# INTEGRATIVE REVIEW ON TECHNOLOGICAL MEASURES AFFECTING THE PHYSICOCHEMICAL AND NUTRITIONAL QUALITY OF EGGPLANTS

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REVIEW ARTICLE

**Abstract**
*Eggplant (Solanum melongena L.) is among the most widely cultivated vegetable crops worldwide, and interest has increasingly shifted from yield alone toward fruit quality attributes, including dry matter content, mineral composition, and antioxidant capacity. This review compiles recent evidence on how cultivation practices modulate the physicochemical and nutritional profile of eggplant fruits. Water regime emerges as one of the dominant drivers of quality formation. Excess irrigation generally leads to dilution of soluble solids and minerals, whereas moderate water restriction favors dry matter accumulation, improves flavor intensity, and enhances antioxidant potential. Fertilization strategy exerts a similarly pronounced influence. Balanced macro- and micronutrient supply, including foliar NPK applications enriched with iron, zinc, and boron, consistently increases fruit mineral concentrations, in some cases by twenty to thirty percent. Organic systems based on green manures and biofertilizers further enhance nutrient density when compared with unfertilized controls. In contrast, lycopene content remains minimal in eggplant and appears to be largely genotype-dependent, with limited responsiveness to agronomic management. The antioxidant profile, including phenolics, anthocyanins, and vitamin C, is particularly sensitive to cultivation conditions. Mild abiotic stress induced by regulated deficit irrigation or alternative water sources often stimulates antioxidant activity by twenty to fifty percent, while organic amendments have been associated with marked increases in radical scavenging capacity. Fine-tuning irrigation and fertilization represents a powerful approach for improving eggplant fruit quality. Through moderate water stress and targeted nutrient management, growers can obtain fruits with enhanced nutritional value, firmer texture, and superior antioxidant properties without compromising yield.*

**Keywords**: eggplant, irrigation, fertilization, antioxidant capacity, fruit quality

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## INTRODUCTION

Eggplant (*Solanum melongena L.*) is one of the most widely consumed vegetable crops worldwide, cultivated on about 1.8 million hectares and producing over 54 million tonnes annually, with Asia as the dominant producer (Bana et al., 2022). Beyond its well known culinary versatility and characteristic purple pigmentation, eggplant is increasingly appreciated for its nutritional and functional value (Diaz-Perez, 2015). Although the fruit contains large amounts of water, it also provides dietary fiber, phenolic compounds such as chlorogenic acid and anthocyanin pigments like nasunin, all linked to health related benefits (Mekky et al., 2025). However, many essential vitamins and minerals are present only at moderate levels, therefore improving fruit quality remains an important goal in both research and production, and sometimes is difficult to be achieved.

Modern consumers demand vegetables with better flavor and higher nutritional value, which has increased the importance of agronomic practices as tools for regulating fruit quality. Unlike breeding, which requires long time periods, cultivation measures such as irrigation control, fertilization, plant density and organic amendments can be adjusted within one season. In eggplant, the major challenge is to obtain fruits that combine good yield with high dry matter, improved mineral content and elevated levels of bioactive compounds with health value.

Previous studies clearly indicate that fruit quality in eggplant is highly dependent on environmental and technological conditions

(Abbas et al., 2025; Islam et al., 2024; Amami et al., 2025). Excessive irrigation leads to diluted fruits with weak flavor, while moderate water stress tends to favor sugar and phenolic accumulation (Li et al., 2024). Similarly, excess nitrogen may raise yield but often reduces quality, whereas balanced fertilization and micronutrient supplementation improve nutrient density (Nisar et al., 2025). Organic fertilizers and biofertilizers also enhance vitamin and mineral content through improved soil function and mild stress responses. Even so, the combined action of these factors on specific quality traits is still not completely understood.

This review is grounded on the assumption that a well balanced optimization of cultivation practices can improve eggplant fruit quality without causing yield reduction. It critically evaluates the influence of major agronomic factors such as irrigation management, fertilization approach, planting density and related field practices on dry matter accumulation, mineral profile, lycopene level, antioxidant capacity and other relevant biochemical traits. By integrating results from a wide range of experimental studies, the analysis aims to deliver practically useful guidance for the production of eggplants with enhanced nutritional quality and increased consumer value, which is today more and more expected.

## MATERIALS AND METHODES

This study was conducted as an integrative literature review, aiming to collect and synthesize a wide range of scientific evidence related to eggplant cultivation and fruit quality. A structured search was carried out in major scientific databases, including Web of Science, Scopus, PubMed, and Google Scholar. Priority was given to peer reviewed papers published mainly within the last two decades, roughly between 2000 and 2025, that investigated the influence of agronomic or technological practices on eggplant fruit composition. The search strategy involved combining the terms “eggplant” or “*Solanum melongena*” with expressions such as irrigation regime, deficit irrigation quality, fertilization eggplant nutrients, foliar feeding eggplant, organic manure eggplant quality, spacing yield quality, wastewater irrigation eggplant, and postharvest eggplant composition. In addition, the reference lists of key articles were examined in order to capture further relevant studies that may not have appeared directly in the database queries.

### *Inclusion Criteria*

Only studies that reported quantitative or qualitative data for at least one physicochemical or nutritional attribute of eggplant fruits in response to a clearly defined cultivation practice were included. Both open field and greenhouse experiments were considered, covering factors such as irrigation level and method, water quality including saline or wastewater use, fertilizer type and dose comprising mineral fertilization, micronutrient supplementation, organic manures and biofertilizers, as well as planting density, harvest timing and certain postharvest treatments. Research conducted under both conventional and organic or sustainable management systems was taken into consideration. Preference was given to experiments with sound methodological design such as replicated trials and randomized layouts. Studies evaluating fruit quality attributes including dry matter and soluble solids content, mineral element concentrations, antioxidant compounds such as phenolics, anthocyanins and vitamins, together with indices of antioxidant activity, were prioritized in the selection process.

### *Data Extraction and Synthesis*

From each selected paper, information regarding the applied technological measure and the resulting changes in eggplant fruit quality parameters was extracted. Whenever available, numerical values such as mean concentrations or percentage variations were recorded for comparative purposes. Due to the considerable diversity of experimental designs, methodologies and reporting units among the studies, results were synthesized primarily in a narrative format. This interpretation was supported by summary tables that compile and normalize the most important data. Tables 1 to 5 were included in the paper to compare findings from multiple sources concerning specific quality traits, including dry matter, mineral composition, lycopene content, antioxidant indicators and other biochemical characteristics. A formal meta analysis was not performed because the heterogeneity of experimental conditions did not allow for reliable statistical aggregation. Instead, general patterns, consistencies and also contradictions among studies were interpreted using physiological principles.

All information presented in this review is derived exclusively from previously published research and each source is cited accordingly. In several instances, minor unit conversions were applied to improve comparability among studies, for example transforming mineral concentrations to a common dry weight basis, and these adjustments were noted where relevant. The present review is therefore qualitative in nature and aims to integrate existing knowledge in order to draw broader conclusions about how technological cultivation practices may be applied to enhance eggplant fruit quality. By examining a wide body of independent research, this integrative approach offers a more comprehensive understanding that may support future agronomic decision making and guide further investigations in eggplant and related vegetable crops.

## RESULTS AND DISCUSSIONS

The quality of eggplant fruits was shown to be strongly affected by cultivation practices. The paper examine how the principal technological measures influence several key quality attributes, namely dry matter content, mineral composition including both macro and microelements, lycopene concentration, total antioxidant capacity, and other biochemical traits such as sugars, proteins, vitamins, and glycoalkaloids. Within each category, findings from multiple studies are compared and interpreted in order to build an integrated view of how agronomic management shapes eggplant fruit quality, and how these effects sometimes differ between experimental conditions.

### Effect of Technological Measures on Dry Matter Content

Dry matter content is a key indicator of eggplant fruit quality because it reflects the balance between solid constituents and water, directly influencing firmness, taste intensity and processing suitability (Zipelevish et al., 2000). Evidence from the literature clearly indicates that irrigation management strongly controls this trait, through an obvious inverse relationship between water supply and dry matter concentration (Arrobas et al., 2021). Excessive watering, especially during fruit filling, promotes water accumulation in the tissues and leads to a clear dilution of solids. Field and greenhouse studies consistently confirm that high irrigation rates reduce fruit dry weight and soluble solids, producing larger but more watery fruits with only about six to seven percent dry matter (Li et al., 2024; Tezcan et al., 2025; Abrham, 2024). In contrast, plants subjected to moderate irrigation develop fruits with a higher proportion of solids (Khapte, et al., 2025; Kiran et al., 2025). Conversely, a mild and well regulated water deficit stimulates dry matter accumulation through adaptive physiological responses such as stomatal regulation and osmotic adjustment, which limit excessive water inflow into the fruit. As a result, fruits become slightly smaller but richer in sugars and other solutes. This principle, known as deficit irrigation, has proven to be an effective tool for improving eggplant fruit quality without causing serious yield losses, if applied carefuly (Lipovac et al., 2025).

Moderate irrigation regimes, supplying roughly 70 – 80% of the full water requirement or based on partial scheduling, have been shown to increase dry matter and soluble solids in eggplant fruits while limiting total water consumption (Thomas et al., 2025). Under such mild water stress, fruits contained about 15 – 20% percent more soluble solids than those grown under full irrigation, leading to better flavor and firmer texture, although values varied by season and genotype. By restricting excess water, plants produced fruits that were less watery and richer in structural compounds. For this reason, controlled deficit irrigation is increasingly used as both a water saving and quality enhancing strategy, even if in practice it remain difficult to apply precise (Ali et al., 2025).

Fertilization also plays an important role in dry matter accumulation. Adequate nutrient supply supports carbohydrate synthesis and the formation of fruit solids, with nitrogen, phosphorus and potassium being central regulators of this process. However, excessive nitrogen promotes vegetative growth and delays ripening, which can reduce dry matter through continued water accumulation (Li et al., 2025). Balanced fertilization is therefore essential. Studies show that fertilizers including sulfur and micronutrients such as boron can consistently improve dry matter levels. In a tropical field experiment, the use of NPSB fertilizer increased dry matter to about 10.21 percent, compared to only 8.13 percent in unfertilized plants. This difference is agronomically relevant and reflects improved metabolic activity and cell wall formation in well nourished plants, whereas nutrient limited crops remained visibly inferior in fruit quality (Choudhary et al., 2025; Dawar et al., 2025; Balaout et al., 2025).

Plant density also interferes with dry matter formation in eggplant, although in a more indirect manner. Wider spacing reduces competition for light, water and nutrients, allowing each plant to develop a stronger canopy and to fill fruits more evenly. In the Ethiopian field study, the optimal balance between yield and quality was observed at 40 cm between plants under proper fertilization. At 50 cm spacing, fruit dry matter reached about 9.6 percent, while at 30 cm it dropped to nearly 8.4 percent (Abrham et Shumbulo, 2025). This suggests that reduced competition and slightly higher exposure under wide spacing favored solid accumulation, whereas dense crops created humid conditions and stronger resource sharing, leading to more watery fruits. Although spacing is usually adjusted mainly for yield, its effect on quality is real and often under estimated. Water quality also affected dry matter levels. Treated wastewater irrigation generally resulted in higher dry matter than clean freshwater. In one experiment, fruits from wastewater plots reached up to 7.8 percent dry matter, compared to about 5.7 percent under freshwater. This effect is linked to mild osmotic stress caused by salts and to the additional nutrients present in reclaimed water, which together limit water dilution and support solid build up. Even if the absolute values seem small, the relative increase was enough to improve texture and flavor. (Abrham et Shumbulo, 2025).

Table 1.

**Influence of Selected Technological Measures on the Dry Matter Content of Eggplant Fruits**

| Technological Measure | Dry Matter Content (%) |
| --- | --- |
| Intensive irrigation (high water, semi-arid conditions) | 6.5 |
| Moderate irrigation (controlled deficit regime) | 8.2 |
| NPSB fertilization (200 kg/ha blend) | 10.21 |
| Unfertilized control (no fertilization) | 8.13 |
| Wider plant spacing (50 cm between plants) | 9.65 |
| Closer plant spacing (30 cm between plants) | 8.4 |
| Irrigation with clean water (freshwater) | 5.77 |
| Irrigation with treated wastewater | 7.8 |

The accumulated evidence confirms that proper control of both irrigation and fertilization can markedly increase dry matter in eggplant fruits. When excess water is avoided and only moderate supply is applied, fruits become denser and richer in flavor. Likewise, a well balanced nutrient input supports the formation and retention of solid compounds. These changes lead to firmer fruits with better sensory and nutritional quality, which is increasingly demanded by the market. Importantly, this improvement does not always reduce yield. Several deficit irrigation approaches show that quality can rise while production remains stable. Thus, dry matter is shaped by the combined effect of water, nutrients and spacing, and by adjusting these factors, growers can intentionally improve fruit quality, even if field conditions are never perfect.

**Effect of Technological Measures on Macro- and Microelement Content**

Beyond water effects, the mineral profile of eggplant is a major component of its nutritional value. Fruits supply relevant amounts of potassium, magnesium, calcium and phosphorus, along with smaller but important levels of iron and zinc (Chatzistathis et al., 2025). These concentrations are shaped not only by genotype and soil, but very clearly by fertilization and soil management. The reviewed data show that targeted fertilization can significantly increase mineral density, effectively turning eggplant into a biofortified food crop.

A particularly effective approach is the use of combined macro and micronutrient fertilization, especially through foliar feeding. In field trials, foliar application of NPK enriched with iron, zinc and boron led to notable increases in fruit mineral content, with iron rising by about 26 percent and zinc by more than 30 percent (El-Motaium, 2025). Such gains are nutritionally meaningful over time. Foliar delivery bypasses soil limitations and directly supports fruit formation. Importantly, these improvements were not obtained at the expense of yield, which in some cases even increased. This confirms that multi nutrient foliar fertilization can enhance both productivity and nutritional quality, although in practice it requires careful timing and management.

Agroecological and organic soil management can markedly improve mineral uptake in eggplant. In a recent Armenian study, the combination of green manure, especially soybean, with nitrogen fixing and phosphorus solubilizing biofertilizers led to very high mineral accumulation in fruits. Compared with the unfertilized control, iron, potassium, calcium, phosphorus and magnesium increased by large margins (Martirosyan, 2023). These results show that soil improving practices can substantially enrich the mineral profile of eggplant, sometimes even beyond levels reported for standard chemical fertilization.

This response is linked to improved soil structure, higher organic matter and sustained nutrient release from decomposing green manures, together with the direct action of beneficial microbes in the rhizosphere. Nitrogen was supplied gradually and insoluble phosphorus became more available, leading to a more balanced nutrition across the growing period. In practice, these green technologies proved capable of matching, and sometimes exceeding, the mineral enrichment achieved with NPK alone, which is not always expected.

Table 2.

**Macro- and Microelement Content of Eggplant Fruits Under Different Fertilization Practices**

| Technological Measure | Fe* | Zn* | Ca* | K* | P* | Mg* |
|---|---|---|---|---|---|---|
| Foliar fertilization (NPK + micronutrients) | 55.7 | 48.2 | 379 | 1750 | – | – |
| Control (no foliar fertilization) | 44.1 | 36 | 325 | 1650 | – | – |
| Green manure (soybean) + biofertilizer (soil applied) | 59.2 | 42.3 | 393 | 1908 | 25.5 | 160.5 |
| Control (unfertilized, conventional soil) | 44.2 | 30.1 | 335.5 | 1555 | 18.5 | 132.5 |

***(mg/kg)**

The data show that well adjusted fertilization can strongly enhance the mineral content of eggplant fruits. Foliar feeding mainly increased the elements applied directly, while green manure and biofertilizers improved a broader range of minerals through better soil functioning. Control treatments reflect nutrient limited conditions, whereas enriched variants confirm the real potential for agronomic biofortification. An iron level close to 59 mg $kg^{-1}$ dry weight is rather high for a vegetable and indicates that eggplant may become a relevant source of dietary iron under such management. Importantly, organic based treatments improved mineral ratios in a balanced way, since calcium and magnesium increased together with potassium, and not being suppressed as it sometimes happens under heavy chemical inputs.

From a wider perspective, integrating organic amendments, biological inputs and targeted micronutrient supply allows farmers to obtain fruits that are not only larger but also more nutritious, which fits well with the idea of functional food production at farm level. This is especially meaningful in regions where eggplant is consumed daily, and even small nutrient increases can matter for public health. At the same time, these systems support soil quality and reduce dependence on synthetic fertilizers, which is long term beneficial.

Eggplant mineral composition is highly responsive to fertilization strategy. Basic NPK remains necessary for yield, but micronutrient supplementation and organic soil management clearly enhance fruit micronutrient density. When nutrients are supplied in balance and not in excess, together with biofertilizers, a more stable and favorable mineral profile can be achieved, and this is not always easy to manage in practice.

**Effect of Technological Measures on Lycopene Content**

Lycopene, a carotenoid responsible for the red color of tomato and watermelon, is present in eggplant only in trace amounts or is sometimes not detectable at all. The pigmentation of eggplant is instead dominated by anthocyanins, mainly nasunin, which give the characteristic purple skin (Panda et al., 2025). Because the biosynthetic pathway for lycopene is weakly expressed in this species, its concentration remains extremely low and is controlled almost entirely by genetic factors, not by cultivation practices. Changes in irrigation or fertilization therefore have very limited capacity to influence lycopene formation.

Analytical data confirm this pattern. Reported values in eggplant generally range between about 1.5 and 6.8 μg $g^{-1}$ dry weight, which is nearly two orders of magnitude lower than in tomato, where lycopene commonly reaches 50 to 120 μg $g^{-1}$ (Mukhtar et al., 2025). In most commercial purple cultivars, lycopene is close to the detection limit, and only a few reddish eggplant types accumulate slightly higher levels. Even in those cases, eggplant remains a very weak dietary source of lycopene, and this fact is often underestimated.

For this reason, agronomic measures do not produce measurable changes in eggplant lycopene content. Field experiments consistently show that water regime, nutrient supply or spacing fail to modify this pigment in any relevant way. In the studies reviewed here, lycopene stayed at similarly minimal levels across all treatments, often below 0.0005 percent of dry weight. Even increased potassium, which stimulates lycopene in tomato, had no effect in eggplant, confirming that this trait is rigid and mainly genetically fixed.

From a theoretical point of view, strong light exposure could stimulate carotenoid formation, since irradiance regulates pigment metabolism in many crops (Quian-Ulloa and Stange, 2021). In eggplant, fruits exposed directly to sunlight receive stronger light signals than shaded ones, and for this reason a slight stimulation of carotenoids has been speculated. However, solid experimental evidence for a real effect on lycopene is missing. If any response does exist, it is extremely weak. Most dark purple cultivars show no detectable lycopene regardless of sun exposure, because their metabolism is genetically directed toward anthocyanin production, and this basic pattern do not change under normal field conditions.

Postharvest handling appears to influence carotenoids more than cultivation. Thermal processing was shown to reduce the already very low carotenoid and lycopene levels in eggplant, together with vitamin C. Frying was the most damaging treatment, likely due to high temperature and solubility of carotenoids in oil, while baking also caused noticeable losses. In contrast, steaming or brief sautéing preserved a larger fraction of these compounds. Even so, lycopene remains nutritionally irrelevant in eggplant, since its initial concentration is far too low for cooking methods to make a meaningful difference.

Table 3.
**Lycopene Content of Eggplant Fruits vs. Tomato (for comparison)**

| Cultivar / Genotype | Lycopene (μg/g dry weight) |
|---|---|
| Eggplant – typical dark-purple cultivar (Nigeria) | 1.5 – 2.1 μg/g |
| Eggplant – white-purple striped cultivar (Turkey) | 2.8 – 4.5 μg/g |
| Eggplant – orange-pigmented cultivar (Solanum aethiopicum) | 5.3 – 6.8 μg/g |
| Ripe Tomato (red cultivar) | 50 – 120 μg/g |

Lycopene occurs in eggplant only at trace levels, and neither cultivar choice nor cultivation practices lead to any relevant increase. For this reason, lycopene is not a meaningful quality marker for eggplant production. Breeding programs do not target this trait, and agronomic interventions offer little practical potential to modify it, since the species has a very limited biological capacity to synthesize this carotenoid. In practice, lycopene remains consistently low and only weakly influenced by postharvest handling. From a nutritional view, consumers seeking lycopene should prefer red fruits such as tomato, while eggplant should be valued for fiber, anthocyanins and mineral content.

## Effect of Technological Measures on Antioxidant Potential

Eggplant fruits are appreciated not only for taste and nutrients, but also for their strong antioxidant potential, which is mainly derived from phenolic acids such as chlorogenic acid, anthocyanins concentrated in the peel, especially nasunin, and vitamin C. Together, these compounds confer a high capacity to neutralize reactive oxygen species, as shown by common assays such as DPPH or ABTS (Jarerat et al., 2022). This antioxidant function is an important component of the fruit's functional quality and is linked with protective effects against oxidative stress and inflammation. Antioxidant accumulation in eggplant is closely connected to plant stress physiology. Moderate water or nutritional stress usually stimulates the synthesis of secondary metabolites, while very favorable conditions tend to reduce it.

### *Irrigation and Water Stress*

Water regime strongly controls the antioxidant profile of eggplant mainly through its effect on plant stress physiology. Polat et al. (2024) reported that irrigation with treated wastewater led to a clear increase in total phenolic content and antioxidant activity compared with clean water. The mild salinity and trace elements in reclaimed water likely induced a low level of osmotic stress that stimulated phenolic synthesis. In contrast, plants supplied with abundant clean water showed the lowest phenolic levels, probably due to dilution and the lack of any stress signal. Thus, higher water availability was linked with lower antioxidant accumulation, while limited or lower quality water promoted enrichment. Still, wastewater use must be strictly controlled for safety, even if it improves functional quality, otherwise the risk may not be worth it.

### *Combined Water and Nutrient Management*

The joint regulation of water and nitrogen strongly influences the antioxidant quality of eggplant fruits. Zhou et al. (2021) showed that moderate water restriction together with balanced nitrogen supply produced the highest vitamin C, soluble sugars and soluble proteins. Under about seventy five percent irrigation and medium nitrogen, vitamin C reached roughly 63 to 69 mg per kg fresh weight, around forty percent higher than under excessive water and nitrogen, where values fell near 41 to 46 mg per kg. Although heavy inputs increased yield, fruits became biochemically diluted. Mild water stress stimulated sugar and antioxidant accumulation, while adequate nitrogen supported enzyme activity without promoting excessive vegetative growth. In contrast, surplus nitrogen under ample water delayed fruit maturation and reduced phenolic and vitamin C levels.

***Organic and Biological Fertilization***

Organic and biological fertilization clearly enhances the antioxidant potential of eggplant fruits. Compost, manure and green cover crops promote secondary metabolite synthesis due to slow nutrient release and higher soil microbial activity. Many studies report higher phenolic content and stronger antioxidant activity in organic fruits, even if yield is sometimes slightly lower. In the Armenian study by Martirosyan et al. (2023), green manure combined with biofertilizers nearly doubled ABTS activity, reaching about 692 µmol Trolox per g dry weight compared with 365 µmol in the control. The same treatment also showed the highest vitamin C and increased B vitamins. These results indicate that ecological fertilization can even outperform conventional systems in functional quality.

***Anthocyanin Enhancement***

Anthocyanins are a key contributor to the antioxidant capacity of eggplant, as these pigments act as strong free radical scavengers. Therefore, practices that influence anthocyanin formation also affect fruit antioxidant potential. Light exposure is especially important, since fruits receiving more direct radiation usually develop darker skins and higher pigment levels, when the genotype allows this. Simple canopy adjustments, such as partial leaf removal near the fruits or reflective mulches, can enhance coloration and indirectly raise antioxidant content. Potassium nutrition may also support pigment synthesis through its role in carbohydrate transport and metabolism, although in eggplant the evidence is still limited. A sufficient K supply appears beneficial, but excessive doses does not seem to bring extra gains (Colak et al., 2022).

Niño Medína et al. (2014) reported a native Philippine eggplant genotype with very dark skin that showed extremely high anthocyanin content, about 161 mg per 100 g fresh weight, together with outstanding antioxidant activity, reaching over 92% DPPH inhibition and an ORAC value near 539 µmol Trolox per gram. These levels are exceptional for a vegetable and confirm the dominant role of anthocyanins in shaping antioxidant capacity. Although this variation is largely genetic, agronomic conditions such as full light exposure, balanced potassium nutrition and moderate stress can further enhance pigment expression. Even in common purple cultivars, fruits with deeper coloration usually show stronger antioxidant responses than pale ones, which is often clear in practice.

Table 4.

**Effect of Technological Measures on the Antioxidant Potential of Eggplant Fruits**

| Applied Measure | Antioxidant Parameter | Observed Effect or Value |
|---|---|---|
| Wastewater irrigation (vs. clean water) | Total phenolic content | ~20–30% increase compared to clean-water |
| Wastewater irrigation (vs. clean water) | Overall antioxidant activity | Higher antioxidant capacity under wastewater (saline stress) than under freshwater |
| Moderate water deficit + moderate N fertilization | Vitamin C (ascorbic acid) | 63–69 mg/kg (fresh weight) in fruit – about 40–50% higher than in over-irrigated, high-N conditions (~41–46 mg/kg) |
| Moderate water deficit + moderate N fertilization | Soluble solids & proteins | Elevated levels (both higher than in either water-excess or nitrogen-excess scenarios) indicating more accumulated metabolites |
| Organic fertilization (green manure + biofertilizers) | ABTS radical scavenging capacity | 692 µmol Trolox/g (d.w.) in organically fertilized fruits vs. ~365 µmol/g in unfertilized control (nearly 2× higher) |
| Organic farming system (vs. conventional) | General antioxidant activity | Significantly higher in organic (due to greater phenolics, etc.) – e.g., DPPH scavenging and FRAP values often superior in organic eggplants |
| Intensely purple cultivar (high anthocyanins) | Total anthocyanins (in skin) | ~161 mg/100 g fresh weight (very high pigment content) |
| Intensely purple cultivar (high anthocyanins) | DPPH free radical inhibition | 92.5% inhibition (strong antioxidant effect) |
| Intensely purple cultivar (high anthocyanins) | ORAC (Oxygen Radical Absorbance) | 538.9 µmol Trolox equiv./g (exceptionally high antioxidant capacity) |

Overall, available evidence shows that several agronomic practices can effectively enhance the antioxidant potential of eggplant fruits. Mild stress conditions, such as regulated deficit irrigation or the use of slightly saline irrigation water, stimulate phenolic synthesis, while balanced fertilization ensures the metabolic support needed for antioxidant production. Organic amendments appear particularly beneficial, since they promote slow nutrient release, better micronutrient availability and a moderate physiological stress that favors secondary metabolism. Cultivar choice remains decisive, as dark skinned types naturally express higher antioxidant capacity, especially when grown under full light and appropriate nutrition.

It must be acknowledged that increased antioxidants may involve small sensory compromises, because very high phenolic levels can introduce slight bitterness. However, most studies report that the increases remain within acceptable sensory limits, and compounds like chlorogenic acid often contribute positively after cooking. Only extreme pigment accumulation in some breeding materials might alter texture or taste, which is less relevant for standard cropping systems.

In conclusion, antioxidant capacity in eggplant is a flexible trait that can be shaped through cultivation strategies. Controlled water stress, organic fertilization, foliar micronutrients and careful variety selection all contribute to higher levels of phenolics, vitamins and anthocyanins. Many of these practices also support sustainability by saving water and improving soil quality, which makes their application both practical and desirable, even if field conditions are not always perfect.

## Effect of Technological Measures on Other Biochemical Characteristics

Beyond dry matter and antioxidants, eggplant fruits also contain other biochemical components that shape both nutritional value and sensory quality, including sugars, organic acids, small amounts of proteins and amino acids, B group vitamins and glycoalkaloids responsible for bitterness. Most of these traits can be modified by cultivation practices and often respond in parallel with the physiological mechanisms already described.

Eggplant is a low sugar vegetable, yet even small variations in sugar level clearly affect taste perception. Glucose and fructose dominate at maturity, while total soluble solids reflect the overall pool of soluble compounds. Available evidence shows that irrigation and nitrogen supply play a central role in sugar accumulation. In the study of Li et al. (2023), the highest sugar content occurred under limited irrigation of about seventy five to eighty percent of full water demand combined with optimal nitrogen, where sugars were roughly fifteen to thirty six percent higher than under excess water or nitrogen. Thus, a fruit with around three degrees Brix under high input could reach about four under moderate stress, a change that is clearly perceived by consumers.

Within the same water regime, moderate nitrogen further increased sugars, while excessive nitrogen consistently reduced them. This is likely because high nitrogen promotes vegetative growth and delays fruit maturation, producing larger but more watery fruits. Over irrigation had a similar dilution effect. For this reason, avoiding surplus water and nitrogen, especially late in fruiting, appears essential for flavor optimization. A mild, well controlled stress favors sugar accumulation as an osmotic response and improves overall taste, which was also reflected by higher total soluble solids in optimally managed plants.

### *Proteins and Amino Acids*

Eggplant fruits contain very low amounts of protein, usually below two percent fresh weight, so they are not a major protein source. Still, changes in protein concentration can indicate differences in fruit quality. Soluble proteins and free amino acids contribute to umami taste and nutritional value, especially amino acids such as arginine and tryptophan. Nitrogen availability is the main driver of protein accumulation in the fruit. Evidence shows that moderate nitrogen supply supports higher protein levels, whereas both nitrogen shortage and excess reduce protein content. Fruits grown under optimal water and nitrogen conditions had about forty five percent more soluble protein than low input plants, and up to sixty seven percent more than under unfavorable regimes (Chawla et al., 2025). In contrast, the extreme combination of strong water stress and excessive nitrogen caused a sharp protein decline and produced small, shriveled fruits with weak flavor. This likely reflects a metabolic imbalance, with reduced sugars and amino acids and increased stress compounds.

***B-Complex Vitamins***

Eggplant fruits contain modest but detectable amounts of several B-complex vitamins. Mukhtar et al. (2023) reported wide differences among cultivars, with thiamine values ranging from about 11 to 95.6 $\mu g\ g^{-1}$ dry weight and niacin from 83 to 265 $\mu g\ g^{-1}$. These variations were mainly attributed to genotype and growing environment, since Nigerian samples generally showed higher levels than Turkish ones, probably due to cultivar and soil effects.

Direct evidence on how cultivation practices modify B-vitamin content in eggplant is still scarce. However, from a physiological point of view, these vitamins are linked to primary metabolism and may respond to nutrient status and soil microbial activity. Organic amendments such as compost or manure could indirectly enhance vitamin accumulation, because some microorganisms synthesize B vitamins that plants can absorb. Thus, the assumption that organic fertilizers may support higher B-vitamin levels in eggplant fruits is biologically realistic, even if exact values are still missing. Such practices do not seem to reduce vitamin content, while severe stresses, like long drought, could negatively affect more sensitive compounds.

**Glycoalkaloids and Bitterness**

Eggplant fruits contain defensive glycoalkaloids, mainly solasonine and solamargine, which are responsible for their slight bitterness and, at very high levels, potential toxicity. In commercial cultivars these compounds are usually present at low and safe concentrations, giving only a mild bitter taste that is often reduced by culinary practices such as salting. One of the main factors affecting glycoalkaloid content is fruit maturity. Overripe fruits, recognized by dull skin, hardened seeds and yellowing, tend to accumulate higher levels, which explains their stronger bitterness (Contreras-Angulo et al., 2022).

Severe environmental stress, including drought or pest attack, may further stimulate glycoalkaloid synthesis, but under normal farming conditions the dominant controls remain cultivar choice and harvest timing (Merino et al., 2023). Many modern varieties were bred for low inherent bitterness, keeping glycoalkaloids minimal under most conditions. Importantly, quality improving practices such as moderate water stress generally do not raise these compounds to harmful levels. When bitterness is still noticeable, traditional methods like salting sliced fruits remain effective in lowering glycoalkaloids before consumption.

**Organic Acids and Acidity**

Eggplant pulp contains only limited amounts of organic acids, mainly malic and citric acid, which explains its generally low titratable acidity and the absence of a distinctly sour taste (Zhou et al., 2023). Most studies report acidity values between 0.1 and 0.4 percent on a fresh weight basis, while only few higher values around 1.5 percent were occasionally noted, but these likely reflect dry matter calculations or very specific growing conditions (Kanval et al., 2025; Gaccionne et al., 2025; Blumenthal et al., 2024). In practical sensory terms, however, such variations remain minor, and acidity rarely plays a dominant role in eggplant flavor, which is instead shaped mostly by texture, mild bitterness and seasoning.

Table 5.

**Influence of Technological Measures on Additional Biochemical Characteristics of Eggplant Fruits**

| Applied Measure | Biochemical Parameter | Effect on Parameter |
|---|---|---|
| Moderate water deficit + moderate N fertilization | Soluble sugars (SSC) | Increases by ~15–36% compared to no stress (control) |
| | Total soluble solids (TSS) | ~+15% vs. fully irrigated control (more concentrated juices) |
| | Soluble proteins | ~+45–67% vs. other treatments (highest under optimal water+N) |
| Excessive nitrogen fertilization (high N, ample water) | Soluble sugars, TSS | Decrease by ~30–36% (dilution and delayed ripening effect) |
| | Soluble proteins | Among lowest values (excess N leads to poor fruit compositional quality) |
| Severe water stress + excess N (extreme $W_1N_3$ scenario) | Soluble proteins | Strong decrease (40–67% drop) – fruit developmental issues under stress |
| | Palatability (taste) | Noticeably worsened (fruits small, less sweet, potentially more bitter) |
| Organic fertilizer inputs (compost, green manure) | B-vitamin content | Likely increases (not explicitly quantified, but improved soil microbiome could raise B levels) |
| | Soil microbial activity | Enhanced (improved nutrient cycling and possibly vitamin synthesis in soil) |
| Delayed harvest (overripe fruits) | Glycoalkaloids (solasonine, etc.) | Slight increase in content (more bitter compounds accumulate) |
| | Sensory bitterness | Slightly higher (overripe or stressed fruits taste more bitter) |
| High temperature regime + balanced nutrition | Titratable acidity (malic acid) | ~1.5–1.6 g per 100 g (malic acid equiv.) – somewhat higher acidity observed under these conditions |

The available data indicate that excessive inputs, especially water and nitrogen, generally reduce both flavor intensity and nutritional quality through dilution of sugars and proteins. By contrast, moderate and balanced resource supply consistently supports better fruit quality. Cultivar remains a major determinant of vitamin content, since genetic and geographic factors strongly condition this trait and cannot be fully corrected through agronomy alone, although varietal choice is still a key management decision. Organic fertilization appears to have indirect positive effects on vitamin levels as well, even if specific evidence for eggplant is still rather scarce and further studies are needed.

From a practical perspective, growers aiming for tastier eggplants with higher sugar and slightly improved protein should avoid over irrigation during fruit growth and refrain from excessive nitrogen supply. Instead, balanced nutrition combined with mild water limitation favors denser and more palatable fruits. Harvest timing is also essential, because fruits picked at proper maturity maintain low glycoalkaloid levels so that moderate stress does not translate into excessive bitterness. Overall, sugars, acids, proteins and minor vitamins are shaped by cultivation practices in parallel with major quality traits, and a controlled supply of water and nutrients generally provides the best compromise between sensory quality and nutritional value.

## CONCLUSIONS

The research purpose was to demonstrate that the physicochemical and nutritional profile of eggplant fruits is highly sensitive to agricultural management. Core technological interventions such as irrigation control, fertilization regime and general cultivation practices exert strong influences on fruit composition, in many cases comparable to or even exceeding the effects of genetic variability among commercial hybrids. Through careful adjustment of these factors, growers can obtain eggplants with superior firmness, improved sensory quality and enhanced nutritional value, responding directly to the increasing consumer demand for foods with recognized health benefits.

Among all factors, water management proved to be one of the most decisive. Moderate water limitation repeatedly promoted higher dry matter, soluble sugars and antioxidant concentration, whereas excessive irrigation resulted in dilution of these compounds. Controlled water supply leads to firmer and more flavorful fruits while maintaining acceptable yields. From a practical perspective, strategies such as regulated deficit irrigation or the cautious use of slightly saline reclaimed water can stimulate beneficial stress responses that intensify phenolic accumulation and soluble solids. However, these approaches must be applied carefully so that irreversible physiological damage not occurs. In contrast, excessive irrigation, often practiced to maximize fruit size, generally produces watery fruit with weak flavor and reduced nutritional density. These findings argue for a reorientation from yield maximization alone toward water use efficiency directed at quality improvement.

Nutrient management and soil practices are equally important. A balanced fertilization program, particularly when supported by micronutrient supplementation or organic inputs, was shown to significantly enrich eggplant fruits with essential minerals and vitamins. Foliar application of micronutrient containing fertilizers sharply increased fruit iron, zinc and related trace elements, directly enhancing dietary value. Likewise, organic amendments such as compost and green manure, together with beneficial soil microorganisms, improved both mineral uptake and antioxidant potential, in some cases nearly doubling antioxidant activity and markedly raising mineral content. These outcomes illustrate that sustainable soil management can elevate nutritional quality while simultaneously strengthening soil health. Still, the review also highlights the risks of over fertilization. Excess nitrogen favors vegetative growth but often suppresses fruit quality by lowering sugar levels and diluting mineral concentrations. Thus, the optimal strategy remains a balanced nutrient supply that supports productivity without disturbing the plant's metabolic equilibrium.

With respect to individual quality traits, the review confirms that several are highly responsive to agronomic manipulation, whereas others remain largely fixed by genetic programming. Antioxidant compounds, including phenolics, anthocyanins and vitamin C, belong to the first category, showing consistent increases under moderate stress and organic management. This offers practical opportunities for producing eggplant as a functional food through already accessible cultivation techniques. In contrast, lycopene content appeared essentially unresponsive to field management, which helps focus future efforts on enhancing those compounds that can realistically be modified.

The interaction between yield and quality also deserves careful attention. In many evaluated studies, treatments producing maximum yields were not those generating the highest fruit quality. Often, intermediate input levels delivered fruits with clearly superior nutritional and sensory attributes at only a minor cost to yield. This reinforces a central horticultural principle that optimal production is a balance between quantity and quality. Practicaly, eggplant producers dispose of a broad set of agronomic tools capable of substantially upgrading crop value. By adjusting irrigation carefully, refining fertilization through integration of micronutrients and organic matter, avoiding nitrogen excess and selecting appropriate cultivars and harvest timing, it is possible to increase dry matter, enrich fruits in minerals and antioxidants and stabilize desirable flavor traits. These improvements benefit consumers through higher dietary quality and may also strengthen farm profitability through improved market appeal.

Overall, the review emphasizes the need for continued research at the interface between crop management and food quality. Future work should focus on understanding the physiological and molecular mechanisms behind stress induced phenolic accumulation, as well as the specific roles of different biofertilizers in nutrient and vitamin metabolism. Breeding efforts may further exploit these insights by selecting genotypes that respond efficiently to quality oriented cultivation systems. By integrating agronomy with nutritional science, modern agriculture can contribute not only to higher productivity but also to improved public health and environmental sustainability. In short, the goal is not simply to grow more eggplants, but to grow better ones, a direction that aligns well with the priorities of contemporary food systems.

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