

In upland cultivation, intercropping vegetables in tree-based systems is a popular practice known as the vegetable agroforestry system (VAF). This integrated approach replaces monoculture with a sustainable and lucrative income source. Conventional resource-intensive agriculture negatively impacts the environment and depletes natural resources. In contrast, VAF systems promote synergies by combining components such as fruit crops and vegetable crops or woody crops and vegetable crops. This results in the creation of sustainable, multifunctional systems that offer a wide range of benefits, including socio-cultural, environmental, and economic advantages. The VAF systems maximize the use of soil, water, and light more effectively than monoculture contributing to a reduction in pesticide and herbicide use. The local economy is stimulated by VAF through job creation and employment due to the diversification of local production resulting from different revenue streams (21). Some refer to this technique as silvo-olericulture, where vegetables are grown alongside legumes, timber, oil-producing trees, and other tree species (22). The shade provided by trees helps to regulate the local microclimate by keeping temperatures low, retaining water in the soil, and preserving soil humidity. VAF systems are interconnected and strong, able to withstand severe weather events with minimal damage. Around a third of the population lives under the poverty line. Vegetable-based agroforestry systems with palmyrah as main crop were with high potentiality for carbon sequestration as compared to either sole palmyrah trees or vegetable crop cultures. Palmyrah-based vegetable farming systems could stock higher carbon, higher soil organic carbon (SOC), and available soil nutrients than other AF and cropping systems. The physicochemical properties of the soil were improved under vegetable-based agroforestry as compared to sole palmyrah tree and vegetable crop cultures. Vegetable-based agroforestry systems could potentially generate food energy cum balanced nutrition, and, thus potential enough to change the diet of the farming community and potentially support the health of community members as a whole by assuring global food security. This way the horticulture-based agro-forestry systems offer a multipurpose way to address environmental preservation, climate change adaptation, and global food security.

Palmyrah, known as 'Kalpagathara' or tree of life not only signifies 800 uses for human kind but also offers scope to the farming community by integrated approach through intercropping with vegetables with a sustainable and lucrative additional income source. Palmyrah trees as the main crop provide optimal photosynthetic photon flux density crucial for the growth and development of vegetables in intercropping systems. Intercropping of vegetables in palmyrah significantly enhances post-harvest soil nutrient status. A study revealed that taro as an intercrop with palmyrah and found that plant density correlated positively with leaf yield, achieving a benefit-cost ratio of 1:6.56 for *Colocasia*. The highest *Colocasia* yield occurred with 41 palmyrah trees per plot (23). Another study investigated intercropping groundnuts with palmyrah trees using various tree densities. It was determined that palmyrah trees at a density of up to 567 trees ha^{-1} provided optimal photosynthetic photon flux density crucial for groundnut growth and development in intercropping systems (1).

The highest increase in plant height, number of branches, and LAI are the results of the interaction between the various treatments in chili under palmyrah as intercrop was obtained by foliar spray of 3% panchagavya because it might be linked to enhanced cell development, protein synthesis and absorption of easily obtained nutrients, particularly N. Furthermore, the presence of helpful micronutrients in panchagavya combined with critical macronutrients like K, phosphorus (P), and N may improve the production of growth-enhancing hormones and chlorophyll production will result in better photosynthesis and increased plant height (24). The tallest plants were achieved through the assimilation of nutrients at the right time. This was a result of applying the required nutrients, leading to taller plants compared to all other treatments. panchagavya (3%) is followed by PPFM (1%) for all the growth, yield, and quality parameters in chili. The enhanced plant growth is due to the ability of the strains to produce spores, colonizing the rhizosphere of tomato crop thereby enhancing its resilience under stressful conditions. It also demonstrated its opportunistic nature and survival under challenging environmental conditions. The application of the recommended dose of fertilizer along with panchagavya (3%) foliar spray increases plant height due to an increase in protein synthesis and all growth in baby corn (25).

A study found that the number of branches per plant increases when auxin (IAA) is present in panchagavya (26). This phenomenon is explained stimulation of cell division and elongation in the axillary buds, which encourages okra development. Gibberellin and IAA in panchagavya cause leaves to expand, potentially altering the LAI and producing larger leaves as shown in legumes and vegetables (27). panchagavya is composed of a high microbial load of fermented organic manure and beneficial microorganisms that boost auxin and gibberellins synthesis. Additionally, discovered that a 3% panchagavya spray led to a corresponding rise in plant height in tomato cultivar cv. Arka Rahshak (28). Similarly, the 3% panchagavya spray on brinjal (29) increased both plant height and the number of branches. *Abelmoschus esculentus* cv. Arka Anamika showed a comparable outcome (30, 31).

In chili flower drop and flower set was one of the major problems in cultivation. Florigen hormone and auxin are contained in panchagavya, promoting early blooming, enhancing flower production, reducing flower drop, and improving fruit set, hence resulting in a greater number of fruits per plant (32). Higher production and movement of photosynthates may have resulted in increased plant height and number of branches, which directly affects the increased photosynthetic area and affects the formation of more fruits with better yield (29). A comparable result was noted in tomato (33). It was reported that the growth and yield properties of chili cv. Kuchinda was enhanced by 3% panchagavya spray (28, 30, 34).

There was a significant increase in the concentration of chlorophyll a, b, and total chlorophyll content in the plants that were treated with 3% panchagavya in chili. This could be because fermented panchagavya contain high quantities of micronutrients and are readily available to plants such as N, P, K, and S which help in the production of chlorophyll in leaves. Additionally, it contains silica (1.5%) and calcium (0.4%) which increase protein content and photosynthetic activity and are essential for chlorophyll synthesis. Similar results were observed in brinjal as well (29, 35).

The application of RDF along with panchagavya

(3%) leads to an increase in photosynthetic pigments such as chlorophyll a, b, and total chlorophyll. This in turn results in the production of larger leaves and a denser canopy, enhancing photosynthetic activity (30). This finding is consistent with the results in other studies (36, 37).

The foliar spray of panchagavya (3%) combined with the recommended dose of fertilizer resulted in a significant increase in yield. This is attributed to the presence of coconut water in panchagavya, which contains kinetin, a substance that enhances biomass and yield. The foliar spray of panchgavya improved all yield and quality parameters, possibly due to the quicker absorption of nutrients like urea, present in panchagavya through the leaf cuticle. This may be due to an adequate supply of nutrients at all stages of crop growth as well as the presence of growth regulators in panchagavya. When panchagavya (3%) is used along with RDF, it has been reported to lead to better photosynthetic activity and a more extensive root system. This allows for better extraction of nutrients from the soil, which was readily available to the crop, leading to an increase in yield and its components (38).

Similar results have also been recorded with panchagavya (3%) spray, which led to an increase in the production, weight of single fruit, and number of fruits per plant in bitter gourd (39). Along with the recommended dosage of fertilizer for baby corn, the yield components like the number of cobs per plant, cob length, and cob width were increased in panchagavya (3%) spray (38). The weight of a single fruit, the number of fruits, and the yield were increased in panchagavya (3%) along with the recommended dose of fertilizer (40). These organic sources also have a high concentration of macro and micronutrients including N which boosts microbial activity and produces a high yield (41, 42).

In addition to the recommended fertilizer dosages, quality characteristics such as ascorbic acid, oleoresin, capsaicin, and capsanthin content were improved with a 3% panchagavya spray. This is likely because panchagavya contains growth boosters that have positive effects on soil and plant characteristics. By enhancing enzyme activity, membrane permeability, and photosynthesis and promoting increased K uptake from panchagavya, it has a significant impact on plants and improves their qualitative characteristics. Similar results were reported in brinjal (29). The higher quality parameter was seen in panchagavya 3% in bhendi. The quality characters were influenced by biochemical changes which were influenced by panchagavya which possesses the unique ability to provide both macro and micronutrients (26). Thus, in turn, assists in increasing quality parameters were also reported (40, 43, 44).

The age of rubber trees and cultivation practices significantly impact various parameters of bird's eye chili (BEC) production. They calculated capsaicin content, and oleoresin content, fresh and dry weight of 100 fruits. Concluding that BEC plants can be successfully intercropped under rubber plantations for up to three years after establishment without compromising yield or quality (45).

The intercropping of chili in drumstick fields, evaluating treatments based on varying distances from drumstick trees. Consequently, the study concludes that cultivating chili in drumstick fields does not compromise yield compared to monoculture conditions for chili cultivation (46).

Conclusion

This research aims to examine the growth, yield, and quality parameters of chili (KKM Ch-1) in relation to the application of bio-stimulants as an intercrop under palmyrah. The result indicated that the maximum yield per ha (6.30 ton per ha), dry yield per plant (65.67 g), dry yield per hectare (2.43 ton per ha), ascorbic acid content (12.27 mg per 100g), capsaicin (0.53%), capsanthin (44.04) and oleoresin (14.51%) were increased with the application of 3% panchagavya followed by PPFM (1%). It can be concluded that the timely assimilation of nutrients through the applications of essential nutrients, including N, P, and K, and minor nutrients along with growth hormones like IAA and gibberellins enhances cell division and elongation. This increase also enhances the photosynthesis activity thereby increasing the source and sinks activity in the crop. It increases the yield and gives additional income to the farmers who utilize the interspaces. It concluded that chili var. KKM Ch-1 as intercrop under palmyrah plantation with along 3% panchagavya as biostimulants increases the growth, yield and quality characters of chili. Vegetable-based farming system could generate sustainable income sources as well as employment covering all the year round as compared to palmyrah monocropping systems, and thus such VFS were very effective in improving living standards even of the marginal and resource-poor farm families. It could also reduce the risk of crop failures. Although it generates additional income for the farmers of Thoothukudi district and other southern districts of Tamil Nadu, it also effectively utilizes the interspace between palmyrah improving soil fertility, and thereby net return of the palmyrah growers.

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Authors' contributions

MN has carried out experiment, data collection and drafted the original manuscript. MIM, VP, MT participated in the design of study and corrected the original draft. SS, KGS provided the laboratory facilities for analysis and also supervise the lab works. NRK participated in design of study.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

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