

## INFLUENCE OF CULTIVAR, GRAFTING, AND FERTILIZATION REGIME ON THE BIOACTIVE COMPOUND PROFILE OF EGGPLANT FRUITS

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### RESEARCH ARTICLE

*Eggplant represents an important vegetable crop from a nutritional point of view, mainly due to its elevated antioxidant potential associated with a high phenolic content. In this research, it was investigated how two commercial cultivars, Mirval F1 and Black Pearl F1, together with grafting practice and fertilization strategy, shape the accumulation of bioactive compounds and the antioxidant behavior of the fruits. A factorial field experiment was established using ungrafted plants or plants grafted onto the commercial rootstock Rezistar F1 and the wild species *Solanum sisymbriifolium*, under four fertilization variants, unfertilized control, Micoseed® biofertilizer, organic fertilizer and conventional chemical fertilizer. Fruit samples were analyzed for total polyphenols, chlorophyll a and b, lycopene, tannins and antioxidant activity by ABTS and DPPH methods. The results indicated that Mirval F1 accumulated significantly higher concentrations of polyphenols and lycopene compared to Black Pearl F1. Ungrafted plants showed the highest pigment contents, while grafting onto *S. sisymbriifolium* clearly improved the antioxidant capacity. Fertilization did not significantly modify total polyphenol content, but both chemical fertilization and the lack of fertilization stimulated chlorophyll and lycopene accumulation more than the biofertilizer. The strongest DPPH activity was observed in unfertilized plants, suggesting that a moderate stress condition may activate antioxidant defenses. Overall, Mirval F1 combined with vigorous rootstocks and balanced nutrition generated fruits with the most pronounced antioxidant profile. These data highlight the combined impact of genotype, grafting and fertilization on eggplant quality and offer practical directions for producing biofortified fruits with enhanced functional value.*

**Keywords:** eggplant, grafting, fertilization, bioactive compounds, antioxidant activity

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### INTRODUCTION

Eggplant (*Solanum melongena* L.) is a widely consumed vegetable appreciated for its nutritional value and its high content of antioxidant compounds, mainly phenolics (Mady et al., 2025), substances that give eggplant functional food properties through their capacity to reduce oxidative stress. Strong differences exist among cultivars, as dark purple or black skinned fruits usually contain higher levels of phenolics and show stronger antioxidant activity than white types. Recent comparative studies confirm that the genetic background largely determines the concentration of phenolics, flavonoids and anthocyanins, and therefore the overall antioxidant potential of the fruit (Kim et al., 2025; Gozel et al., 2025; Josef et al., 2025).

Beyond varietal choice, grafting has become an important horticultural tool for improving both plant performance and fruit quality. Grafting onto vigorous or disease resistant rootstocks, such as *Solanum torvum* or *S. sisymbriifolium*, enhances tolerance to stress and often increases yield. Several studies also report higher fruit phenolic content in grafted plants (Lal et al., 2025; Ashraf et al., 2025). For example, Gisbert et al. observed about a 31 percent increase in phenolics after grafting, while other authors confirmed similar trends depending on the rootstock used (Gisbert et al., 2011). Still, grafting effects are not always consistent, since some combinations may reduce phenolic accumulation, showing that careful rootstock selection is essential for improving fruit quality and not only yield.

Nutrient management is a major factor controlling the phytochemical profile of

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eggplant. As a crop with high nutrient demand, eggplant reacts strongly to fertilization type, whether mineral, organic or biological. Moderate nutrient limitation or organic inputs can stimulate phenolic synthesis as part of a defense response, while excessive fertilization often favors growth at the expense of antioxidant compounds (Thingujam et al., 2020). Studies on tomato and other vegetables have shown higher phenolic levels under reduced nitrogen or organic fertilization, supporting this concept (González et al., 2022; Benard et al., 2009; Zhang et al., 2024). In contrast, abundant mineral nutrition tends to dilute secondary metabolites (Tang et al., 2024). Biostimulants and microbial inoculants are also of interest, since they can improve nutrient uptake and trigger mild stress responses that influence antioxidant accumulation, though results are not always uniform.

Still, only limited information is available on how cultivar, grafting and fertilization together shape eggplant fruit quality. In this context, all three factors, and their interaction, strongly affect phenolics, pigments and tannins, and therefore antioxidant capacity. Vigorous hybrids such as Mirval F1 may accumulate more bioactive compounds than darker but less productive types like Black Pearl F1, while grafting and sustainable fertilization could further modify this response. The present study was designed to evaluate these combined effects and to identify cultivar, rootstock and fertilizer combinations able to produce fruits with higher functional value, which is not always simple in practice.

## MATERIALS AND METHODES

The study was carried out during one vegetation season at the V. Adamachi Experimental Farm of the University of Life Sciences in Iași, Romania, on a typical chernozem soil. Two commercial eggplant hybrids, Mirval F1 and Black Pearl F1, were selected as scion material because of their contrasting fruit traits and high relevance for current production systems. Seedlings were produced under greenhouse conditions, and when they reached the stage of 4–5 true leaves, part of the plants from each cultivar was subjected to grafting. Three propagation variants were considered: ungrafted plants used as self rooted controls, plants grafted onto the commercial tomato rootstock Rezistar F1, known for its strong vigor and disease tolerance, and plants grafted onto the wild

species *Solanum sisymbriifolium*, recognized for its resistance to soil borne pathogens such as Verticillium and bacterial wilt, as well as for its potential to enhance plant performance. Grafting was performed using the splice grafting technique, and the grafted seedlings were maintained under high humidity conditions for 7 to 10 days to allow proper healing of the graft union.

After the grafts were fully established, both grafted and ungrafted plants were transplanted to the open field in late spring, around mid May, using a planting distance of 70 cm between plants and 80 cm between rows. The experiment was organized following a split plot factorial design with three experimental factors, cultivar, grafting or rootstock type, and fertilization regime. Each combination of treatments was replicated three times, with individual plots consisting of 15 to 20 plants. Throughout the growing period, standard agrotechnical practices specific for eggplant were applied, and pest control was conducted according to integrated pest management recommendations, so that additional uncontrolled stress was kept as low as possible.

## Fertilization Treatments

Four distinct fertilization strategies were implemented at sub plot level. The unfertilized control received no nutrient input or soil amendment and was used as a reference variant, reflecting a condition of moderate nutritional limitation. The biological fertilization treatment consisted of the commercial mycorrhizal product Micoseed® MB, which contains arbuscular mycorrhizal fungi from the genus *Glomus*, together with other beneficial microorganisms such as *Beauveria*, *Metarhizium* and *Trichoderma*. This treatment was intended to stimulate nutrient uptake through natural symbiosis and to enhance soil biological processes. Micoseed was incorporated into the soil at planting at a rate of about 30 kg per hectare and reapplied at the beginning of fruit set, using the same dose, in accordance with the producer recommendations, so that root colonization could be ensured.

The organic fertilization program was based on a composted organic fertilizer combined with a microbial biostimulant, Nutryaction®. The organic product was applied twice during mid season, reaching a cumulative rate close to 800 kg per hectare, and it was supplemented through fertigation with the biostimulant

solution in order to activate rhizosphere microbial activity. These organic inputs provided nutrients in a gradual release form and supported soil biological balance, which is in line with principles of sustainable agriculture. The chemical fertilization variant followed a conventional high input mineral regime based on balanced NPK fertilizers from the Nutrispore® range. A total dose of approximately 800 kg per hectare of compound fertilizer was divided into three applications, half before planting, followed by two additional applications at early fruiting and mid fruit set. The formulations supplied both macroelements such as nitrogen, phosphorus, potassium and magnesium, as well as microelements including boron, iron, manganese and zinc, all in readily available forms. This variant was designed to represent an intensive nutrition strategy aimed mainly at maximizing vegetative growth and yield, even if sometimes quality traits can be affected.

#### **Data Collection and Chemical Analyses**

Fruits were harvested at commercial maturity from each experimental plot during the main harvest period. For every treatment, a mixed sample of five to six fruits per replicate was collected and immediately transported to the laboratory. All biochemical analyses were performed on fresh material. After homogenizing the whole fruit pulp including the peel, several chemical determinations were carried out.

Total polyphenols were quantified using the Folin Ciocalteu method, with methanolic extracts measured at 725 nm and results expressed as mg gallic acid equivalents per 100 g fresh weight (Perez et al., 2023). Tannins were evaluated by a spectrophotometric method and expressed as mg tannic acid equivalents per 100 g fresh weight, mainly to follow treatment induced variation since eggplant is normally low in tannins. Chlorophyll a and b were extracted in acetone and measured at 645 and 663 nm, while lycopene was extracted with hexane acetone and read at 503 nm. All pigment contents were expressed as mg per 100 g fresh weight.

Antioxidant activity was assessed using ABTS and DPPH assays. Sample extracts were reacted with the respective radicals and absorbance decrease was recorded at 734 nm for ABTS and 517 nm for DPPH. Trolox served as reference standard and results were expressed as Trolox equivalents or relative scavenging activity.

These tests provided an integrated estimation of antioxidant potential linked mainly to phenolics and pigments.

#### **Statistical Analysis**

The experimental results were processed by analysis of variance adapted to the factorial experimental structure. A three factor ANOVA was applied in order to test the individual effects of cultivar, rootstock and fertilization, together with their combined interactions, on all analyzed parameters, namely total polyphenols, chlorophyll a and b, lycopene, tannins and antioxidant activity measured by ABTS and DPPH. Whenever significant interaction effects were detected, the data were further examined through simple effect analyses, by separating the influence of each factor for a clearer biological interpretation. The comparison of treatment means was performed using Tukey HSD test at a probability threshold of  $p < 0.05$ . Results are expressed as mean values  $\pm$  standard error, and different letters shown in the tables indicate statistically significant differences among variants. All statistical procedures was carried out using the SPSS software package version 21.0.

## **RESULTS AND DISCUSSIONS**

### **1. Results on Antioxidant Activity (DPPH and ABTS), Total Polyphenol Content (TPC), and Tannin Content in Eggplant Fruits**

The chemical composition of eggplant fruits obtained during the experiment, focusing on total polyphenols, tannins, chlorophyll a and b and lycopene as shown in Table 1, reflects key aspects of nutritional and functional quality. These compounds are directly linked to antioxidant activity, pigmentation and sensory traits. Evaluating how cultivar, rootstock and fertilization influence these parameters offers useful guidance for selecting cultivation variants that improve fruit quality, even if some responses were not perfectly uniform.

Table 1.  
Chemical Composition of Eggplant Fruits in Relation to Cultivar, Rootstock, and Fertilization Regime

Cultivar	1	2	3	4	5
Mirval F1	2.97 ± 0.01	3.44 ± 0.07	4.74 ± 0.18	1.58 ± 0.05	0.11 ± 0.00
Black Pearl F1	2.15 ± 0.05	2.19 ± 0.02	2.82 ± 0.02	0.93 ± 0.01	0.10 ± 0.00
Significance	*	*	*	*	*
Rootstock					
Ungrafted	2.70 ± 0.04 a	3.63 ± 0.04 a	4.97 ± 0.08 a	1.67 ± 0.02 a	0.11 ± 0.00 a
Rezistar	2.51 ± 0.05 b	2.10 ± 0.02 c	2.66 ± 0.01 c	0.89 ± 0.01 c	0.11 ± 0.00 a
S. sisymbriifolium	2.52 ± 0.01 b	2.86 ± 0.05 b	3.92 ± 0.14 b	1.29 ± 0.05 b	0.10 ± 0.00 b
Significance	*	*	*	*	*
Fertilization					
Unfertilized	2.60 ± 0.02	3.30 ± 0.03 a	4.44 ± 0.08 a	1.47 ± 0.02 a	0.11 ± 0.00 a
Mycoseed	2.58 ± 0.03	2.46 ± 0.01 d	3.23 ± 0.01 c	1.03 ± 0.02 d	0.10 ± 0.00 b
Organic	2.54 ± 0.05	2.65 ± 0.03 c	3.63 ± 0.09 b	1.25 ± 0.00 c	0.10 ± 0.00 b
Chemical	2.59 ± 0.01	3.04 ± 0.01 b	4.10 ± 0.11 a	1.37 ± 0.03 b	0.10 ± 0.00 b
Significance	ns	*	*	*	*

\*1. Total polyphenols (mg/100 g); 2. Chlorophyll A (mg/100 g); 3. Chlorophyll B (mg/100 g); 4. Lycopene (mg/100 g); 5. Tannins (mg/100 g)

\*\*Legend: Values represent the mean ± standard error. Values followed by different letters within the same column indicate statistically significant differences ( $p < 0.05$ ).

ns = non-significant differences; \* = significant differences.

### Cultivar Influence

The two cultivars showed clear differences in bioactive accumulation, with Mirval F1 consistently outperforming Black Pearl F1. Mirval F1 registered higher total polyphenols and lycopene, indicating a stronger genetic capacity for synthesizing antioxidant compounds. This advantage is likely linked to its more intense pigmentation and a more active secondary metabolism. Although Black Pearl F1 also contained relevant bioactives, its values were systematically lower. These results suggest that Mirval F1 is better suited for obtaining fruits with higher nutritional quality under the studied conditions.

### Rootstock Influence

Rootstock choice significantly affected fruit composition. Ungrafted plants showed the highest levels of most compounds, including polyphenols, chlorophylls and lycopene, possibly because grafting related vigor did not interfere with metabolite accumulation. Among grafted variants, S. sisymbriifolium performed better than Rezistar, leading to higher chlorophyll and lycopene contents. Tannins remained almost unchanged across treatments. Rezistar generally showed the lowest pigment values, suggesting a dilution effect under high vigor. In contrast, S. sisymbriifolium represented a better balance between grafting

benefits and fruit biochemical quality, even if not all responses was perfectly uniform.

### Influence of Fertilization

Fertilization had little effect on total polyphenols, which remained relatively constant across treatments, indicating a strong genetic control. In contrast, chlorophylls and lycopene responded clearly to nutrition, with the highest values in the control and chemical variants, and the lowest under Micoseed, while organic fertilization showed intermediate effects. This suggests that both mild stress and high nutrient availability can favor pigment accumulation through different mechanisms. Tannins decreased slightly under fertilized conditions, likely due to reduced stress in well nourished plants.

Antioxidant activity measured by ABTS and DPPH showed only minor differences between cultivars, with Mirval F1 being slightly higher, especially in DPPH, in line with its greater phenolic and lycopene content. Still, both hybrids displayed comparable overall antioxidant capacity, probably due to compensation by other compounds in Black Pearl, which seems plausible.

Rootstock influence was much stronger. Ungrafted plants had the lowest antioxidant values, whereas grafting, especially on S. sisymbriifolium, significantly increased both ABTS and DPPH. Rezistar showed intermediate effects. This indicates that the wild rootstock stimulated antioxidant metabolism, likely by improved uptake or mild induced stress.

Fertilization modified antioxidant activity in an assay dependent manner. Micoseed gave the highest ABTS values, while the control showed the highest DPPH response, supporting the idea that nutrient limitation can stimulate lipophilic antioxidant synthesis. Organic and chemical treatments maintained high activity, but did not surpass the control in DPPH, which is quite interesting.

Overall, Mirval F1 remained superior for antioxidant traits, S. sisymbriifolium proved the most effective rootstock for enhancing activity, and low input conditions activated stress related phenolic metabolism. Together, cultivar, grafting and fertilization clearly act in combination to shape the functional quality of eggplant fruits.

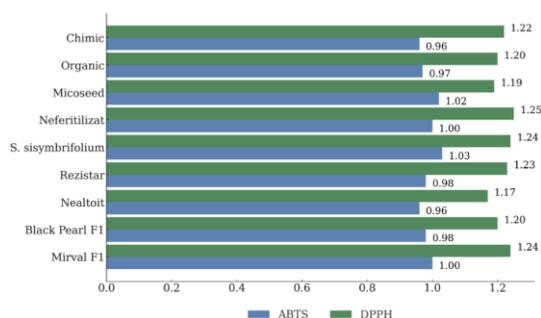


Figure 1. Antioxidant capacity of eggplant fruits determined by ABTS and DPPH assays in relation to cultivar, rootstock, and fertilization regime

## 2. Combined Influence of Cultivar × Rootstock on the Content of Bioactive Compounds in Eggplant Fruits

To clarify how cultivar and grafting jointly shape fruit quality, the combined effects of scion and rootstock were evaluated on key biochemical traits. Table 2 summarizes changes in polyphenols, chlorophylls, lycopene, and tannins across each cultivar–rootstock combination. This comparison shows that fruit composition depends not only on genotype but also on the chosen rootstock, and sometimes this interaction is more important than expected. These results are directly relevant for nutritional and functional quality, offering growers practical guidance for selecting cultivar and rootstock pairs that maximize fruit value.

Table 2. Influence of Cultivar × Rootstock Interaction on Polyphenol Content, Photosynthetic Pigments, Lycopene, and Tannins in Eggplant Fruits

Experimental factor	1	2	3	4	5
Mirval F1 × Ungrafted	2.96 ± 0.02 a	4.70 ± 0.17 a	6.65 ± 0.34 a	2.24 ± 0.09 a	0.11 ± 0.00 a
Mirval F1 × Rezistar	2.92 ± 0.02 a	2.05 ± 0.03 d	2.42 ± 0.03 d	0.80 ± 0.02 d	0.11 ± 0.00 ab
Mirval F1 × <i>S. sisymbriifolium</i>	3.03 ± 0.01 a	3.57 ± 0.06 b	5.15 ± 0.22 b	1.71 ± 0.07 b	0.09 ± 0.00 c
Black Pearl F1 × Ungrafted	2.45 ± 0.06 b	2.56 ± 0.09 c	3.29 ± 0.18 c	1.10 ± 0.06 c	0.10 ± 0.00 abc
Black Pearl F1 × Rezistar	2.10 ± 0.07 c	2.15 ± 0.02 cd	2.90 ± 0.02 cd	0.97 ± 0.01 cd	0.10 ± 0.00 abc
Black Pearl F1 × <i>S. sisymbriifolium</i>	2.01 ± 0.00 c	2.15 ± 0.04 d	2.69 ± 0.06 cd	0.87 ± 0.02 cd	0.10 ± 0.00 bc
Significance	*	*	*	*	*

\*1. Total polyphenols (mg/100 g); 2. Chlorophyll A (mg/100 g); 3. Chlorophyll B (mg/100 g); 4. Lycopene (mg/100 g); 5. Tannins (mg/100 g)

### Total Polyphenols (TPC)

The highest polyphenol concentrations were consistently observed in Mirval F1 combinations, with the maximum recorded in Mirval grafted onto *S. sisymbriifolium* (3.03

mg/100 g), followed closely by the ungrafted and Rezistar-grafted Mirval variants. All Mirval treatments clearly exceeded Black Pearl values, which remained below 2.5 mg/100 g in all cases. This confirms the strong genetic control of phenolic accumulation in Mirval. Grafting slightly enhanced TPC only when Mirval was combined with *S. sisymbriifolium*, while Black Pearl showed small declines after grafting. Thus, cultivar effect was dominant, while rootstock acted only as a secondary modifier.

### Photosynthetic Pigments

The highest chlorophyll contents were recorded in ungrafted Mirval fruits, indicating superior pigment retention under own-root growth. Mirval grafted on *S. sisymbriifolium* maintained intermediate values, whereas grafting on Rezistar caused a marked pigment reduction. Black Pearl showed consistently lower chlorophyll levels, especially after grafting. These results suggest that grafting, particularly onto vigorous rootstocks, may accelerate fruit maturation and reduce chlorophyll persistence, and this effect appear stronger in Black Pearl.

### Lycopene

Lycopene followed a pattern similar to chlorophyll. Ungrafted Mirval showed the highest values (2.24 mg/100 g), while Mirval grafted on *S. sisymbriifolium* ranked second. Rezistar markedly reduced lycopene, especially in Mirval, where values dropped below those of Black Pearl. This indicates a strong negative rootstock effect on carotenoid formation, likely linked to altered ripening physiology. Overall, Mirval expressed a much higher inherent carotenoid potential, while *S. sisymbriifolium* proved the most suitable rootstock for preserving this trait.

### Tannins

Tannin levels varied only slightly among treatments, remaining within the generally low range typical for eggplant. The highest values were observed in ungrafted Mirval and Mirval grafted on Rezistar, both close to 0.11 mg/100 g, while Mirval on *S. sisymbriifolium* showed the lowest value at about 0.09 mg/100 g. Most Black Pearl variants remained around 0.10 mg/100 g and were little affected by rootstock choice. This indicates that grafting Mirval on the wild rootstock slightly reduced tannin accumulation, which may improve taste by lowering bitterness. In contrast, Black Pearl showed little response. The significant

interaction suggests that tannin expression depend on both cultivar and rootstock, and the lower tannins in Mirval on *S. sisymbriifolium* may reflect a shift toward other non tannin phenolics.

Data from Table 2 confirm that Mirval F1, particularly when ungrafted or grafted on *S. sisymbriifolium*, produced fruits richer in bioactive compounds than Black Pearl F1. The grafting effect depended strongly on rootstock. Mirval on *S. sisymbriifolium* combined high polyphenols with well preserved pigments, while Mirval on Rezistar maintained high polyphenols but showed lower pigment values. Black Pearl had consistently lower phytochemical content, and grafting did not improve its profile, in some cases it even decline. This confirms that scion genotype remains the main driver of fruit nutritional quality, while rootstock only fine tunes the response.

Antioxidant results from Figure 2 followed the same pattern. Ungrafted plants had the lowest ABTS and DPPH values in both cultivars. Grafted Mirval variants showed the highest activities, with Mirval on Rezistar leading DPPH and Mirval on *S. sisymbriifolium* leading ABTS. This suggests that grafting amplified Mirval natural antioxidant potential, likely through modified nutrition and stress signaling. In Black Pearl, grafting caused only moderate improvements and values stayed below those of Mirval.

DPPH separated the treatments more clearly than ABTS, indicating a stronger role of lipophilic antioxidants. Although ungrafted Mirval had the highest pigments, its antioxidant activity was lower than in grafted plants, showing that pigments alone are not sufficient. Overall, Mirval F1 combined with appropriate rootstocks proved most efficient for antioxidant enhancement. *S. sisymbriifolium* offered the most balanced improvement in polyphenols, pigments and antioxidant capacity, while ungrafted Mirval remained superior for chlorophyll and lycopene. These results confirm that grafting can steer biochemical quality when genotype compatibility is correctly selected.

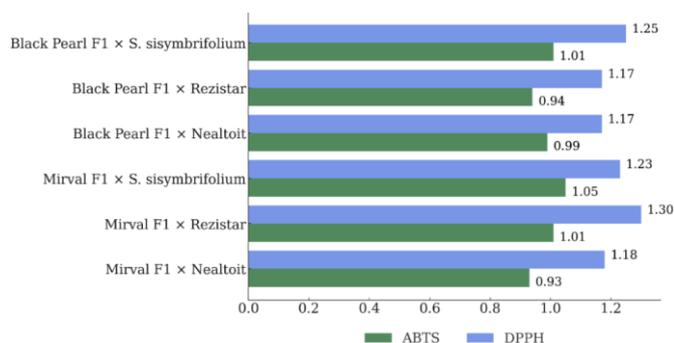


Figure 2. Antioxidant capacity (ABTS and DPPH assays) of eggplant fruits in relation to cultivar × rootstock combination

### 3. Effect of Cultivar × Fertilization Interaction on Bioactive Compounds in Eggplant Fruits

At the same time, Was evaluated how different fertilization strategies affected the accumulation of major bioactive compounds in the two eggplant cultivars, including polyphenols, chlorophylls, lycopene and tannins. By examining the interaction between cultivar and fertilization, cultivar specific nutritional responses to nutrient supply can be identified and better management options for improving fruit quality can be outlined (Table 3).

Table 3. Effect of Fertilization Regime on Polyphenol Content, Photosynthetic Pigments, Lycopene, and Tannins in Two Eggplant Cultivars

Cultivar	1	2	3	4	5
Mirval F1 × Control	2.76 ± 0.01 b	3.21 ± 0.01 b	4.18 ± 0.08 b	1.39 ± 0.03 bc	0.11 ± 0.00 bc
Mirval F1 × Micoseed	3.01 ± 0.02 a	3.19 ± 0.07 b	4.19 ± 0.12 b	1.33 ± 0.06 c	0.10 ± 0.00 cd
Mirval F1 × Organic	3.00 ± 0.04 a	3.14 ± 0.12 b	4.49 ± 0.22 b	1.57 ± 0.02 b	0.11 ± 0.00 bc
Mirval F1 × Chemical	3.11 ± 0.05 a	4.22 ± 0.07 a	6.11 ± 0.29 a	2.04 ± 0.07 a	0.11 ± 0.00 b
Black Pearl F1 × Control	2.44 ± 0.02 c	3.39 ± 0.05 b	4.71 ± 0.08 b	1.56 ± 0.01 b	0.12 ± 0.00 a
Black Pearl F1 × Micoseed	2.15 ± 0.03 d	1.74 ± 0.05 d	2.27 ± 0.11 c	0.74 ± 0.02 e	0.11 ± 0.00 bc
Black Pearl F1 × Organic	2.09 ± 0.06 d	2.16 ± 0.05 c	2.76 ± 0.04 c	0.93 ± 0.02 d	0.10 ± 0.00 d
Black Pearl F1 × Chemical	2.07 ± 0.06 d	1.85 ± 0.05 cd	2.09 ± 0.07 c	0.69 ± 0.02 e	0.09 ± 0.00 e
Significance	*	*	*	*	*

\*1. Total polyphenols (mg/100 g); 2. Chlorophyll A (mg/100 g); 3. Chlorophyll B (mg/100 g); 4. Lycopene (mg/100 g); 5. Tannins (mg/100 g)

### Polyphenols

Mirval F1 showed consistently higher polyphenol levels than Black Pearl F1 under all fertilization regimes. In Mirval, fertilization slightly increased TPC, with chemical and biofertilizer treatments giving the highest

values, while the control remained only slightly lower. In contrast, Black Pearl reached its maximum polyphenols under the unfertilized control and showed reduced values after fertilization. This confirms a clear genotype dependent response, where Mirval benefits from nutrient input, while Black Pearl seems to express higher phenolics under mild stress, and extra nutrients do not help, maybe even depress it.

### Chlorophylls

Fertilization strongly modified pigment content in a cultivar specific manner. Chemical fertilization greatly enhanced chlorophyll a and b in Mirval fruits, showing the highest pigment retention under this treatment. Black Pearl behaved oppositely, as its control plants had the highest chlorophyll while fertilization, especially chemical and Micoseed, caused sharp pigment losses. This suggest that Mirval maintains greenness under strong nutrition, while Black Pearl matures faster and loses pigments when well fed.

### Lycopene

Mirval again outperformed Black Pearl across all treatments. The highest lycopene was recorded in Mirval under chemical fertilization, while even its lowest value remained above the best Black Pearl treatment. In Black Pearl, fertilization sharply reduced lycopene, with the minimum under chemical input. This indicates that Mirval converts nutrients efficiently into carotenoids, while Black Pearl responds better to low input or mild stress, and high fertility suppresses carotenoid buildup.

### Tannins

Tannin levels varied only slightly but showed contrasting behavior. Black Pearl had the highest tannins in the unfertilized control and the lowest under chemical fertilization, indicating stress related accumulation. Mirval maintained nearly stable tannin values across all treatments, with only a minor decrease under Micoseed. Although statistically significant, these differences are likely minor in sensory perception.

The cultivar by fertilization interaction indicates that Mirval F1 shows a higher nutritional adaptability. It efficiently converts added nutrients, especially under chemical fertilization, into increased polyphenols, pigments and lycopene, resulting in fruits with superior quality. In contrast, Black Pearl F1

reached its best biochemical values mainly in the control and biofertilizer treatments, while high fertilization often lowered its quality traits. This suggest that Black Pearl is better suited for low input systems, whereas Mirval performs best under optimized nutrition. Accordingly, the Mirval F1 with chemical fertilization proved to be the most productive combination overall.

Figure 3 confirms these patterns through antioxidant assays. The highest ABTS values were observed in Black Pearl under control and Micoseed, indicating strong antioxidant activity under minimal or biological input. Mirval achieved similar ABTS levels mainly under organic fertilization, while its chemical and biofertilizer treatments were slightly lower. These data show that Black Pearl expresses hydrophilic antioxidant activity mostly under natural nutrient supply, while Mirval responds more positively to balanced or organic fertilization, although not all responses are identical between genotypes.

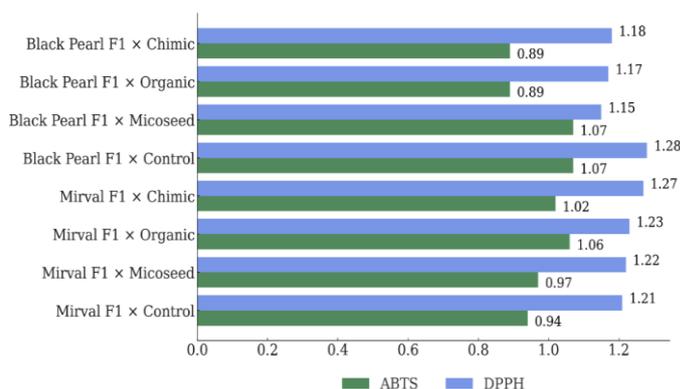


Figure 3. Antioxidant capacity (ABTS and DPPH assays) of eggplant fruits in relation to cultivar × fertilization interaction

In the DPPH assay, which reflects mainly lipophilic antioxidants, a different ranking was observed. The highest values occurred in Black Pearl F1 under control conditions and in Mirval F1 under chemical fertilization, showing two contrasting physiological responses. In Black Pearl, the strongest activity appeared without fertilization, suggesting that mild nutrient stress stimulated antioxidant accumulation. In Mirval, the top DPPH value was linked to full nutrient supply, indicating that this hybrid uses added resources to intensify antioxidant synthesis. Organic and Micoseed treatments in Mirval also produced high DPPH values, only slightly below the chemical variant, showing that this genotype remains highly responsive even under non mineral inputs. By contrast, fertilized Black Pearl variants displayed clearly lower DPPH

activity, confirming a weaker positive response to nutrient addition.

These responses indicate that antioxidant fractions measured by ABTS and DPPH do not react uniformly to fertilization. Black Pearl appears to rely more on stress activated compounds, while Mirval benefits from nutrient driven metabolic activation. The consistently high DPPH value of Mirval under chemical fertilization supports the idea that its antioxidant pathways are strongly nutrient sensitive. In turn, Black Pearl achieved its maximum antioxidant potential mainly under nutrient limitation, suggesting that additional inputs tend to shift its metabolism toward growth rather than defense.

Taken together, the data confirm that antioxidant behavior depends strongly on the cultivar–fertilization interaction. Black Pearl performs best under low input or biostimulant based systems, while Mirval expresses higher and more stable antioxidant capacity under organic and chemical fertilization. This emphasize that fertilization strategies should be adapted to the genetic background if functional quality is the main production goal.

#### 4. Combined Impact of Rootstock × Fertilization on the Content of Bioactive Compounds in Eggplant Fruits

The interaction between rootstock type and fertilization regime was further evaluated to assess how combined propagation and nutrient strategies influence the bioactive profile of eggplant fruits. By analyzing this interaction in Table 4, it becomes possible to identify whether specific rootstocks respond more favorably to particular fertilization approaches in terms of improving fruit phytochemical content. This integrated perspective allows a clearer understanding of how paired technological inputs can optimize nutritional quality, even if responses are not always uniform.

Table 4.  
Polyphenol, Chlorophyll a and b, Lycopene, and Tannin Content of Eggplant Fruits in Relation to Rootstock × Fertilization Interaction (mean ± standard error)

Factor	1	2	3	4	5
Ungrafted × Control	2.35 ± 0.03 e	4.41 ± 0.02 a	5.94 ± 0.01 a	1.96 ± 0.00 a	0.11 ± 0.00 bcd
Ungrafted × Microseed	2.61 ± 0.03 cde	2.48 ± 0.04 f	3.37 ± 0.06 de	1.13 ± 0.03 cd	0.09 ± 0.00 de
Ungrafted × Organic	2.98 ± 0.11 ab	4.15 ± 0.05 b	6.01 ± 0.14 a	2.08 ± 0.01 a	0.12 ± 0.01 a
Ungrafted × Chemical	2.88 ± 0.02 abc	3.49 ± 0.06 c	4.57 ± 0.13 b	1.51 ± 0.04 b	0.11 ± 0.00 abc
Rezistar × Control	2.34 ± 0.03 e	3.24 ± 0.03 d	4.47 ± 0.14 bc	1.49 ± 0.03 b	0.12 ± 0.00 ab
Rezistar × Microseed	2.38 ± 0.10 e	2.04 ± 0.07 g	2.40 ± 0.12 fg	0.78 ± 0.05 e	0.10 ± 0.00 bcd
Rezistar × Organic	2.74 ± 0.08 bcd	1.47 ± 0.00 h	1.80 ± 0.02 g	0.62 ± 0.01 e	0.10 ± 0.00 cd
Rezistar × Chemical	2.57 ± 0.03 de	1.65 ± 0.04 h	1.96 ± 0.07 g	0.65 ± 0.02 e	0.10 ± 0.00 cd
S. sisymbriifolium × Control	3.11 ± 0.06 a	2.26 ± 0.05 fg	2.92 ± 0.10 ef	0.98 ± 0.02 d	0.11 ± 0.00 abc
S. sisymbriifolium × Microseed	2.74 ± 0.05 bcd	2.87 ± 0.08 e	3.92 ± 0.09 cd	1.18 ± 0.09 c	0.11 ± 0.00 abc
S. sisymbriifolium × Organic	1.92 ± 0.04 f	2.33 ± 0.05 f	3.06 ± 0.11 e	1.05 ± 0.02 cd	0.08 ± 0.00 e

\*1. Total polyphenols (mg/100 g); 2. Chlorophyll A (mg/100 g); 3. Chlorophyll B (mg/100 g); 4. Lycopene (mg/100 g); 5. Tannins (mg/100 g)

#### Polyphenols

Polyphenol levels differed strongly with the rootstock and fertilization pairing. The highest value occurred in *S. sisymbriifolium* × Control (3.11 mg/100 g), suggesting that this wild rootstock favors phenolic accumulation under low input conditions, likely through mild physiological stress. Ungrafted plants supplied with organic or chemical fertilizer also showed high values, whereas Rezistar combinations were consistently lower, indicating a possible dilution effect linked to excessive vegetative vigor. Notably, *S. sisymbriifolium* × Organic showed the lowest value (1.92 mg/100 g), implying that high nutrient availability suppressed phenolic synthesis in this pairing.

#### Chlorophylls

The highest chlorophyll a and b contents were recorded in Ungrafted × Control and Ungrafted × Organic treatments, showing that self rooted plants retained more green pigments, probably due to slower ripening. High values were also observed in *S. sisymbriifolium* × Chemical, while

Rezistar under organic or chemical fertilization showed the lowest pigment levels. This indicates that vigorous growth induced by Rezistar combined with high nutrients accelerated chlorophyll loss in fruits.

### Lycopene

Lycopene accumulation was greatest in Ungrafted × Organic, Ungrafted × Control, and *S. sisymbriifolium* × Chemical, all near 2.0 mg/100 g. These results suggest that both natural nutrition and wild rootstock under high nutrient supply can favor carotenoid synthesis. In contrast, Rezistar under organic or chemical fertilization produced the lowest lycopene values, below 0.7 mg/100 g, showing a strong negative interaction between this rootstock and high nutrient input for carotenoid accumulation.

### Tannins

Tannin levels remained low overall, yet small differences were observed. The highest values appeared in Ungrafted × Organic and Rezistar × Control (0.12 mg/100 g), while the lowest occurred in *S. sisymbriifolium* × Organic and *S. sisymbriifolium* × Chemical (0.08 mg/100 g). This suggests that the wild rootstock under good nutrition reduced bitterness related compounds, which could be favorable for fruit palatability.

Overall, ungrafted plants under organic or low input conditions and wild rootstock under chemical fertilization emerged as the most favorable systems for maximizing pigments, lycopene, and polyphenols, while Rezistar combined with strong fertilization often depressed these quality traits.

The synthesis of Table 4 confirms that both grafting and fertilization strongly regulate the biochemical profile of eggplant fruits through clear interactive effects. Ungrafted plants, especially under organic or chemical fertilization, showed the highest chlorophyll and lycopene levels, reflecting intense pigment metabolism. In contrast, the Rezistar rootstock consistently produced the weakest responses for most quality traits, indicating that its vigor favors yield rather than phytochemical enrichment. The *S. sisymbriifolium* rootstock stimulated the highest polyphenol accumulation under control conditions, suggesting that this

wild rootstock induces a beneficial stress or improves nutrient scavenging. Under heavy fertilization, however, the same rootstock shifted metabolism toward pigments rather than phenolics or tannins. Overall, ungrafted plants and *S. sisymbriifolium* under moderate nutrition appear most suitable for achieving broad nutritional quality, while Rezistar under rich nutrition tends to dilute fruit value.

Antioxidant activity further clarified these trends. The highest ABTS values were observed in Rezistar × Micoseed and *S. sisymbriifolium* × Control, showing that both microbial input and wild rootstock under low nutrients can strongly enhance hydrophilic antioxidants. In the DPPH assay, the best performance was recorded for *S. sisymbriifolium* × Control and *S. sisymbriifolium* × Chemical, indicating that this rootstock ensures consistently strong lipophilic antioxidant activity across fertilization levels. In contrast, Rezistar × Control and Rezistar × Chemical ranked among the lowest in both assays. These results highlight that *S. sisymbriifolium* provides the most stable antioxidant performance across conditions, while Rezistar requires specific interventions like Micoseed to partially compensate. Taken together, the data show that rootstock selection is as critical as fertilization strategy for maximizing functional quality. Wild rootstocks paired with balanced nutrition clearly offer the most reliable route for enhancing antioxidant value, while mismatched combinations may still give high yields but poor nutraceutical quality.

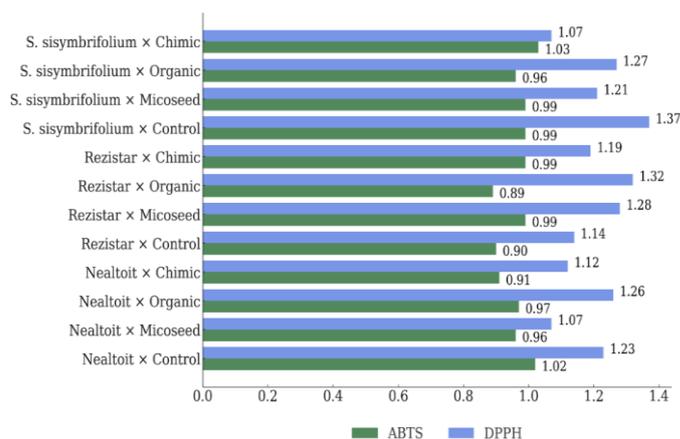


Figure .4. Antioxidant activity (ABTS and DPPH assays) of eggplant fruits in relation to grafting × fertilization interaction

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## CONCLUSIONS

The present investigation demonstrates that the biochemical quality of eggplant fruits is governed by a close interaction between genetic background, grafting strategy and fertilization regime rather than by any isolated factor alone. When considered together, the data indicate that decisions taken at each of these three levels, cultivar, rootstock and nutrition, are able to shift the balance between vegetative vigor aimed at yield and the accumulation of health related bioactive compounds.

First of all, cultivar choice proved to be the most stable and influential determinant of fruit quality. Across all tested variants, Mirval F1 accumulated consistently higher levels of total polyphenols, chlorophylls and lycopene, and, in parallel, exhibited slightly stronger antioxidant activity than Black Pearl F1. This superiority was maintained across different grafting and fertilization treatments, confirming that a favorable phytochemical profile is primarily genetically controlled. From a practical standpoint, Mirval F1 clearly represents a more suitable candidate for production systems targeting functional or nutraceutical quality, while Black Pearl F1 appears less adapted to such objectives, particularly under intensive fertilization, even if its agronomic behavior may still be acceptable.

Second, grafting acted not as a simple switch that turns quality on or off, but rather as a fine regulatory instrument whose effects depended strongly on the scion–rootstock interaction. Ungrafted plants generally produced fruits with the highest pigment contents, especially in terms of chlorophylls and lycopene, yet the antioxidant assays revealed that grafting, particularly onto *S. sisymbriifolium*, can markedly enhance radical scavenging activity. The wild rootstock provided a well balanced profile, combining high or very high antioxidant capacity with satisfactory levels of phenolics and pigments. In contrast, the commercial rootstock Rezistar frequently led to lower concentrations of key bioactive compounds, and only in a few specific cases, such as Mirval F1 × Rezistar for DPPH or Rezistar × Micoseed for ABTS, did it partially compensate through improved antioxidant response. Overall, *S. sisymbriifolium* appears to be the more appropriate rootstock when fruit quality is a core target, whereas Rezistar seems better

suitable for production systems where vigor and yield dominate over nutritional density.

Third, fertilization exerted a more nuanced and differentiated influence, affecting pigments and antioxidant activity more strongly than total polyphenol content. Total phenolics remained relatively stable across the fertilization treatments, but both pigment accumulation and antioxidant behavior showed clear responsiveness. Unfertilized control plants often exhibited elevated antioxidant capacity, particularly in DPPH, indicating that moderate nutritional stress can activate endogenous defense mechanisms and stimulate phenolic metabolism. Chemical fertilization, on the other hand, strongly promoted chlorophyll and lycopene accumulation in Mirval F1 and in certain grafted combinations, for example *S. sisymbriifolium* × Chemical, showing that well nourished high vigor plants are also able to develop very rich pigment profiles. Organic fertilization generally produced intermediate responses, often close to control, and appeared to offer a compromise between productivity and functional quality. The Micoseed biofertilizer induced more contrasting effects, tending to reduce pigment accumulation but, in some combinations, Rezistar × Micoseed, Black Pearl × Micoseed, coinciding with high ABTS values which suggests a shift in antioxidant composition rather than a simple overall decline.

From a technological perspective, the most favorable combinations for obtaining high quality fruits appear to be the following, (i) Mirval F1 grown ungrafted or grafted onto *S. sisymbriifolium* under moderate to high fertilization, organic or chemical, when the emphasis is placed on pigments and total antioxidant potential, and (ii) *S. sisymbriifolium* rootstock under either unfertilized or balanced mineral fertilization when the goal is to maximize antioxidant activity across diverse production contexts. Black Pearl F1, in contrast, expressed its highest antioxidant potential under low input conditions, control, Micoseed, yet even in these situations it did not reach the absolute bioactive levels observed in Mirval. These observations indicate that in quality oriented eggplant chains, cultivar and rootstock should be selected first based on functional targets, and fertilization should afterwards be adjusted to fine tune stress intensity rather than simply to maximize biomass.

In conclusion, the present study confirms that the bioactive compound profile of eggplant

fruits is highly plastic and can be deliberately steered through informed combinations of cultivar selection, grafting and fertilization. Mirval F1, especially when associated with *S. sisymbriifolium* or with carefully managed nutrition, is capable of producing fruits with superior phenolic, pigment and antioxidant profiles. Grafting, particularly onto wild rootstocks, should therefore be viewed not only as a tool for disease resistance and stress tolerance, but also as a powerful lever for improving nutritional and functional value. Integrating these strategies into commercial practice may support the development of eggplant production systems that ensure both agronomic performance and added value for consumer health, fully aligned with the broader principles of sustainable and health oriented horticulture.

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