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GRAFT-HYBRIDIZATION THROUGH INTRA-SPECIFIC GRAFTING IN BRINJAL (*SOLANUM MELONGENA L.*): DUAL-FRUIT PRODUCTION FROM A SINGLE ROOT STOCK UNDER CONTROLLED CONDITIONS

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Abstract

Grafting techniques are widely used in horticulture to increase growth and stress tolerance in vegetable crops, including in Solanum melongena L. This study presents an example of Hybrid-Grafting in brinjal under controlled as well as stressed conditions in greenhouse of Pakistan Council of Scientific and Industrial Research PCSIR, Lahore, Pakistan. The present investigation was carried out in the year of 2024-25, in completely randomized design (CRD). Reciprocal grafted combinations (P1 and P2), a combined heat and water deficit stress treatment (P3), and non-grafted controls (P4 and P5) were evaluated. Growth and yield parameters were recorded and analyzed using one-way analysis of variance (ANOVA) The grafted plants grew under limited input conditions and exhibited a high grafting success rate of 90%. The grafted plants demonstrated vigorous growth, high stress tolerance, and prolonged fruiting. Between grafted combinations, P1 showed superior growth and yield performance. Stress-treated grafts showed moderate reduction in yield but not at abrupt level, showed partial stress tolerance in grafted plants. Control plants showed lower growth and yield than grafted plants. A notable finding was the simultaneous production of white and purple fruits on the same grafted plant. This signified effective vascular integration accompanied by independent phenotypic expression. The wild rootstock enhanced the grafted plant's ability to withstand adverse conditions, and increased overall plant vigor and stress tolerance. These results indicated that intra-specific graft hybridization in brinjal is quite successful, may act as a sustainable, space-saving, and cost-efficient method for crop diversification and urban agriculture.

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INTRODUCTION

Eggplant is also referred to as Solanum Melongena L and is among the important crops that belong to the Solanaceae family. This specific family of crops is cultivated all around the world, especially the tropical and subtropical regions (Vavilov, 1951; Zeven & Zhukovsky, 1975). Besides the crops being of nutritional value, the family of crops is recognized for economically benefitting both subsistence and commercial farming. On a yearly basis, the cultivation of brinjal in Pakistan is in the top ranking of cultivated crops, although the productivity is negatively affected by the following conditions: high temperature, irregularity in the water supply, low soil fertility, and the presence of biotic interactions such as soil diseases and pests (Bletsos et al., 2003). In addition, increasing interest has emerged in increasing plant resilience through grafting under stressed conditions.

Grafting, in the world of horticulture, is defined as a practice that brings together two plant parts, also referred to as the scion and the rootstock. This mechanism allows the two parts of the plant to function as a singular plant and perform various physiological activities together. One of the oldest sectors/growing fields that used grafting as a method is the woody perennial crops. As of today, the use of grafting has moved to the herbaceous vegetable crops and has become more prevalent in the East Asian countries like Japan and Korea (J.-M. Lee et al., 2010). In contemporary vegetable production systems, grafting is routinely done as a means to enhance the vigor of the plants. It generally improves the uptake of water and nutrients, increases candidate plants' tolerance to abiotic stresses, and lowers the incidence of disease related to the soil, thereby reducing the need for chemical inputs (Colla et al., 2010). Recent studies have further highlighted the impact of grafting in increasing plant performance under abiotic stress conditions such as heat and water deficit (Mauro et al., 2022; Razi et al., 2024).

In eggplant cultivation, grafting has been integrated since the late 1950s, mainly using wild Solanum species as rootstock due to their robust root systems and adaptability, as well as their tolerance to various forms of stress (Bletsos et al., 2003) Numerous studies indicate that grafting cultivated eggplant varieties on wild rootstocks promotes growth of the plants, as well as their yield and survival, in both protected and open-field circumstances (Bletsos et al., 2003; Kumar et al., 2017). In addition, the growth of grafting technologies, specifically mechanized and semi-automated system grafting, has made this technique a more viable and sustainable option for production (Davis et al., 2008). Moreover, reciprocal grafting system have been increasingly used to evaluate scion-rootstock interactions and their impact on plant productivity and growth.

There has been a lot of research on grafting and the possible benefits of grafting for disease resistance, enhancing yields, and improving fruit quality. However, research has been sparse on grafting's ability to create diverse morphologies and the potential for the production of 'dual' fruits. Many research studies describe the removal of the rootstock shoots, which keeps the scion dominant. This is done without examining the potential of retaining rootstock branches to investigate independent phenotypic expression within a common vascular system (Aloni et al., 2010; Kumar et al., 2017). Therefore, the research on the ability of a single grafted eggplant to produce two fruit phenotypes have been neglected. However, limited research has worked on combined effect of reciprocal grafting and simultaneous water deficit and heat stress in brinjal under controlled greenhouse conditions.

This research looks at the potential of intra-specific graft hybridization in eggplant (Solanum melongena) and involves grafting a white hybrid brinjal scion onto a wild purple brinjal rootstock (P1) and wild purple scion onto a white hybrid brinjal rootstock (P2) in a controlled greenhouse setting. In contrast to other

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methods, some of the lateral branches of the rootstock are purposely left to assess 'dual' fruiting, grafting compatibility, and the physiological performance of the plant. This research also looks at plant vigor, stress tolerance as heat and water deficit stress applied (P3), and productivity in low-input organic systems to intercept sustainable horticulture (Bletsos et al., 2003; Rouphael et al., 2018). This work also proposes a model for urban and controlled-environment agriculture that expands the functional scope of vegetable grafting beyond traditional yield enhancement and is both innovative and space-efficient (Bie et al., 2025).

MATERIAL AND METHODS

The experiment was conducted in the controlled greenhouse facility of PCSIR (Pakistan Council of Scientific and Industrial Research), Lahore. The study was performed entirely under monitored environmental conditions, where the factors such as temperature, humidity, and light exposure were maintained according to growth requirements of Solanum melongena (brinjal). The setup represented a low-input sustainable cultivation model using locally available materials and natural kitchen waste, ensuring minimal dependence on chemical fertilizers or synthetic supplements. The growing media consisted of locally available garden soil mixed with organic compost prepared from kitchen and domestic organic waste. The compost was completely organic and free from any chemical fertilizers, ensuring an eco-friendly and cost-effective cultivation method. The soil mixture was examined and sterilized before use to make sure the elimination of pathogens and ensure optimal aeration and drainage. Two cultivars of Solanum melongena L were selected:

A high yielding White hybrid brinjal (Commercially available F1 hybrid), selected for its fruit quality.

A Purple wild brinjal variety, locally sourced and known for its hardiness and disease tolerance.

Table 1: ***Scion-Rootstock Combinations as Treatments***

Treatment no.	Treatment Combination
P-1	White hybrid brinjal x Purple wild brinjal
P-2	Purple wild brinjal x White hybrid brinjal
P-3	White hybrid brinjal x Wild purple brinjal (stressed conditions)
P-4	Control-Plant (Purple wild brinjal).
P-5	Control-Plant (White hybrid brinjal)

Figure 1: Protocol to follow while grafting procedure.

In P3, combined abiotic stress was given through fluctuated temperature conditions (heat stress) and water deficit by reducing irrigation frequency compared to controlled conditions for other treatments (P1, P2, P4, P5). This treatment was designed specifically to evaluate the performance of grafted plants under stressed conditions relative to non-stressed grafted plants (P1, P2).

Both cultivars were raised from seeds in seedling trays and small pots with soil and compost mixture, until

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grafting stage. The Cleft stem grafting technique was used as performed in (J.-M. Lee & Oda, 2002). Grafting was conducted in mid-April within the PCSIR Greenhouse under controlled conditions, humidity maintained at approximately 70-80%, to facilitate a strong graft union formation. The root stock (40- 45 days old) and scion (40-45 days old) were cut with the help of sharp sterilized cutter to avoid any infection to plants and carefully joined using Cleft stem grafting method, while eggplant is herbaceous plant as shown in (J.-M. Lee & Oda, 2002). The graft union was secured with grafting tape to ensure tight contact between the vascular tissues.

Note during grafting, the rootstock plants retained some of their original lateral branches and basal shoots below and above the graft union. These were intentionally left unpruned to observe natural growth behavior. This approach was used to study functional graft-hybridization through simultaneous reproductive expression of both graft partners under a common root system. As a result, the rootstock itself continued to grow alongside scion. The union was secured by grafting tape and placed in a shaded area. The grafted plants were observed carefully for about 8-10 days (Healing period) to minimize transpiration and promote healing. Regular misting was done to maintain moisture around the graft union and to avoid dehydration conditions. After two weeks (Hardening period) the grafts showed signs of success with new leaf emergence from scion. Once new leaves appeared on the scion (approximately after two weeks), the plants were gradually hardened by increasing the light exposure. Fully healed grafted plants were then transferred to larger pots for further growth and development within the controlled greenhouse. Successfully grafted plants were transplanted in larger clay pots (14 inches) with the same soil-compost mixture. They were irrigated using tap water based on soil moisture needs, with no additional fertilizer inputs. Environmental conditions and parameters such as temperature (25-35 °C), humidity and light intensity were monitored and examined on regular basis. Observations were made on various vegetative and reproductive parameters:

Flowering began in late June and peaked by early July. Fruiting started in mid- July, with the plant producing dual fruits, white brinjals from scion, and purple brinjals from wild plant allowing for simultaneous expression of both scion-derived and rootstock-derived fruit. The phytochemical and quality parameters especially TSS content and Anthocyanin content of fruit was analyzed from freshly harvested fruits. The TSS content of fruits was measured by spectrophotometric method. Total anthocyanin content calculated according to a modification of the method described by (J. Lee et al., 2005). The morphological and agronomical parameters e.g., days to first flowering and days needed for fruit set to maturity were recorded on regular intervals accordingly. The total weight of the fruits from each harvest was used to measure fruit yield per plant.

Regular observations were made on:

- Graft survival and healing.
- Days to scion sprouting and flowering.
- Fruit color, number, size and morphology.
- Overall plant health and response to environmental conditions.

The time intervals for each phase and key stages of this experiment are as follow:

- Grafting starts: Mid of April.
- Healing period: 8-10 days.
- Hardening period: 5-6 days.
- Flowering initiation: End of June and peak by start of July.

For physicochemical analysis, total soluble solids (TSS), were evaluated using a digital refractometer, while pH was determined using a calibrated pH meter. Total phenolic count (TPC), total flavonoid count (TFC), and anthocyanin content were analyzed using standard spectrophotometric methods.

Statistical analysis: The experiment was conducted under a Completely Randomized Design (CRD), with

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three grafted plants treatments (P1, P2, P3) including reciprocal grafts (P1 and P2), stress treated grafted plants, and two non-grafted controls (P4 and P5). Each treatment consisted of three biological replicates. Data were subjected to Analysis of Variance (ANOVA) to determine treatment effects. Mean comparison was performed using Tukey's Honestly Significant Difference (HSD) test at a 5% significance level ($p < 0.05$). Statistical analysis was carried out using SPSS version 25. Normality and homogeneity of variance were checked prior to analysis, to determine significant differences among treatments.

Experimental units: Each treatment consisted of three biological replicates, with one healthy plant maintained per replicate in separate 14-inch clay pots under identical greenhouse conditions. Thus, a total of fifteen experimental plants were used across five treatments (P1–P5). For morphological and yield-related observations, data were recorded individually from each replicate plant and averaged for statistical analysis. In physicochemical, phytochemical, and nutritional analyses, freshly harvested fruits from each replicate were analyzed separately, and each laboratory measurement was performed in triplicate (n = 3) to ensure analytical accuracy and reproducibility. Random placement of pots within the greenhouse was maintained to minimize positional and environmental variation.

RESULTS AND DISCUSSIONS

Plants (Control)	Plant height	Days for flowering	Days for fruit set	No. of fruits per plant	Fruit weight (g/fruit)	Total fruit yield (g -1)
P-4 (W)	56 ± 1.8[b]	70-75	85-90	11	29.65 ± 1.2[b]	326.15 ± 15.2[b]
P-5 (P)	59 ± 2.0[a]	70-75	85-90	25	34.43 ± 1.4[a]	860.75 ± 22.1[a]

The white hybrid brinjal scion succeeded in grafting onto the wild purple rootstock (P1), and the purple wild brinjal scion succeeded in grafting onto the white hybrid root stock as shown by the approximate 90% grafting success rate. Early scion sprouting 10 to 12 days after grafting was a success in graft union formation. The rapid establishment of the scion, evidence to successful vascular connection and integration, both physiologically and in functioning, to the rootstock. Previous studies on eggplants also noted similar durations for successful graft formations when using compatible Solanum rootstocks (Bletsos et al., 2003; J.-M. Lee & Oda, 2002).

Table 2: ***Morphological and agronomic characters of eggplants after grafting***

Plants	Plant height (cm)	Days for flowering	Days for fruit set	No. of fruits per plant		avg fruit weight (g/fruit)		Fruit yield (g plant -1)		Total fruit yield (g -1)
				W	P	W	P	W	P	
P-1	77 ± 2.8[a]	70	85-90	16	09	41.25 ± 1.8[a]	35.88 ± 1.4[a]	660.09 ± 22.9[a]	322.98 ± 16.5[a]	983.07 ± 30.2[a]
P-2	75 ±	70	85-90	07	05	37.25 ±	34.16 ±	260.99 ±	205.00 ±	465.99 ± 20.7[c]
P-3	63 ± 2.1[b]	70	85-90	10	06	38.16 ± 1.5[b]	36.73 ± 1.3[a]	381.66 ± 18.5	220.39 ± 13.2[b]	602.05 ± 25.1[b]

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Figure 2: Dual-fruiting shown by grafted plants (P1, P2, P3)

Figure 3: White control plants on fruiting (P4)

Figure 4: Purple wild control plants on fruiting (P5)

The scion rapid sprouting and establishment showed that the wild purple rootstock was able to assist shoot growth with the water, nutrients, and hormones necessary for early development. Grafted plants have been shown increased vigor compared to non-grafted controls. This was attributed to the root systems and their functionality, as well as to the root to shoot signaling present in grafted systems (Aloni et al., 2010; Colla et al., 2010). Grafted plants began to flower approximately 70 days after grafting, with flowering beginning in late June. The moving from vegetative to reproductive growth shows that grafting didn't cause a delay in floral induction; it facilitated normal reproductive growth. The morphological parameters especially plant height, number of leaves and rooting behavior of grafted plants were substantially better than non-grafted plant. These effects of present investigations are in agreement with the finding of (Bletsos et al., 2003), who confirms that grafted plants were taller and more stronger than self-rooted plants. In contrast, the non-grafted white hybrid control plants demonstrated comparatively weaker growth in the vegetative and reproductive compartments. Prior work noted that, in many cases, grafting moderates flowering under duress by optimizing nutrient and hormonal availability (Davis et al., 2008; Rouphael et al., 2018). As recorded by (YETİŞİR et al., 2007) all grafted watermelon plants demonstrated both increased leaf count and greater dry weight compared to the non-grafted control plants.

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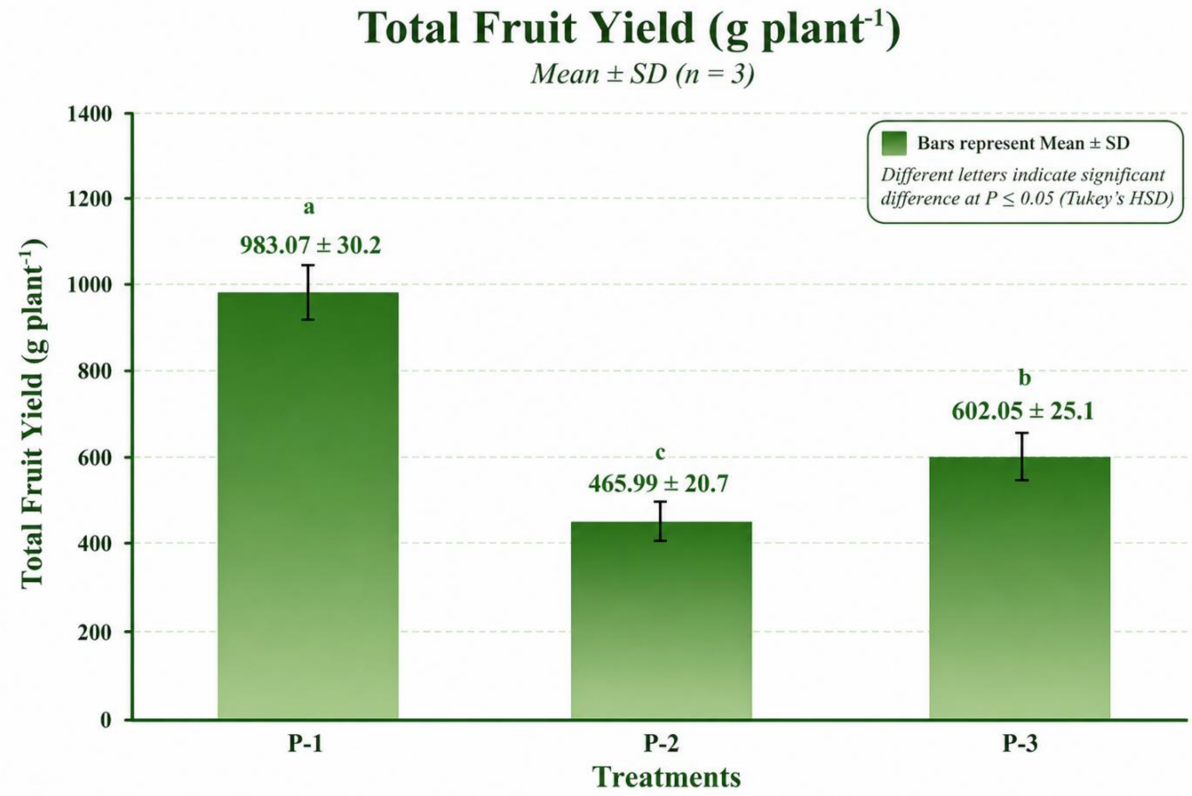
The grafting increased the root system of the plants, resulting in healthier growth and greater yield. Further all grafted plants had maximum root length as compared to non-grafted plants, is in line with the report of (Alan et al., 2007).

In grafted plants, Fruiting started in mid-July, marking approximately 85-90 days post-grafting, in mid-July. After grafted plants initiate fruiting, they actively continued to set fruit, showcasing impressive reproductive success. The fruit set and development were consistent. The absence of physiological disorders, strengthen the positive influence of the wild purple rootstock on the scion. The experimented plants demonstrated excellent growth vigor, maintained consistent development. Grafted plants yielded more fruit both in individual quantity and total weight than non-grafted plants. These results are consistent with previous studies showing grafted eggplants have better fruiting due to increased root development and more efficient nutrient and moisture uptake (Bletsos et al., 2003; Kumar et al., 2017).

Under combined heat and water deficit stress conditions (P3), plants showed a moderate reduction in yield and growth compared to P1 and P2. However, the reduction was not abrupt, showing partial stress tolerance in grafted plants. This showed that grafting, particularly with a wild rootstock, contributes to improved resilience under abiotic stress condition as recorded in P1 treatment.



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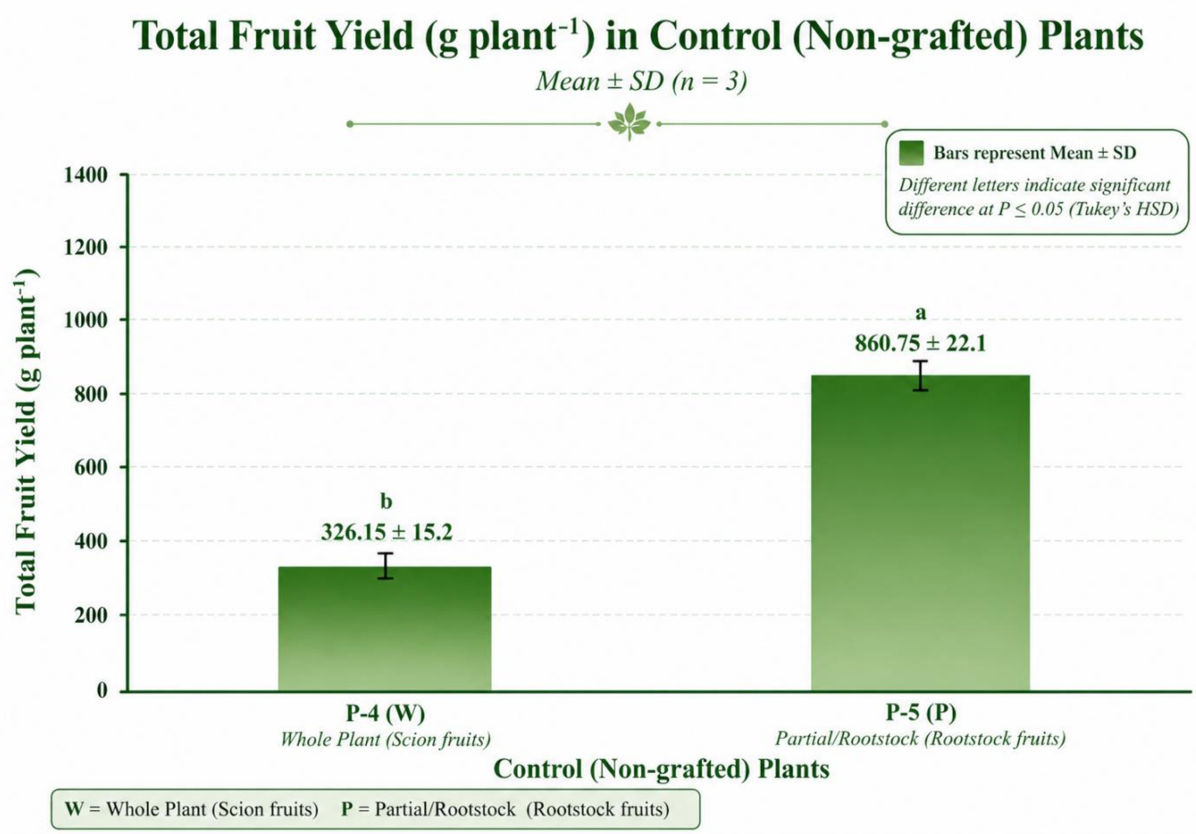

Statistical analysis (ANOVA) indicated significant differences among treatments ($p \leq 0.05$). The yield performance of grafted plants of brinjal showed significant variation across treatments, indicating a strong influence of graft combination on productivity (Table 2). Among all treatments, P-1 exhibited the highest total fruit yield of 983 ± 30.2 g plant^{-1}, with white fruit contributing 660.09 ± 22.9 g plant^{-1} and purple fruits contributing 322.98 ± 16.5 g plant^{-1}, showing a strong contribution from both fruit types. P-3 showed intermediate performance with total yield of 602.05 ± 25.1 g plant^{-1}, (Table 2). The number of fruits plant^{-1} also fluctuate considerably, with P-1 producing the highest number (16 W and 9 P fruits), followed by P-3 and P-2, showing improved reproductive ability in superior graft combinations.

The average weight of fruit also differed between white (W) and purple (P) fruits across treatments (Table 2), with W fruits generally showing slightly higher values as compared to P fruits, suggesting variations and fruit development pattern variations between the two fruit types. The higher yield in P-1 can be attributed to improve vegetative growth, better uptake of nutrients, and increased physiological efficiency of the grafted system. This is further supported by the production of dual fruiting (Figure 2), where both types of fruit contributed independently to total yield, therefore increasing the overall productivity of grafted plant. In comparison, the control plants (Table 3) showed significantly lower yield performance, with white control plants (P4) producing 326.15 ± 15.2 g plant^{-1} and purple control plants (P5) producing 860.75 ± 22.1 g plant^{-1}, indicating that grafting significantly increases the yield potential and allowed simultaneous production of two phenotypically distinct fruit types.

Additionally, two different fruit types, namely white (W) and purple (P), were observed across treatments, contributing separately to total yield. The phenomenon of dual fruiting is a unique and novel finding of this study. One grafted plant produced two types of fruit at

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the same time. The plant produced both white fruit from the white hybrid scion and purple fruit from the retained branches of the wild purple rootstock. This case demonstrates the ability of the scion and rootstock to physiologically and phenotypically express independently while integrating vasculature. Most studies involving grafting recommend that the grafting of eggplants should involve the removing of the rootstock shoots so as to ensure that the scion is dominant (Kumar et al., 2017). In the present study, however, the intentional keeping of rootstock branches shows that grafting can also function in the production of multi-phenotypic fruit within the same root system. The rootstock-scion interactions hypothesized in the prior physiological studies of grafting suggest that this unique and coordinated expression is a function of a signaling system and assimilate transport across the graft union (Aloni et al., 2010).

One of the most relevant findings of this investigation is the extended period of fruiting and more significantly, fruiting during the winter period by (P1) group plants. The grafted plants continued to bear fruit during winter. The non-grafted white hybrid control plants did not produce fruit during winter and thus strongly represents the positive aspects of grafting. This observation strongly indicated that the wild purple rootstock reduces the stress of the scion and thus enhanced the physiological resilience of the scion. The rootstock plays a crucial role in fruiting during the winter season. Rootstocks have been known to positively respond to the winter period due to their hardness and wild nature, increasing root systems and signal the stress caused during the winter (Colla et al., 2010; Rouphael et al., 2018). The improvement in yield stability gained through the winter fruiting capability of grafted plants, shows the suitability of grafting for extending the production potential. In comparison with control plants, grafted plants had a greater number of roots, root length, and fresh and dry root biomass. This improved root system was responsible for enhanced water and nutrient uptake and supported the vegetative growth and continuous fruiting. The fruit quality parameters, Total Soluble Solids (TSS), and Anthocyanins, were within the acceptable range, confirming that the grafting process had no negative effects in fruit quality. The mentioned findings agree with previous studies that state grafting improves yield and stress tolerance in eggplant without any negative effects in fruit quality (Davis et al., 2008; J.-M. Lee & Oda, 2002).

Table 4: ***Physicochemical analysis, fruits harvested from experimental groups (P-1, P-2, P-3)***

Plants	**pH**		TSS(°Brix)		**Total acidity %**		**Ash content %**	
	W	**P**	**W**	**P**	**W**	**P**	**W**	**P**
P-1	6.38 ± 0.03^{a}	5.51 ± 0.03^{b}	4.023 ± 0.015^{b}	3.893 ± 0.014^{b}	0.36 ± 0.01^{a}	0.29 ± 0.01^{b}	0.47 ± 0.01^{a}	0.41 ± 0.01^{b}
P-2	6.13 ± 0.03^{b}	5.33 ± 0.03^{b}	4.042 ± 0.015^{a}	4.002 ± 0.015^{a}	0.32 ± 0.01^{b}	0.34 ± 0.01^{a}	0.43 ± 0.01^{b}	0.44 ± 0.01^{a}
P-3	5.97 ± 0.03^{c}	5.76 ± 0.03^{a}	4.061 ± 0.016^{a}	4.043 ± 0.015^{a}	0.33 ± 0.01^{b}	0.27 ± 0.01^{b}	0.44 ± 0.01^{b}	0.47 ± 0.01^{a}

Means followed by different letters (superscripts) indicate statistically significant differences.

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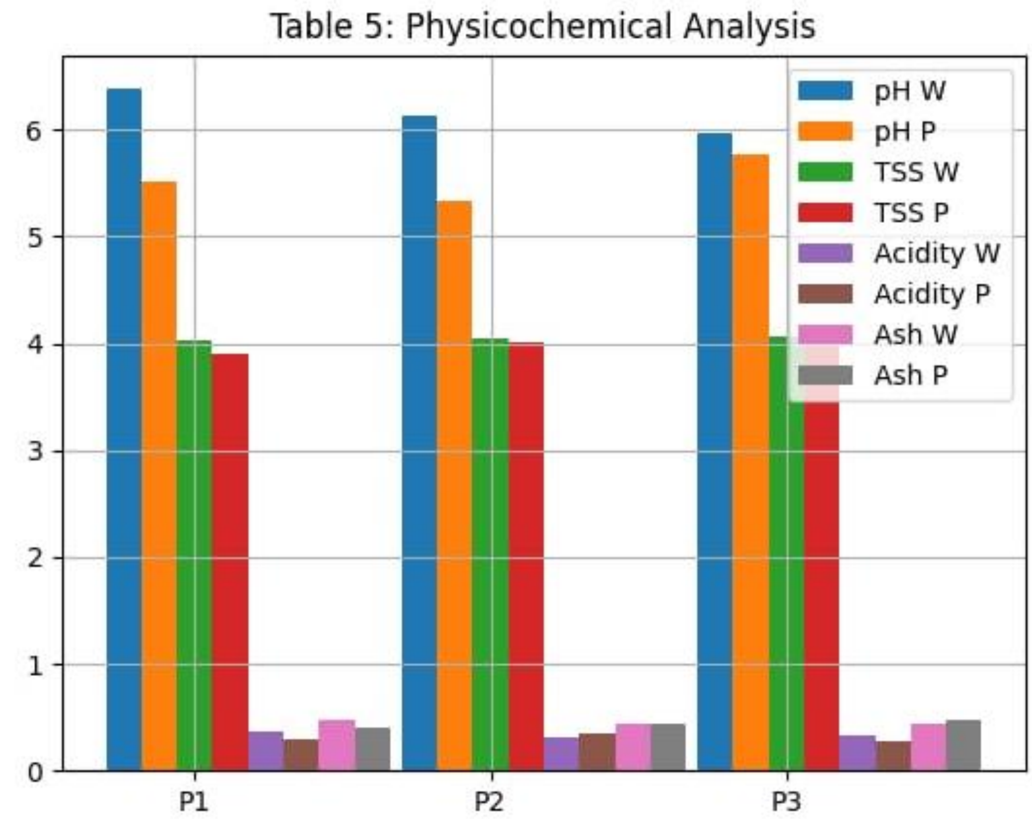

Statistical analysis (ANOVA) indicated significant differences among treatments ($p \leq 0.05$). The physicochemical properties of white (W) and purple (P) brinjal fruits showed clear variation across treatments, indicating genotype-dependent biochemical differences influenced by grafting (Table 5). The pH values ranged from 5.97 to 6.38 in white fruits, while purple fruits showed comparatively lower values ranging from 5.33 to 5.76, suggesting higher acidity in purple fruits due to increased organic acid accumulation, possibly linked to pigment-associated metabolic activity. (TSS) total soluble solids showed minimal variations among fruit types, ranging from 3.893 to 4.061 °Brix (Table 5), showing that sugar accumulation remained relatively stable and was not strongly influenced by grafting or fruit type, although slight differences may reflect variations in assimilate transport efficiency. Total acidity ranges from 0.27% to 0.36% (Table 5), with slight differences between white (W) and purple (P) fruits, suggesting difference in organic acid metabolism and respiratory activity, which can influence flavor development and post-harvest quality. Ash content ranged between 0.41% to 0.47% (Table 5), with slightly higher values observed in purple (P) fruits in some treatments, indicating increased mineral accumulation and translocation efficiency in pigmented tissues.

Table 5: ***Phytochemical Analysis of fruits harvested from experimental groups (P-1, P-2, P-3).***

Plants	Anthocyanins (mg 100 g-1)		TFC (mg/100g)		TPC (mg/100g)	
	W	P	W	P	W	P
P-1	0.406 ± 0.005^{b}	0.411 ± 0.006^{b}	2.80± 0.04^{b}	2.77 ± 0.04^{b}	5.80 ± 0.05^{a}	5.67 ± 0.05^{b}
P-2	0.423 ± 0.006^{a}	0.439 ± 0.007^{a}	2.88± 0.05^{a}	2.89 ± 0.05^{a}	5.76 ± 0.05^{b}	5.81 ± 0.05^{a}
P-3	0.409 ± 0.005^{b}	0.397± 0.006^{b}	2.84 ± 0.04^{b}	2.76 ± 0.04^{b}	5.79 ± 0.05^{ab}	5.77 ± 0.05^{ab}

Means followed by different letters (superscripts) indicate statistically significant differences.

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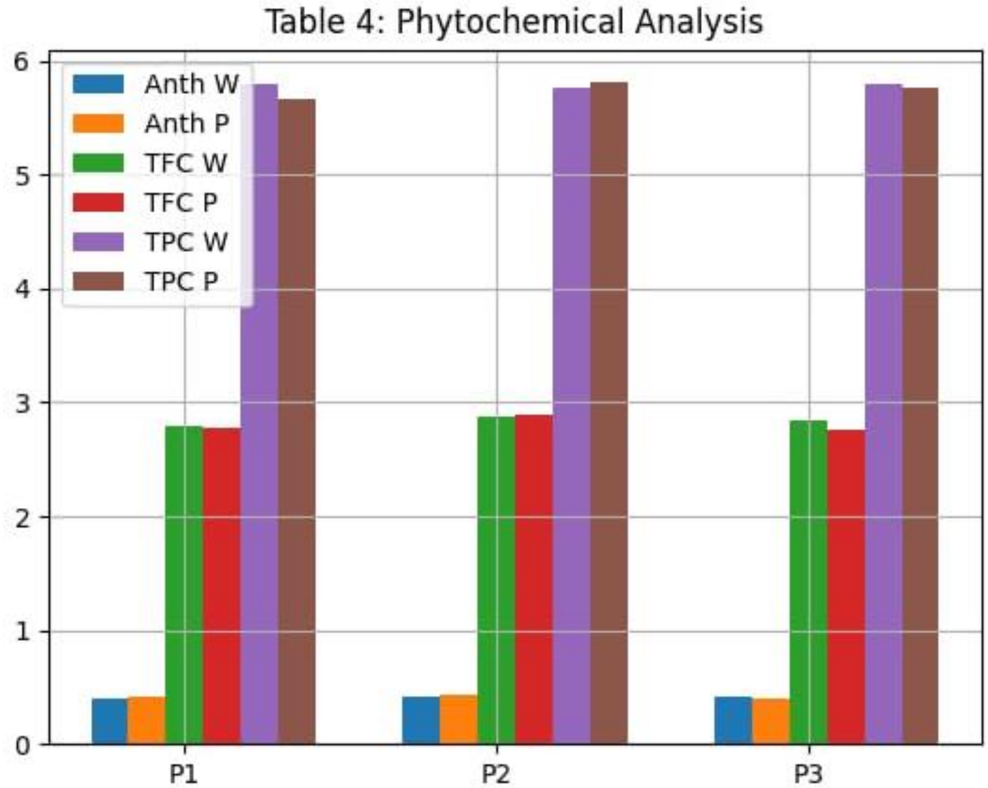

Statistical analysis (ANOVA) indicated significant differences among treatments ($p \leq 0.05$). The phytochemical composition also showed variation between fruit types, particularly in anthocyanin content, which was consistently higher in purple (P) fruits (0.397–0.439 mg/100 g) compared to white (W) fruits (0.406–0.423 mg/100 g) (Table 4), confirming active anthocyanin biosynthesis responsible for pigmentation and antioxidant potential. Total flavonoid content (TFC) showed minor difference among white (2.76–2.88 mg/100 g) and purple fruits (2.77–2.89 mg/100 g) (Table 4), indicating relatively stable flavonoid metabolism across treatments. Similarly, total phenolic content (TPC) ranged from 5.76 to 5.80 mg/100 g in white (W) fruits and 5.67 to 5.81 mg/100 g in purple fruits (Table 4), suggesting that phenolic biosynthesis remain mainly conserved with only minor genotype related variation. These results showed that while anthocyanin content strongly differentiate between white and purple fruits, other antioxidants related compounds remain relatively stable across treatments.

Table 6: ***Nutritional analysis of fruits harvested from experimental groups (P-1, P-2, P-3)***

Plants	Carbohydrates%		Proteins %		Fats %		Fiber%	
	W	P	W	P	W	P	W	P
P-1	2.42 ± 0.03[a]	2.39 ± 0.03[a]	1.26 ± 0.02[b]	1.34 ± 0.02[a]	0.17 ± 0.01[a]	0.16 ± 0.01[b]	3.11 ± 0.05[b]	3.13 ± 0.05[b]
P-2	2.46 ± 0.03[a]	2.40 ± 0.03[a]	1.39 ± 0.02[a]	1.39 ± 0.02[a]	0.12 ± 0.01[b]	0.19 ± 0.01[a]	3.52 ± 0.06[a]	3.21 ± 0.05[b]

Means followed by different letters (superscripts) indicate statistically significant differences.

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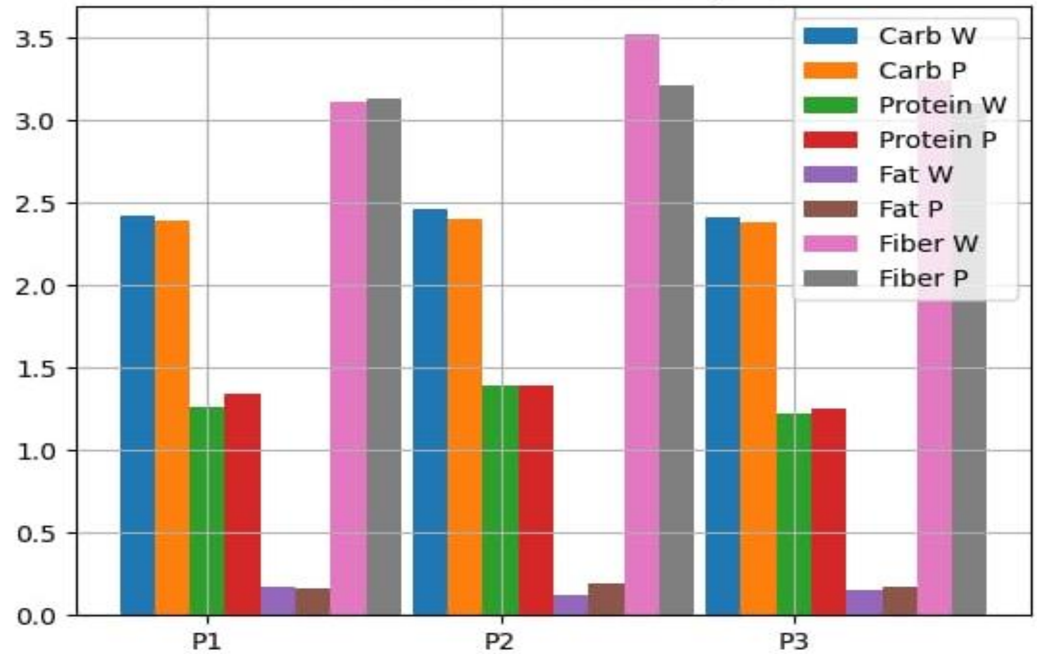
Table 6: Nutritional Analysis



Statistical analysis (ANOVA) indicated significant differences among treatments (p ≤ 0.05). the nutritional profile analysis revealed that macronutrients composition was majorly unaffected by fruit type or grafting (Table 6), carbohydrate composition remained stable across treatments, ranging from 2.38 to 2.46%, showing consistent photosynthate accumulation in both white W and purple P fruits. Protein content showed slight changings between 1.22 and 1.39% (Table 6), possibly showing variations in nitrogen assimilation efficiency among treatments. Fat content ranged from 0.12 to 0.19%, indicating a minor variability without a clear trend, suggesting stable lipid metabolism across fruit types. Fiber content ranged between 3.10 to 3.52% (Table 6), with a minor-high values in some treatments, which may be associated with improved structural development and cell wall formation. Overall, these results demonstrate that grafting and presence of dual fruit types (white and purple) do not negatively affect the nutritional quality of brinjal fruits, while maintaining and improving stable level of macronutrients.

In addition, the observed dual fruiting behavior is illustrated in Figure 2, where both white W and purple P fruits are produced simultaneously on the same grafted plant. This visual evidence supports the biochemical and yield data presented in Tables 2, 4, 5, and 6, confirming that both fruit types contribute independently to overall productivity while maintaining distinct physiochemical and phytochemical profiles. The combined advantages of enhanced yield, partial stress tolerance, dual fruiting behavior, and extended harvesting period highlight its potential for sustainable agriculture, resource-efficient production systems, and urban farming applications. this innovative grafting approach covers the way for increased crop diversification, efficient resource utilization, and continuous supply of vegetables throughout the year. The findings of this study offer evidence that intra-specific graft hybridization in brinjal can be seen as a multi-angled horticultural innovation, going beyond the conventional goals of improving yield and reducing disease incidence. The diverse benefits of the technique including dual fruiting, longer seasonal harvest, and low input organic farming advocate its suitability for sustainable agriculture, and resource-efficient urban farming. With the provision of two

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distinct fruit phenotypes and the ability to maintain prolonged production.

The findings of the present study are in agreement with previous reports that grafting enhances plant vigor, yield, and stress tolerance through improved root system efficiency and physiological integration. However, unlike conventional studies, the current research demonstrates the unique phenomenon of dual fruiting, which highlights an advanced level of graft compatibility and functional independence between rootstock and scion.

LIMITATIONS

Even though the present research demonstrated successful graft-hybridization under greenhouse conditions, further studies involving larger sample sizes, molecular characterization, multi-season trials, and detailed physiological analyses are required to better understand long-term compatibility, signaling interactions, and commercial applicability of this grafting system.

CONCLUSION

Grafting improved growth, yield, and stress tolerance in brinjal. P1 performed better than P2, showing the advantage of wild purple rootstock. Grafted plants outperformed control plants. Under stress (P3), yield reduction was seen but not at abrupt level, indicating tolerance. Dual fruiting was successfully observed. This study provides novel insight into grafting biology by demonstrating the simultaneous productivity of both rootstock and scion, a phenomenon rarely reported in eggplant grafting systems. The research can be broadened to study various other wild species and cultivars of eggplant to monitor in detail the different quantitative and qualitative characteristics of the yield attributing traits. Overall, grafting is an effective method for improving brinjal and other vegetable production on commercial scale.

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RECOMMENDATION

Further studies on physiological and molecular mechanisms underlying graft compatibility and long-term performance are recommended.

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