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RESEARCH ARTICLE

Impact of different mycorrhizal species and leaf extracts on nutrient content and fruit quality of Satluj Purple plum

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Abstract

Mycorrhizal fungi are mutualistic symbiotic associations among fungi and plants and are a great boon to crop growers. These symbiotic associations enhance the assimilation of nutrients and facilitated the overall plant growth, evaluating how the combination of different mycorrhizal species and leaf extracts influence fruit nutrients and the quality of plums. The recent investigation aimed to assess the impact of different mycorrhizal species combined with leaf extracts on the nutrient content and quality parameters of Satluj Purple plum. The investigation design utilized a Randomized Block Design factorial setup including twelve treatments, which had three replications including a control group. Among the different treatments, *Rhizophagus fasciculatus* + mixed leaf extracts (custard apple, citrus and guava) @ 0.5 % (RfLE0.5) showed a positive impact on the nutritional content and quality parameters of Satluj Purple plum. The combination of mycorrhizal fungi and leaf extracts was found to be effective in the absorption of nitrogen, phosphorus and potassium, which accounted for better quality and nutrient content. Also, Pearson's correlation measured the strength and direction of individual treatments and variables, which showed the direct and indirect effects of variables. The study revealed that the application of RfLE0.5 is beneficial not only for mitigating the nutritional content but also for intensifying the calibre of fruit quality of plum fruit.

Keywords: leaf extract; mycorrhiza; nutrients; *Prunus salicina*

Introduction

Plums are stone fruits cultivated in temperate and subtropical parts of the world. They belong to the Rosaceae family, within the subfamily Amygdaloideae, order Rosales and genus Prunus. Among all stone fruits, it is the second most economically significant fruit after peaches. It is a fruit crop that is deciduous and is cultivated in regions with scorching winters and summers (1). While there are 19-40 plum species found around the world, the European plum (*Prunus domestica* L.) and Japanese plum (*Prunus salicina* Lindl.) are the two most often grown plums for commercial purposes. The chilling times and ploidy levels needed for these two Prunus species vary. In contrast to the hexaploidy (2n = 6x = 48) European plum, the Japanese plum is diploid (2n = 2x = 16). It is believed that European plums came from Asia Minor, whereas Japanese plums came from China. Major plum-producing regions include China, the United States, the European Union, Serbia, Chile and Romania (2). Although primarily cultivated in temperate and subtropical regions, plums are considered a temperate-zone fruit crop. The nutritional content in these fruits includes vitamins K, C and A, together with potassium and antioxidant dietary fiber, along with other necessary minerals. Other bioactive compounds such as quercetin, tryptophan and sorbitol, also help aid the body's physiological functions (3).

The extensive use of chemical fertilizers is at one's fingertips everywhere, which ultimately helps in polluting the environment as well as degrading the soil. So, the use of new management techniques has altered the worldwide strategy for creating a sustainable agricultural system. In light of this, it is crucial to regard the biological and integrated systems, especially biofertilizers, to attain the plant nutritional requirements and reduce the utilization of chemical fertilizers (4). Mycorrhizal fungi (AMF) and leaf extracts can be beneficial since they are organic, environmentally friendly, cost-effective and a major source of vitamins, macro- and micro-elements, pro-enzymes and growth regulators and so play an important role in sustainable soil fertility (5).

Arbuscular mycorrhizal fungi such as *Rhizophagus irregularis* (RI) and *Rhizophagus fasciculatus* (RF, previously referred to as *Glomus fasciculatum*) form extensive symbiotic relationships mainly with the roots of vascular plants to the advantage of both the interacting partners. They have obtained fixed carbon from their plant hosts, which is the result of photosynthesis and as a contribution, they supply mineral nutrients, including phosphorus and nitrogen, promoting increments in plant growth (6, 7). A type of ericoid mycorrhiza, *Oidiodendron echinulatum* (OE), is known to enhance growth in plants belonging to the Ericaceae family (8). An essential function of ErM fungi is to provide nutrients to host plants and to lower land poisoning (9, 10). These microbes are crucial to plant nutrition, particularly in humus-free soils that are low in P, N and other nutrients. They enable plants to acquire P that is inaccessible and unabsorbed in the growth media. (11). In general, mycorrhizal symbiosis can play a key role in maintaining soil fertility and stabilizing soil structure when increasing plant water uptake, yield and quality (12). Thus, bio-fertilizers can improve the quantity and quality of fruit crops.

Leaf extracts of custard apple, guava and citrus plants are useful in enhancing fruit crop production as they are rich in secondary metabolites such as flavonoids, alkyl ketones and sesquiterpenes. Plants process antioxidant-rich bioactive-enriched custard apple leaf extract to boost their pest and disease defense strategies and experience improved growth and better fruit quality because of its nutritious makeup (13). Citrus leaf extract contains essential oils (EOs), ascorbic acid, sugars, carotenoids, flavonoids, dietary fiber, polyphenols and various micro elements, which underline its antimicrobial effectiveness and help in protecting crops from fungal and bacterial infections (14). These extracts provide environmentally friendly and sustainable methods for improving the yields of fruit crops and increasing productivity in agriculture while minimizing the use of artificial chemicals. The natural biopesticide qualities of guava leaf extract come from its flavonoid and tannins compounds, which can operate without requiring chemical applications. The compound improves both soil health and biological operations, which results in better nutrient efficiency and increased crop production levels (15). Multiple studies revealed the influence of mycorrhizal impact on fruits' growth and production and others focused on leaf extracts to magnify fruit quality. But no results are found till date in the literature about the application of mycorrhizal fungi in combination with different leaf extracts to intensify the biochemical attributes of plum. In this context, the present research goal is to evaluate the effects of a different leaf extract-custard apple, citrus and guava (CCG) and mycorrhizal fungi, along with their interaction on the nutrient content and biochemical properties of plum. The prime question was, does mycorrhizal fungi inoculation combined with CCG leaf extracts improve the nutrient content and biochemical properties of plum?

Materials and Methods

Experiment site

This study focuses on evaluating how different mycorrhizal species and combinations of leaf extracts influence fruit nutrients and the quality of plums. The research began in October 2023 at the Government Garden and Nursery in Jalandhar Cantt, Punjab. A deep sandy loam soil exists at the site because of alluvial deposition while slightly alkaline conditions with pH 7.9 feature moderate drainage. The region has a hot, humid climate with cool winters and a hot, humid summer climate. In summer, temperatures range between 35 ° C and 39 °C, occasionally exceeding 42 °C in May and June, while winter brings temperatures down to 4-6 °C during December and February. The region receives an average annual rainfall of about 703 mm, with an elevation area of 232 m at the experimental location situated near 31.9°N latitude and 75.60°E longitude. The study design utilized a Randomized Block Design factorial setup including twelve treatments, which had three replications including a control group. The study was conducted on 36 five-year-old Satluj Purple plum plants to ensure reliable and consistent results (Table 1).

Treatment details

The investigation includes the soil application of three different mycorrhizal species (*Oidiodendron echinulatum*, *Rhizophagus irregularis* and *Rhizophagus fasciculatus*) and foliar application of two different concentrations of leaf extracts of custard apple, citrus and guava combined at a ratio 1:1:1 (0.5 % and 1 %). The mycorrhizae were collected from the Institute Microbial Type Culture Collection and Gene Bank (MTCC), SOM Phytopharma Ltd., India (Agri Life Pvt. Ltd.) and Seed2Plant store. An amount of 20 g of mycorrhiza with a subordinate of 20 kg of cow dung was applied to each plant in the orchard (Table 1). It was applied by removing the weeds and making a trench around the trees by digging soil up to 6 inches (16). The orchard has a spacing of 10ft × 10ft of plant to plant and row to row. Adequate water was supplied to the field after the mycorrhizal application.

Leaf extract preparation

For the preparation of leaf extracts, the leaves were washed out with distilled water, then parched with an oven at 60 °C and crushed into a crude substance with around 1 mm of diameter. Extraction was executed utilizing the maceration method into 96 % ethanol solvent for 48 hr, employing the "intermittent shaking" method to get an extract. A rotary evaporator was applied to evaporate the extract at 50 rpm and 40 °C until a concentrated extract was obtained. The concentrated extract was then laid down in a beaker glass and covered with an aluminium foil and stored in a refrigerator at 4 °C to protect from damage. The solvent used was sodium carboxymethyl cellulose (CMC Na) with 1 % concentration to obtain the extract with several concentrations (17).

Observations

Nutrient content

To evaluate the trees, we carefully marked the experimental ones in the field and recorded observations on leaf and fruit nutrient content (N, P and K) and expressed in %.

Table 1. Treatment details

Treatments	Notation	Quantity/plant
Control	C	No mycorrhiza and leaf extract
No mycorrhiza + CCG@0.5 %	LE0.5	80 mL approx.
No mycorrhiza + CCG@1 %	LE1	80 mL approx.
OE + No CCG	Oe	20 g mycorrhiza + 80 mL approx.
OE + CCG@0.5 %	OeLE0.5	20 g mycorrhiza + 80 mL approx.
OE + CCG@1 %	OeLE1	20 g mycorrhiza + 80 mL approx.
RI + No CCG	Ri	20 g mycorrhiza + 80 mL approx.
RI + CCG@0.5 %	RiLE0.5	20 g mycorrhiza + 80 mL approx.
RI + CCG@1 %	RiLE1	20 g mycorrhiza + 80 mL approx.
RF + No CCG	Rf	20 g mycorrhiza + 80 mL approx.
RF + CCG@0.5 %	RfLE0.5	20 g mycorrhiza + 80 mL approx.
RF + CCG@1 %	RfLE1	20 g mycorrhiza + 80 mL approx.

Vanado-Molybdo phosphoric yellow colour method was employed to identify phosphorus and double beam ultra visible spectrophotometer was employed to measure the intensity of color at 440 nm. Flame photometer 130 (Systronics) was employed to find potassium using the photometer. Micro-Kjeldhal method was employed to quantify nitrogen, which was further expressed as a percentage (18).

Where,

$$N\ \% = \frac{14.01 \times 0.1N\ \times (\text{Titre value}\ -\ \text{Blank value})}{\text{Sample weight}\ \times\ 1000} \times 100$$

14.01 - Ammonia's Molecular Weight.

0.1N - Titration Solution's Normality.

Quality parameters

For the quality assessment, ten ripe fruits were randomly selected from each experimented tree. We collected data on various characteristics, total soluble solids (°B), titratable acidity (%), ripening index, total sugar (%), reducing sugar (%) and non-reducing sugar (%). The analyses for total soluble solids (TSS), titratable acidity (TA) and sugar in fruits followed established laboratory methods provided by Latimer (19).

TSS were assessed by placing 1-2 drops of plum juice on the prism of a digital refractometer. TA was determined by titrating the fruit pulp against 0.1N NaOH, with the results expressed as a percentage of acid. The evaluation methods allowed researchers to measure the essential quality characteristics of the fruit. Owing to the dominance of malic acid in plum fruits, TA was estimated based on the equivalent weight of malic acid (20). The ripening index (RI) was determined by taking the value of TSS with its respective TA value. To measure total sugar (TS), we added citric acid to the sample, then boiled the solution to ensure complete sucrose inversion. Reducing sugar (RS) content was determined using a titration method, where fruit juice was titrated with methylene blue as an indicator against Fehling's solution. Moreover, non-reducing sugar (NRS) was obtained by subtracting the RS value from TS (21).

Statistical analysis

A healthy and dropped fruit samples were analyzed statistically, with significance of $p < 0.05$. The statistical software packages OPSTAT and R Studio were used for conducting the analysis. Tukey's HSD Test determined the treatment differences through its evaluation method. Pearson's correlation technique determined the connection points between traits and production outputs. Principal component analysis (PCA) helped uncover the main data patterns by analyzing the information collected.

Results and Discussion

The combination of leaf extracts of custard apple, citrus and guava along with mycorrhiza has shown promising results towards the nutrient content and fruit quality of plum. The leaf extracts were rich in nutrients and had bioactive compounds, which turned out to be beneficial for the plum plant. Moreover, mycorrhiza improved in overall quality of fruit trees by intensifying the ingestion of mineral nutrients.

Nutrient content

The application of mycorrhiza and leaf extracts from custard apple, citrus and guava has a significant impact on the nutritional content, particularly NPK (nitrogen, phosphorus and potassium) of plum leaves. NPK content in leaves of plum plant (Table 2) as influenced by different treatments showed that the content of nitrogen ranged from 2.66 % to 5.24 %. Nitrogen content was significant and found maximum (5.24 %) in RfLE0.5 while minimum nitrogen content of 2.66 % was recorded in the control treatment (Table 2). Phosphorus (P) level was significantly higher in RfLE0.5 (1.48 %) and found the lowest in untreated C group (0.77 %). The highest potassium 6.70 % was found significant in RfLE0.5 followed by OeLE0.5 (3.38 %), while minimum (1.34 %) K content was obtained in C group (Table 2).

The symbiotic fungi that grow with plant roots enable them to obtain essential soil nutrients through phosphorus, specifically which aids root growth and nutrient distribution within the plant. The use of mycorrhizal inoculation methods results in substantial percentage increases of leaf nitrogen, phosphorus and potassium levels (22, 23).

The leaf extracts from custard apple, citrus and guava plants contain bioactive components which contribute to enhancing nutrient availability within the soil. The extracts activate soil microorganisms while improving soil fertility, which results in better nutrient availability for plants (24). Guava leaf extracts are also known to enhance phosphorus availability due to their high nutrient content (25, 26). The combined application of mycorrhizae and these leaf extracts not only boosts the NPK levels in plum leaves but also promotes better growth.

NPK content of plum fruit (Fig. 1) as influenced by different treatments showed that nitrogen in plum fruit ranged from 1.36 % to 2.83 %. Nitrogen content was significant and found maximum

Table 2. Impact of different treatments on nutrient content of plum leaves

Treatments	Observations		
	N (%)	P (%)	K (%)
C	2.66 ± 0.022^{e}	0.77 ± 0.012^{g}	1.34 ± 0.031^{g}
LE0.5	2.81 ± 0.044^{e}	0.83 ± 0.009^{fg}	1.73 ± 0.019^{f}
LE1	2.72 ± 0.025^{e}	0.80 ± 0.010^{fg}	1.43 ± 0.026^{g}
Oe	2.87 ± 0.034^{e}	0.92 ± 0.010^{e}	1.93 ± 0.029^{e}
OeLE0.5	4.75 ± 0.091^{b}	1.20 ± 0.013^{b}	3.38 ± 0.042^{b}
OeLE1	4.01 ± 0.054^{c}	1.11 ± 0.013^{c}	2.81 ± 0.045^{c}
Ri	2.81 ± 0.031^{e}	0.87 ± 0.010^{ef}	1.77 ± 0.035^{f}
RiLE0.5	3.44 ± 0.033^{d}	1.03 ± 0.004^{cd}	2.55 ± 0.054^{d}
RiLE1	3.37 ± 0.040^{d}	1.03 ± 0.010^{cd}	2.48 ± 0.032^{d}
Rf	2.89 ± 0.037^{e}	0.96 ± 0.012^{de}	1.94 ± 0.028^{e}
RfLE0.5	5.24 ± 0.063^{a}	1.48 ± 0.013^{a}	6.70 ± 0.078^{a}
RfLE1	4.07 ± 0.052^{c}	1.12 ± 0.012^{c}	2.88 ± 0.042^{c}

All values of the parameters are mean and error of three replications. The superscript letters represent the significance ofthe mean values at $p < 0.05$.

(2.83 %) in RfLE0.5 while minimum nitrogen content of 1.36 % was recorded in the control treatment (Fig. 1). Phosphorus (P) levels were significant and approximately similar in OeLE0.5, OeLE1, RiLE0.5, RiLE1, RfLE0.5 and RfLE1 in the fruit flesh of plum ranged from 0.13 % to 0.45 %, maximum P content was obtained in treatment RfLE0.5 treatment. The highest potassium 3.26 % was found significant in RfLE0.5 followed by OeLE0.5 (3.20 %), while minimum K content was obtained in C (2.00 %). The application of leaf extracts positively influences NPK accumulation in fruits due to soil fertility enhancement by microbial activity and nutrient availability, root absorption efficiency for nutrients due to phosphorous and efficient nutrient translocation from roots to plants by potassium (27, 28). Mycorrhizal inoculation improved the overall quality of fruit trees by enhancing the uptake of mineral nutrients (29). Florida Prince peach administered with mycorrhiza revealed a significant increment in nutrient content, weight and yield of fruit and reduced fruit drop as well (30).

Quality parameters

The content of TSS, TA, TS, RS and NRS in the fruit juice was determined at ripening. Different treatments were applied to influence the optimization of fruit flavour characteristics by improving some of the attributes of fruit quality like TSS, RI, RS and TS, combined with a drop in TA. The maximum TSS content of fruit juice was significantly influenced by RfLE0.5 (Table 3). (17.15°B) followed by OeLE0.5 treated fruits (16.20°B) which was significantly higher than the TSS content in C (8.45°B). TA was detected to be significantly lower in RfLE0.5 treated fruits (0.47 %) that were followed by OeLE0.5 treated fruits (0.52 %) compared with 1.05 % of untreated fruits (Table 3). Compared to the C, in treated fruits, the ripening index (TSS: acidity ratio) was greatest in RfLE0.5 (36.39). Melon fruit that was treated with *Rhizophagus* sp. contained the highest amounts of TSS and TA reduction (31). The nutrient in leaf extracts, mainly K (potassium), is critical for sugar metabolism and translocation as K promotes enzymatic activity (e.g., invertase) that hydrolyzes sucrose into glucose and fructose, elevating TSS. Thus, leaf extracts significantly increased TSS, RI by enhancing sugar accumulation and neutralizes organic acid by converting to sugars (32, 33).

The TS, RS and NRS content in fruit juice were notably impacted by the application of various treatments (Table 3). The utmost content of total sugar (7.63 %) was observed with the fruit juice treated with RfLE0.5 treatment being closely followed by OeLE0.5 (7.57 %), RfLE1 (7.57 %) and the recorded minimum in untreated fruits (6.17 %). In this study, the utmost concentration of RS was found in plum fruits of RfLE0.5 treatment (6.22 %), closely followed by OeLE0.5 (6.18 %). RS was found to be significant in RfLE0.5 treatment when compared to other treatments. Lastly, NRS was recorded maximum (2.50 %) in the control (Table 3). The inoculation of AM (arbuscular mycorrhiza) fungi in papaya significantly improved TS, RS and NRS (34). Nutrients present in leaf extracts mainly N enhanced chlorophyll synthesis and photosynthetic efficiency, increasing carbohydrate production

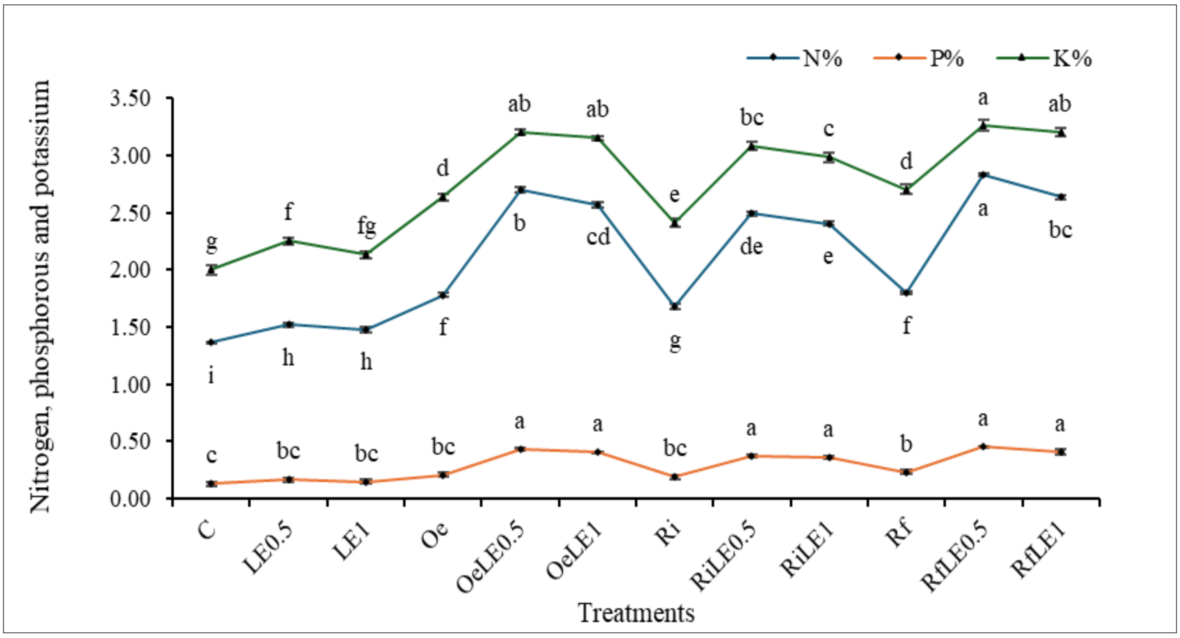

Fig. 1. Impact of different treatments on fruit nutrient content of plum.

Table 3. Impact of different treatments on fruit quality parameters of plum

Treatments	Observations					
	TSS (°B)	TA (%)	RI	TS (%)	RS (%)	NRS (%)
C	8.45±0.20^{f}	1.05±0.01^{a}	8.02±0.15^{h}	6.17±0.09^{f}	3.67±0.08^{i}	2.50±0.00^{a}
LE0.5	11.75±0.20^{de}	0.97±0.01^{ab}	12.16±0.20^{fg}	6.38±0.08^{ef}	4.21±0.10^{g}	2.18±0.03^{b}
LE1	11.05±0.09^{e}	1.00±0.06^{a}	11.13±0.70^{g}	6.27±0.09^{f}	4.04±0.10^{h}	2.23±0.02^{b}
Oe	12.80±0.35^{d}	0.81±0.02^{cd}	15.83±0.68^{e}	6.59±0.08^{de}	4.80±0.05^{e}	1.79±0.04^{cd}
OeLE0.5	16.20±0.40^{ab}	0.52±0.01^{ef}	30.96±0.54^{b}	7.57±0.12^{ab}	6.18±0.09^{a}	1.39±0.06^{ef}
OeLE1	14.60±0.23^{c}	0.56±0.00^{ef}	26.23±0.56^{cd}	7.55±0.14^{ab}	5.97±0.12^{bc}	1.58±0.05^{de}
Ri	12.55±0.38^{d}	0.89±0.01^{bc}	14.18±0.66^{ef}	6.52±0.09^{de}	4.63±0.07^{f}	1.89±0.05^{c}
RiLE0.5	14.80±0.06^{c}	0.58±0.01^{e}	25.67±0.30^{cd}	7.37±0.12^{bc}	6.13±0.09^{ab}	1.23±0.03^{fg}
RiLE1	14.55±0.20^{c}	0.59±0.01^{e}	24.81±0.45^{d}	7.23±0.11^{c}	5.94±0.07^{c}	1.29±0.08^{fg}
Rf	12.85±0.26^{d}	0.79±0.01^{d}	16.27±0.40^{e}	6.63±0.09^{d}	5.49±0.08^{d}	1.14±0.03^{g}
RfLE0.5	17.15±0.03^{a}	0.47±0.02^{f}	36.39±1.70^{a}	7.63±0.12^{a}	6.22±0.10^{a}	1.41±0.02^{ef}
RfLE1	15.60±0.06^{bc}	0.55±0.01^{ef}	28.37±0.19^{bc}	7.57±0.14^{ab}	6.14±0.09^{a}	1.43±0.05^{ef}

All values of the parameters are mean and error of three replications. The superscript letters represent the significance ofthe mean values at $p < 0.05$.

leading to improvement in total sugars accumulation (35). The metabolism of ATP-driven pathways becomes faster through phosphorus use, which reduces RS levels, while K improves sucrose transportation and enzymatic conversion of sucrose (36, 37).

Principal component analysis

PCA performed demonstrates a comprehensive method for studying variable and individual (sample) interactions and their contributing variations (Fig. 2). The first main component (Dim 1) represents 94.35 % of the total data variance yet the second main component (Dim 2) adds 4.26 % to the total variability. Only one dominant factor controls the dataset, yet secondary factors produce a minor effect on its composition. The PCA biplot of individuals shows how different samples (C, LE1, LE0.5, Ri, Oe, Rf, etc) are distributed in this reduced-dimensional space. The plot shows similar characteristics between samples which are situated near each other and distinct characteristics among samples which are positioned further apart (Fig. 2). The clustering patterns of samples show the possibility of underlying biological or environmental or chemical differences between samples.

The variable correlation plot helps in understanding the contribution and interrelationships of the measured variables to the principal components. Titratable acidity (TA), non-reducing sugars (NRS), reducing sugars (RS), total sugars (TS), total soluble solids (TSS) and ripening index (RI) form the vectors which are studied. The vector direction, together with vector length, reveals the link between the variables and both principal components. Variables that have longer vectors contribute more significantly to the PCA, meaning they have a strong influence in differentiating individuals. The measurement of variable correlation occurs through the angle relationship between their vectors as matching directional vectors indicate positive

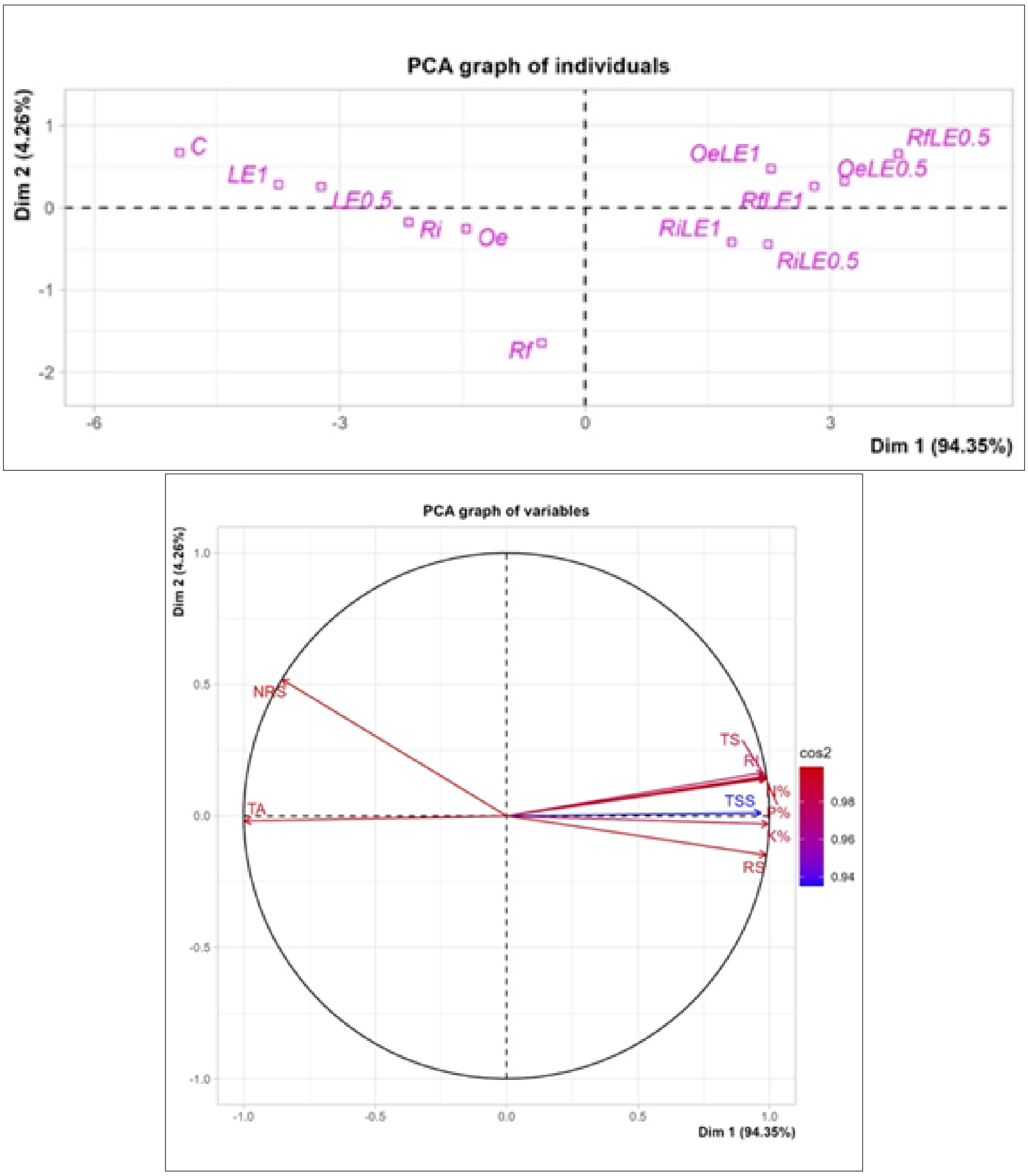

Fig. 2. Principal component analysis of variables (observations) and individuals (treatment combinations). [N: Nitrogen (%); P: Phosphorous (%); K: Potassium (%); TSS: Total soluble solids (°B); TA: Titratable acidity (%); RI: Ripening Index; TS: Total sugar (%); RS: Reducing sugar (%); NRS: Non-reducing sugar (%); C: No treatment; LE0.5: No mycorrhiza + mixed leaf extracts @0.5 %; LE1: No mycorrhiza + mixed leaf extracts @1 %; Oe: *Oidiodendron echinulatum* + No leaf extract; OeLE0.5: *Oidiodendron echinulatum* + mixed leaf extracts @0.5 %; OeLE1: *Oidiodendron echinulatum* + mixed leaf extracts @1 %; Ri: *Rhizophagus irregularis* + No leaf extract; RiLE0.5: *Rhizophagus irregularis* + mixed leaf extracts @0.5 %; RiLE1: *Rhizophagus irregularis* + mixed leaf extracts @1 %; Rf: *Rhizophagus fasciculatus* + No leaf extract; RfLE0.5: *Rhizophagus fasciculatus* + mixed leaf extracts @0.5 %; RfLE1: *Rhizophagus fasciculatus* + mixed leaf extracts @1 %].

connection and opposing vectors signal negative correlation. From the correlation circle, it is evident that TA and NRS are positioned in a similar direction, indicating a strong positive correlation between them (Fig. 2). The increase in TA concentration results in higher NRS content, according to this evidence. On the other hand, RS, TS, TSS and RI are clustered in the same general direction but are slightly separated, suggesting that they are positively correlated with each other and have a similar influence on Dim 1. The quantity of RS content in the sample directly influences TS and TSS as well as RI levels. Additionally, the fact that TA and NRS are positioned nearly opposite to RS, TS and TSS suggests a strong negative correlation between acidity and sugar content. Each increase in TA within a sample results in reduced RS and TS because acidity and sugar accumulation show an opposite relationship.

Since Dim 1 explains most of the variance, sugar-related variables (RS, TS and TSS) and acidity (TA) are the primary distinguishing factors among individuals (Fig. 2). Samples that are positioned more towards the positive side of Dim 1 are likely to have higher sugar content, while those towards the negative side of Dim 1 are characterized by higher acidity. A small portion of variance in the analysis is explained by Dim 2, which probably measures smaller RI changes and secondary variable variations. The distribution of individuals in the PCA graph of individuals aligns with these variable relationships, where samples that are positioned near the sugar-related variables likely contain higher sugar content, while those closer to the TA vector are more acidic.

Hence, the PCA analysis graphically shows that acidity and sugar content are the major sources of variability across the samples. The negative correlation between the TA and sugar variables shows that the more acidic the samples, the lower the sugar content and vice versa. This is a typical trend in fruit and plant research, where the level of ripeness and acidity dictates the total sugar content.

Pearson's correlation

The Pearson correlation matrix, which is shown in Fig. 3, shows various variable correlation coefficients that show the direction and strength of variable associations. The variables RS, TS, RI, TA, TSS, K, P and N are listed on both axes of a triangular matrix. Relationships with positive 1 values indicate strong positive links, while negative 1 values show strong inverse effects. Zero values indicate no relationships between variables. The graph's circular elements display correlation coefficients that range from -1 to 1. To improve the visual interpretation of the data, strong negative correlations are shown in yellow hues, while strong positive correlations are shown in green tones. Strong relationships show up as larger circles and weak relationships show up as smaller circles because the circles' sizes maintain a direct correlation to magnitude. The data shows a negative correlation of -0.99 between TA and P and a positive correlation of 0.98 between N and P. This matrix helps in identifying significant relationships between variables, which aids in statistical analysis, feature selection and the comprehension of measurement dependency.

Conclusion

The current study emphasizes the significant contribution of mycorrhizal inoculation and leaf extracts to enhance the chemical content and nutritional value of Satluj Purple plum, especially in subtropical regions where environmental stress restricts productivity. The most effective synergistic use of *Rhizophagus fasciculatus* + mixed leaf extracts (custard apple, citrus and guava) @ 0.5 % enhanced nutrient uptake (NPK), fruit quality and decreased titratable acidity, thus enhancing the palatability of the fruit. These beneficial impacts are induced by improved

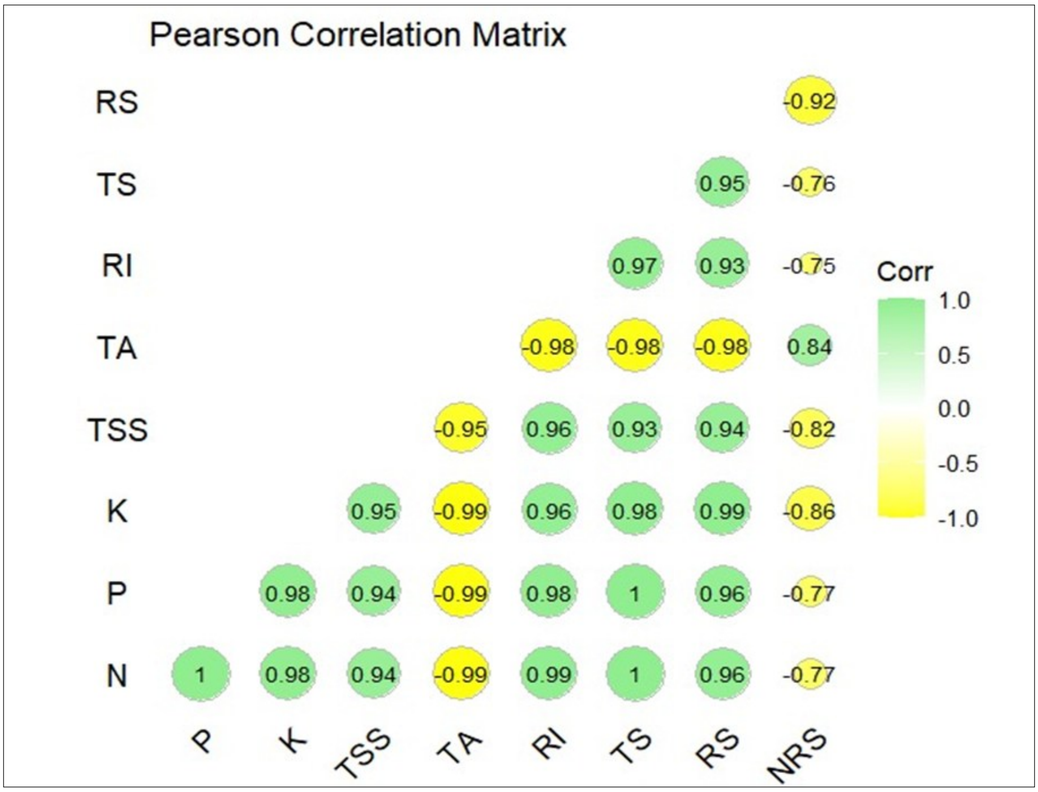

Fig. 3. Pearson's correlation matrix [N: Nitrogen (%); P: Phosphorous (%); K: Potassium (%); TSS: Total soluble solids (°B); TA: Titratable acidity (%); RI: Ripening Index; TS: Total sugar (%); RS: Reducing sugar (%); NRS: Non-reducing sugar (%)].

water and nutrient uptake, which is crucial to sustain productivity under water-scarce and low-fertility regimes. The study validates the hypothesis that combinations of mycorrhizal fungi and leaf extracts enhance the biochemical qualities and market value of plums. Further research would be necessary to establish the most optimal combinations of mycorrhizal species and leaf extracts to be used at a commercial scale.

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Authors' contributions

JT performed the statistical analysis and drafted the manuscript. AK and AT participated in drafting and paraphrasing of the manuscript. All the authors read and approved the final manuscript.

Compliance with ethical standards

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

Ethical issues: None

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