



Influence of Cultivar Selection and Horticultural Practices on Tomato Fruit Color, Flavor, and Nutritional Value

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Abstract: Tomato (*Solanum lycopersicum* L.) fruit quality defined by color, flavor, and nutritional value is a multigenic trait influenced by complex genotype-environment (GxE) interactions. Historical breeding has prioritized yield and shelf-life, often at the expense of



sensory and nutritional attributes, leading to a "dilution effect" in commercial cultivars. This review explores the genetic foundations of quality traits, including key loci (*LIN5* and *SICDPK27* for sugars, *FUL1/FUL2* for ripening) and CRISPR-enabled enhancements that increase sugar content without yield penalties. Environmentally sensitive traits like lycopene and volatiles are modulated by precision horticulture, such as moderate deficit irrigation (boosting sugars by up to 86% and carotenoids), temperature management, and biological fertilization. Integrated approaches combining omics-driven breeding with targeted practices offer pathways to stable, high-quality varieties. Future directions emphasize predictive GxE models, long-term soil health studies, and biofortification to meet consumer demands for flavorful, nutrient-rich tomatoes in changing climates.

Keywords: *Tomato quality; Genotype-environment interaction; Cultivar selection; Flavor volatiles; Carotenoids; Deficit irrigation; CRISPR breeding; Nutritional biofortification; Ripening regulation; Precision horticulture*

I. Introduction

The tomato (*Solanum lycopersicum* L.) stands as the most economically valuable fruit or vegetable cultivated worldwide, serving both fresh consumption markets and extensive processing needs (Adunola, et al., 2024). Beyond its culinary importance, tomatoes are recognized as a vital source of health promoting bioactive chemicals, including flavonoids, phenolic acids, carotenoids, and essential vitamins (Ofori et al., 2022). This nutrient profile underscores its critical role in mitigating chronic diseases and improving global health outcomes. Historically, modern breeding programs have been overwhelmingly focused on optimizing commercial viability and yield performance (Mata Nicolás et al., 2020). Since the late 19th century, breeders have prioritized enhancing agronomic traits such as resistance to biotic and abiotic stresses, extended shelf life, and fruit firmness (Adjebeng-Danquah et al., 2019). This sustained selection pressure, driven by the demands of industrialized agriculture and long-distance transport, inadvertently led to genetic divergence. This divergence compromised intrinsic quality characteristics, specifically flavor and nutritional density, a phenomenon often referred to as the dilution

effect (Davis et al., 2009). The physical characteristics prioritized by commerce directly reflect this trade off (Xu et al., 2024). For example, regular, large fruited commercial tomato varieties exhibit firmness 32.75% to 157.82% higher than tasty or cherry tomato varieties. While this increased firmness ensures better handling and merchantability, it often correlates with insufficient flavor and aroma profiles. Conversely, consumer preference often aligns with "tasty" or cherry tomatoes, which command significantly higher sensory scores due to superior flavor and aroma (Tripodi et al., 2021).

The quality of the tomato fruit defined by its color, flavor, and nutritional composition is a highly complex, multigenic trait controlled by intensive metabolic activity (Martina, et al., 2024). Tomato fruit ripening requires simultaneous expression and regulation of more than 1000 genes. These genetic mechanisms govern metabolic pathways responsible for synthesizing crucial compounds such as sugars, organic acids, volatiles, and carotenoids. Crucially, the final quality phenotype is not solely dictated by genetics but is heavily modulated by strong Genotype x Environment (GxE) interactions (Sopory et al., 2025). The knowledge gained through system approaches, integrating genetics and biochemistry, is essential to defining the regulatory hierarchy of genetic control over the entire ripening process. This regulatory knowledge facilitates targeted improvements in specific traits, such as flavor and vitamin content. This review synthesizes current understanding regarding the inherent potential established by cultivar selection and the precision modulation of this potential achieved through targeted horticultural practices, examining their collective influence on the quality triad: color, flavor, and nutritional value (Yuan et al., 2025).

2. Defining the Quality Triad: Biochemical and Molecular Determinants

Flavor perception in tomatoes is primarily driven by the ratio and concentration of soluble solids (sweetness) and organic acids (tartness/acidity). Soluble solids account for roughly 60% of the tomato fruit's dry weight (Naves et al., 2019). The primary soluble sugars in tomato fruit are fructose and glucose, with fructose content often observed to be slightly higher than glucose. Significant genetic variation exists across tomato types regarding sugar accumulation (Rasheed et al., 2017). Analysis of various tomato varieties demonstrates that the average fructose and glucose contents in flavorful "tasty" varieties were substantially higher than in commercial "regular" tomatoes specifically, 65.60% higher for fructose and 126.22% higher for glucose (Chen et al., 2024). This quantitative difference underlines the genetic basis for sweetness, a critical component of consumer satisfaction (Wang et al., 2024). Organic acids, particularly citric acid, confer the essential tartness necessary for balanced flavor (Van Delden et al., 2021). Acidity, measured as titratable acidity (TA), also exhibits variation based on both cultivar and management practices. For instance, a comparison between an unfertilized 'Cristal' cultivar, which registered the lowest acidity (0.4 g citric acid per 100 g fresh weight), and a biologically fertilized 'Siriana' cultivar, which provided the highest value (0.61 g citric acid per 100 g fresh weight), revealed the interplay of genetics and environment. Interestingly, unlike many other quality metrics that are highly environmentally sensitive, TA demonstrates a high degree of genetic stability. Heritability estimates for TA can reach 87%, signifying that this trait is largely controlled by the genotype and is least affected by environmental variables (Gascuel et al., 2017). The harmonious interaction between soluble sugars and organic acids forms the basis of desirable flavor. Consequently, fruit flavor is positively related to the content of soluble solids, fructose, glucose, and citric acid (Osei et al., 2018). Accurate assessment of the sugar acid ratio is paramount, as this comprehensive flavor trait must be systematically quantified to guide breeding efforts toward developing varieties with improved sensory properties (Davis et al., 2009).

Aroma contributes profoundly to the perceived flavor, with volatile organic compounds (VOCs) providing the specific bouquet associated with fresh tomatoes. These VOCs are synthesized through complex metabolic pathways, stemming from precursors such as fatty acids, amino acids (e.g., phenylalanine), and carotenoids (yielding apocarotenoids) (Wu et al., 2020). Sensory analysis confirms the relationship between these compounds and flavors. The flavor of tomatoes is shown to be positively correlated with specific components, including the apocarotenoid beta ionone (Xu et al., 2024). Different tomato classes possess distinct volatile profiles; cherry tomatoes, for example, are known to have 10 characteristic aroma components, dominated by floral and woody aroma types, which significantly contribute to their high sensory scores (Mata Nicolás et al., 2020). Molecular studies have successfully pinpointed the genetic factors governing these aroma profiles. A quantitative trait locus (QTL) identified on chromosome 4 affects the levels of phenylalanine derived volatiles (PHEVs), such as 2 phenylethanol (Adunola, et al., 2024). Fruits contrasting for this locus display significant differences in the perception of fruity and rose hips like aroma. Fine mapping of this QTL led to the identification of *FLORAL4* as a candidate gene (Tripodi et al., 2021), subsequently confirmed via gene editing (CRISPR Cas9) to be the key factor regulating PHEV accumulation (Martina, et al., 2024). The complexity of manipulating aroma is amplified by the fact that the final content of any given volatile is determined by a kinetic balance between synthesis, reversible modification, and catabolism (Sopory et al., 2025). For instance, certain tomato varieties have very low concentrations of volatile esters because a ripening specific esterase actively cleaves them to their corresponding free alcohols. This mechanism demonstrates that success in molecular breeding requires not only enhancing biosynthetic pathways but potentially suppressing catabolic pathways to prevent the degradation of desirable flavor compounds. Therefore, systematic capture and accurate assessment of all flavor traits not just sweetness and acidity is essential for developing improved varieties (Yuan et al.,

2025). Fruit color, a key visual quality metric, is determined by the accumulation of pigments, primarily the carotenoids lycopene (red) and beta carotene (orange/yellow). These compounds are also potent antioxidants, linking color directly to nutritional value (Ofori et al., 2022).

Unlike titratable acidity, lycopene exhibits low heritability. This physiological reality confirms that lycopene accumulation is highly sensitive and largely influenced by the growing environment and extrinsic factors (Naves et al., 2019). Light is a crucial environmental regulator, positively impacting fruit pigmentation by upregulating gene expression in the carotenoid biosynthesis pathway, particularly phytoene synthase (Rasheed et al., 2017). This sensitivity means that while the cultivar establishes the potential for color development, environmental conditions determine the degree to which this potential is realized (Van Delden et al., 2021).

Tomatoes are recognized as a nutrient dense food, containing various health promoting phytochemicals such as flavonoids, phenolic acids (chlorogenic acid), and vitamins (C and E). These compounds confer antioxidant, anti-inflammatory, and cardioprotective properties (Chaudhary et al., 2018). The occurrence of these phytochemicals is a product of genetic factors, environmental conditions, and postharvest handling. Evidence confirms that cultivar selection provides the foundational basis for high nutritional content. For example, local cultivars, such as 'Siriana', are inherently rich in specific nutritional compounds, like rutin, indicating a strong genetic ability to accumulate certain metabolites regardless of the applied fertilization regime. Understanding the genetic and molecular mechanisms governing the biosynthesis of these compounds is vital for developing biofortified tomato varieties (Xu et al., 2024).

Table 2.I Key Quality Parameters and Underlying Biochemical Constituents in Tomato Fruit

Quality Attribute	Key Compounds/Constituents	Primary Function/Sensory Impact	Primary Regulatory Factor	Relevant Genetic Loci/Pathways
Flavor (Sweetness)	Fructose, Glucose (Total Soluble Solids, TSS)	Palatability, Taste intensity, Osmotic potential	Primarily Genetic, Modulated by MD Stress	<i>LIN5</i> (Li et al., 2024), <i>SSC11.1</i> (<i>SICDPK27/26</i>) (Lin et al., 2024)
Flavor (Acidity)	Citric Acid, Malic Acid, Ascorbic Acid (TA)	Balance, Tartness, Freshness, Stress response	Highly Genetic (High Heritability)	Carboxylic Acid Metabolism, GxE Low (Ristea et al., 2024; Hurtado Lugo et al., 2012)
Aroma/Bouquet	Volatiles (PHEVs, Apocarotenoids, Esters)	Aromatic complexity (Floral, Fruity)	Genetic (Specific TFs), Modulated by MD Stress	<i>FLORAL4</i> (Luo et al., 2020), ABA pathways, Carotenoid Cleavage (Xu et al., 2023;

				Gascuel et al., 2017; Wu et al., 2018)
Color (Red/Orange)	Lycopene, β Carotene	Red Pigmentation, Potent Antioxidant	Highly Environmental (Low Heritability), Light, Temperature	Phytoene Synthase, Carotenoid Biosynthesis (Hurtado Lugo et al., 2012; Deng et al., 2020)
Nutritional Value	Rutin, Polyphenols, Vitamins C & E	Antioxidant Capacity, Health Promotion	Cultivar Specificity, Fertilization Type	Flavonoid/Phenolic Biosynthesis Pathways (Ofori et al., 2025; Ristea et al., 2024)

3. Cultivar Selection and the Genetic Architecture of Quality

Improving flavor requires precise manipulation of the genes that control the accumulation and partitioning of sugars. Fructose and glucose accumulation are regulated by key loci, providing specific molecular targets for quality enhancement (Wu et al., 2020). One critical regulator is *LIN5*, a key gene encoding Cell Wall Invertase (CWIN),

which governs the accumulation of sugars, particularly fructose, in tomato fruits. Further genetic analysis identified *SSCII.1* as another major quantitative trait locus (QTL) associated with high glucose and fructose contents (Adunola, et al., 2024). Research on this locus revealed a 12-base pair (bp) insertion in the promoter of *SICDPK27*, which is strongly associated with the desired high sugar allele (Mata Nicolás et al., 2020). The identification of these molecular targets offers sophisticated strategies to overcome the historical antagonism between fruit size/yield and flavor. Specifically, genetic intervention targeting *SICDPK27* and its paralogue *SICDPK26* demonstrated the potential to engineer superior flavor (Adjebeng-Danquah et al., 2019). Genome editing of these genes successfully increased glucose and fructose contents by up to 30% (Triodi et al., 2021). Crucially, this enhancement was achieved without any adverse consequences on fruit weight or yield. This molecular approach provides a means to bypass the physiological limitations imposed by metabolite concentration (the dilution effect), enabling the development of large, fruited cultivars that are also inherently sweeter, thus resolving a long-standing conflict in tomato breeding (Martina, et al., 2024). The complex process of fruit ripening, which dictates the final accumulation of color and many flavor volatiles, is governed by master transcriptional regulators (Sopory et al., 2025). Key among these is the MADS box transcription factors (TFs) *FUL1* and *FUL2*, which function as central regulators of tomato fruit ripening by controlling the expression of numerous downstream targets (Yuan et al., 2025).

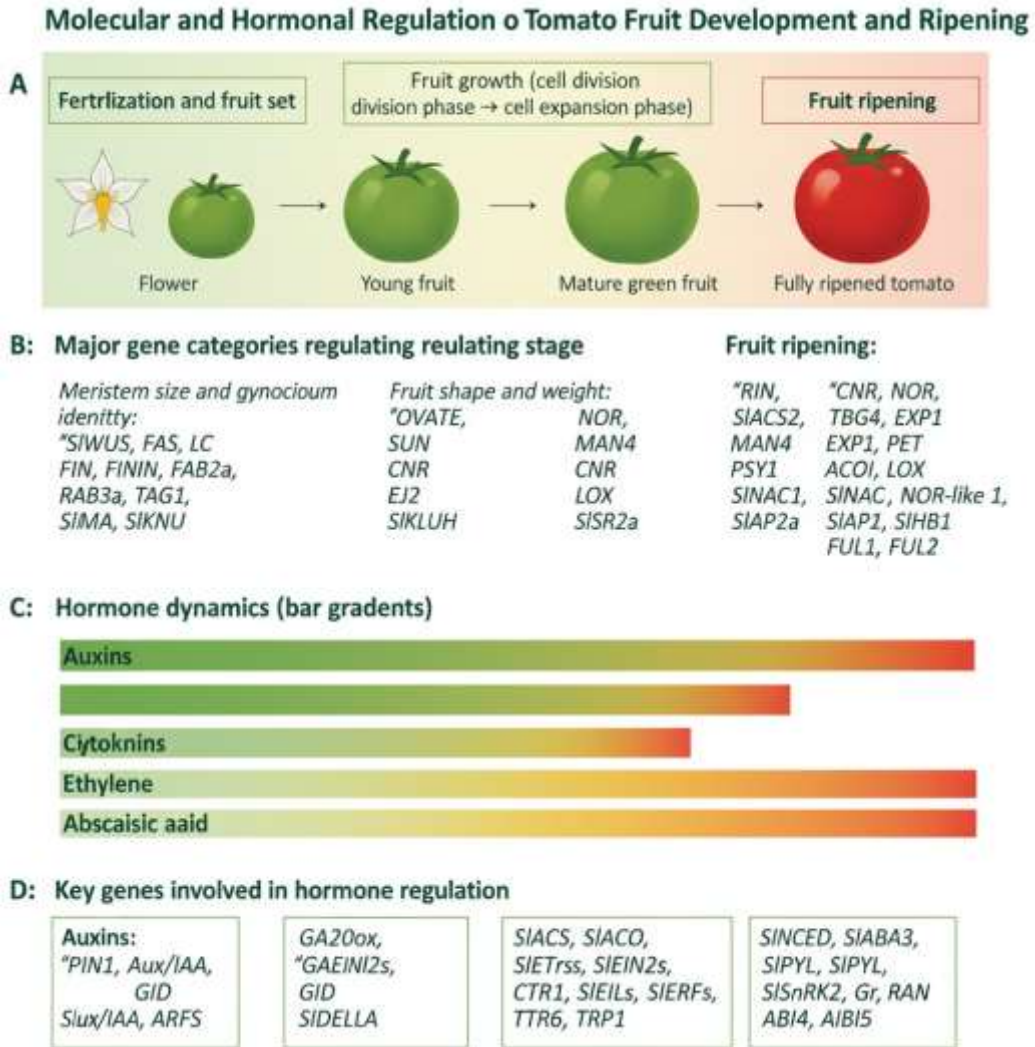
Recent studies indicate that these regulatory mechanisms are themselves subject to epigenetic control, illustrating how environmental conditions can influence the genetic potential for quality. The DNA demethylase gene *DML2* is essential for normal ripening. Disruption of *DML2* leads to genome wide DNA hypermethylation, which subsequently impairs fruit ripening (Rasheed et al., 2017). The mechanism involves the inhibition of *RIN* and *FUL1* expression and, critically, blockage of *RIN* binding to a subset of its

target genes *in vivo*. Loss of binding RIN correlates strongly with an increase in DNA methylation within 100 bp of the binding site (Naves et al., 2019).

This molecular regulatory axis suggests that environmental factors that influence the plant's epigenetic status during early fruit development can establish a biological "memory" that dictates the subsequent efficiency and quality of the ripening process (Wang et al., 2024). Since the RIN and FUL1 TFs ultimately control the synthesis of color and flavor compounds, the *DML2*RIN/*FUL1* pathway acts as a crucial molecular integrator, translating long term environmental history (such as stress conditions or nutritional availability) into the final expressed fruit quality phenotype (Van Delden et al., 2021). Breeding objectives must now extend beyond maximizing yield potential to include quality and stability across varied production systems. The negative correlation between yield and nutrient density, leading to the dilution effect, remains a central challenge (Davis, 2009). Beyond the yield quality balance, cultivars must also demonstrate optimal GxE stability. Significant variability in yield performance across diverse environmental conditions is observed, and this variability is quantified by tools like the AMMI (Additive Main Effects and Multiplicative Interaction) model. Analysis shows that environmental factors account for 47.5% of yield variability, genotypes account for 43.3%, and the Genotype x Environment Interaction (GEI) accounts for 8.2% (Mullualem et al., 2024). Identification of stability parameters is crucial for deployment strategy. Genotypes such as Arka Meghali and NDF 9 exhibit optimal stability and high yield performance across diverse environments, making them ideal candidates for resilient, sustained production in variable climates. Conversely, genotypes like Roma and CO 3 may possess high yield potential under favorable conditions, but they display greater instability. (Stella et al., 2023). This distinction dictates cultivar deployment: stable genotypes are suitable for broader cultivation niches, while unstable, high potential genotypes are best utilized in environments where intensive management practices allow

for tight control over environmental factors, maximizing the potential return on investment (Wu et al., 2020).

Figure 3.I Molecular, Hormonal, and Genetic Regulation of Tomato Fruit Development and Ripening Phases



4. Horticultural Practices as Precision Modulators of Quality (GxE Interaction)

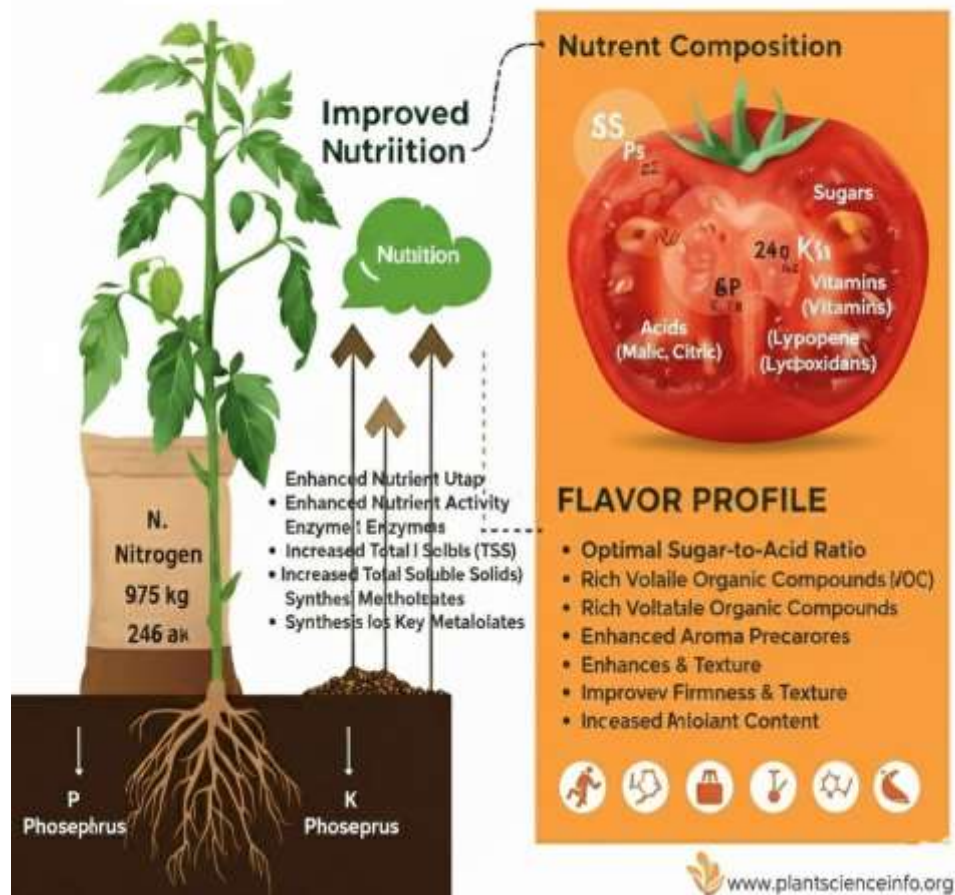
Horticultural practices serve as powerful modulators of the genetically encoded quality potential of a tomato cultivar (Xu et al., 2024). By inducing specific, controlled abiotic stresses, producers can redirect the plant's metabolism toward secondary metabolite

production, maximizing fruit quality (Adunola, et al., 2024). One of the most effective and extensively researched methods for quality enhancement is the strategic application of Moderate Water Deficit (MD), commonly achieved through regulated deficit irrigation (DI) (Tripodi et al., 2021). Moderate water deficit treatment (e.g., irrigated every 6 days, corresponding to 60% of maximum field moisture capacity, FMC) significantly improves both nutritional and flavor quality components during the ripening process, without negatively impacting fruit size or color development (Raffaelli et al., 2025). The metabolic shift induced by MD results in substantial enhancement of flavor components. Total soluble sugar content was significantly increased by 48.69% compared to control conditions at the ripening stage. Specifically, glucose levels showed a dramatic increase of 86.70%, and fructose increased by 19.83% (Martina, et al., 2024). The resulting sugar acid ratio was improved by 43.09% (Sopory et al., 2025). MD treatment biofortified the fruit with carotenoids. β carotene content increased by 63.89%, lycopene by 11.85%, and lutein by 12.28%. Furthermore, MD enhanced aroma characteristics, leading to improved flavor quality, detectable as increased response values across sensors of an electronic nose (Gascuel et al., 2017). The success of MD strategies lies in its ability to act as a metabolic switch. Water stress triggers the accumulation of the phytohormone abscisic acid (ABA), which plays a key role in quality determination (Wu et al., 2020). ABA promotes the biosynthesis of specific flavor compounds, including fatty acid derived volatiles, volatile apocarotenoids, and branched chain volatiles. Simultaneously, ABA boosts lycopene and β carotene accumulation by upregulating the genes encoding carotenoid biosynthetic enzymes (Naves et al., 2019). The improved color under water stress is also linked to an increased content of ethylene in the fruit. The central functional mechanism is the reallocation of resources: the plant, under mild osmotic stress, prioritizes the synthesis of osmotically active compounds (sugars) and stress protective secondary metabolites (carotenoids) in the fruit, concentrating these quality attributes. This strategy effectively

promotes high quality cultivation while conserving water resources (Rasheed et al., 2017). Temperature is a major environmental determinant of tomato quality, often exerting a significant GxE effect. Reproductive organs are generally more sensitive to heat stress than vegetative parts. Temperatures of 35 degrees C or higher impose severe heat stress, causing physiological and biochemical damage that results in reduced yield, decreased fruit set, and smaller, lower quality fruits (Van Delden et al., 2021). High temperature stress significantly impacts key quality parameters, notably reducing lycopene content. This reduction is physiologically explained by the temperature sensitivity of key enzymes in the carotenoid biosynthetic pathway, particularly phytoene synthase (Osei et al., 2018). High temperatures disrupt metabolic stability, affecting photosynthesis, changing membrane fluidity, and causing oxidative stress. Furthermore, heat stress disrupts sink source associations, inhibiting root growth, impairing root nutrient uptake, and disrupting sugar metabolism and proline transport in reproductive tissues. However, the response is complex. High temperature conditions can lead to increased Titratable Acidity (TA), Total Soluble Solids (TSS), and ascorbic acid content in the fruits that do mature, even as lycopene decreases (Davis et al., 2009).

Figure 4.I Horticultural Practices as Precision Modulators of Quality (GxE Interaction)

Balanced Fertilization Improved Tomato Quality



The impact of temperature is highly cultivar dependent. Experiments comparing distinct tomato types demonstrated this strong interaction while warmer temperatures raised the level of lycopene in the Ros Cultivar, the same climatic variation had no effect on the Gustavo Cultivar (Astija et al., 2023). This divergence necessitates the identification of heat tolerant genotypes capable of maintaining yield and nutritional quality parameters under elevated temperatures for future breeding programs. The management of nutrient delivery and soil biology profoundly influences the synthesis of health promoting compounds (Adjebeng-Danquah et al., 2019). Tomato fruits are often richer in quality microelement contents under certain fertilization regimes. Research

indicates that tomato cultivars react positively to microbiological fertilization when compared to chemical fertilization, resulting in fruits with higher contents of total polyphenolic compounds, lycopene, and β carotene. This suggests that sustainable management practices support the plant's secondary metabolic pathways (Dumont et al., 2020). The superior quality achieved under microbiological fertilization implies that a healthy soil microbe system provides enhanced bioavailability of trace elements and complex mineral compounds necessary as cofactors for the biosynthesis of antioxidants. This linkage demonstrates that improving soil health is a direct pathway to improving human health outcomes through biofortified produce. The balance of mineral nutrition is critical for growth and fruit composition (Martina, et al., 2024). Variations in nutrient medium composition, particularly the concentrations of calcium and nitrate, have been shown to produce the greatest differences in plant growth and fruitfulness over wider concentration ranges compared to other elements. Greenhouse cultivation, which protects plants from external stressors and pesticides, often results in fruits possessing greater nutritional element contents due to the maintenance of a controlled, nutritionally rich environment (Adunola, et al., 2024).

Figure 4.I Horticultural Practices as Precision Modulators of Quality (GxE Interaction)

Table 4.I Mechanistic Summary of Horticultural Practice Modulation on Tomato Quality

Horticultural Practice	Effect on Quality Component	Quantitative Example (MD)	Underlying Physiological/Molecular Mechanism	Relevant Cultivar Interaction
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Moderate Deficit Irrigation (MD)	Significantly Increase Sugars, Carotenoids, Volatiles; Increase Sugar Acid Ratio.	Glucose +86.70%, β Carotene +63.89% (Jiang et al., 2024)	Osmotic stress; Upregulation of ABA/Ethylene pathways promoting metabolite concentration and synthesis (Mou et al., 2015; Barickman et al., 2016; Duan et al., 2021)	Efficacy depends on genetic drought tolerance of the cultivar (Saidi et al., 2023)
High Temperature Stress (35 C or higher)	Decrease Lycopene synthesis, Decrease Fruit Set/Yield; Increase TSS/TA in some cases.	Lycopene content decreased (Ahmed et al., 2020)	Inhibition of temperature sensitive enzymes (carotenoid pathway); Disruption of root nutrient uptake and pollen function (Kumar et al., 2022; Giri et al., 2017; Larkindale et al., 2005; Assel et al., 2023)	Highly Genotype Dependent : Differentia l lycopene response between cultivars (Sharma & Kumar, 2017)
Biological/Organic Fertilization	Increase Antioxidants , Phenolic	Enhanced antioxidant contents	Improved soil health; enhanced microelement bioavailability;	Local cultivars ('Siriana')

	compounds (Rutin), Microelement content.	compared to chemical fertilization (Ristea et al., 2024)	Stimulation of plant defense/secondary metabolite production (Ofori et al., 2025; Ristea et al., 2024)	display strong inherent adaptability and positive response (Ristea et al., 2024)
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5. Integrated Strategies and Future Outlook (Breeding 5.0)

The comprehensive analysis of tomato quality underscores that optimal results cannot be achieved through the manipulation of a single factor (Tripodi et al., 2021). Future agricultural success relies on integrated systems management that strategically combines superior genetics with sophisticated, targeted horticultural practices. This approach must move beyond conventional, input focused nutrient management toward optimizing the entire soil plant system (Davis et al., 2009). Achieving superior quality requires a fundamental shift in managing tradeoffs. The goal is to identify genotypes that maximize the combined metrics of productivity, resilience, and quality. High performing genotypes must be evaluated rigorously across multiple environments to ensure their stable and reliable production capability. This allows breeders to effectively match genotype stability (eNDF 9) to specific cultivation niches (intensive control versus marginal environments) (Yuan et al., 2025). The complexity of multigenic traits necessitates the application of advanced systems biology tools. 'Omics' approaches, including metabolomics, transcriptomics, and proteomics, are foundational for elucidating the regulatory networks

and identifying key metabolic steps governing quality (Ofori et al., 2022). The sequencing of the high-quality tomato genome has accelerated the application of these strategies. These data facilitate network analyses, such as gene co expression modeling, which reveals previously unknown cellular regulatory networks linked to taste, quality, and stress resistance (Xu et al., 2024). Modern molecular breeding technologies, particularly genome editing systems like CRISPR Cas9, provide the necessary precision for implementing these findings (Naves et al., 2019). The successful, targeted engineering of increased glucose and fructose concentrations via *SICDPK27/26* editing without compromising yield serves as a powerful paradigm for future quality improvement. This demonstrates that genomic enhancement strategies can be integrated seamlessly into breeding programs to meet the evolving demands for sustainable, high quality food production (Rasheed et al., 2017). Despite significant progress in genetic and metabolic understanding, several critical research gaps remain that must be addressed to transition toward truly precision horticulture

First, a crucial lacuna exists in long term comparative studies designed to rigorously link diverse soil management practices (e.g., organic versus conventional systems) to specific changes in crop nutritive value (Davis, 2009). This research is necessary to ultimately define the relationship between agricultural practices and human health outcomes (Mata Nicolás et al., 2020). Second, the complexity of flavor mandates a more sophisticated, standardized approach to assessment. Accurate and systematic capture of complex flavor traits, particularly the full spectrum of volatile compounds, remains a prerequisite for effective flavor focused breeding programs. Finally, future research must focus on developing sophisticated predictive GxE models. These models must incorporate cultivar specific physiological and molecular responses to environmental variables such as specific MD regimes or localized heat spikes (Van Delden et al., 2021) to enable true precision agriculture. By quantifying the divergent GxE interactions, researchers can

provide actionable, genotype specific recommendations for maximizing quality and tolerance to stresses like drought. The quality of tomato fruit is fundamentally defined by the intricate interaction between the cultivar's genomic potential and the environmental conditions under which it is cultivated (Gascuel et al., 2017). Genetic advancements have identified core loci controlling sweetness (*LIN5*, *SICDPK27/26*) and ripening (*RIN*, *FUL1*), offering molecular tools to decouple yield maximization from quality degradation. Concurrently, precision horticultural strategies, such as moderate deficit irrigation, function as powerful environmental levers, maximizing the expression of environmentally plastic quality traits like lycopene and glucose accumulation by initiating beneficial stress induced metabolic shifts. (Naves et al., 2019). The future of tomato breeding and production lies in synthesizing these domains. By leveraging high resolution genomic data and applying targeted, environmentally informed management protocols, the agricultural sector can successfully engineer high yielding, resilient, and demonstrably nutritionally superior tomato varieties, satisfying both the economic necessities of global food production and the escalating consumer demand for enhanced flavor and health benefits (Ofori et al., 2022).

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