Print ISSN : 0972-8813
e-ISSN : 2582-2780

[Vol. 21(2) May-August 2023]

Pantnagar Journal of Research

(Formerly International Journal of Basic and Applied Agricultural Research ISSN : 2349-8765)

G.B. Pant University of Agriculture & Technology, Pantnagar

ADVISORYBOARD

Patron
Dr. Manmohan Singh Chauhan, Vice-Chancellor, G.B. Pant University of Agriculture and Technology, Pantnagar, India
Members
Dr. A.S. Nain, Ph.D., Director Research, G.B. Pant University of Agri. & Tech., Pantnagar, India
Dr. J.P. Jaiswal, Ph.D., Director, Extension Education, G.B. Pant University of Agri. & Tech., Pantnagar, India
Dr. S.K. Kashyap, Ph.D., Dean, College of Agriculture, G.B. Pant University of Agri. & Tech., Pantnagar, India
Dr. S.P. Singh, Ph.D., Dean, College of Veterinary & Animal Sciences, G.B. Pant University of Agri. & Tech., Pantnagar, India
Dr. K.P. Raverkar, Ph.D., Dean, College of Post Graduate Studies, G.B. Pant University of Agri. & Tech., Pantnagar, India
Dr. Sandeep Arora, Ph.D., Dean, College of Basic Sciences & Humanities, G.B. Pant University of Agri. & Tech., Pantnagar, India
Dr. Alaknanda Ashok, Ph.D., Dean, College of Technology, G.B. Pant University of Agri. & Tech., Pantnagar, India
Dr. Alka Goel, Ph.D., Dean, College of Home Science, G.B. Pant University of Agri. & Tech., Pantnagar, India
Dr. Malobica Das Trakroo,Ph.D., Dean, College of Fisheries, G.B. Pant University of Agri. & Tech., Pantnagar, India
Dr. R.S. Jadoun,Ph.D., Dean, College of Agribusiness Management, G.B. Pant University of Agri. & Tech., Pantnagar, India

EDITORIALBOARD

Members
Prof. A.K. Misra, Ph.D., Chairman, Agricultural Scientists Recruitment Board, Krishi Anusandhan Bhavan I, New Delhi, India
Dr. Anand Shukla, Director, Reefberry Foodex Pvt. Ltd., Veraval, Gujarat, India
Dr. Anil Kumar, Ph.D., Director, Education, Rani Lakshmi Bai Central Agricultural University, Jhansi, India
Dr. Ashok K. Mishra, Ph.D., Kemper and Ethel Marley Foundation Chair, W P Carey Business School, Arizona State University, U.S.A
Dr. B.B. Singh, Ph.D., Visiting Professor and Senior Fellow, Dept. of Soil and Crop Sciences and Borlaug Institute for International Agriculture, Texas A&M University, U.S.A.
Prof. Binod Kumar Kanaujia, Ph.D., Professor, School of Computational and Integrative Sciences, Jawahar Lal Nehru University, New Delhi, India
Dr. D. Ratna Kumari, Ph.D., Associate Dean, College of Community / Home Science, PJTSAU, Hyderabad, India
Dr. Deepak Pant, Ph.D., Separation and Conversion Technology, Flemish Institute for Technological Research (VITO), Belgium
Dr. Desirazu N. Rao, Ph.D., Professor, Department of Biochemistry, Indian Institute of Science, Bangalore, India
Dr. G.K. Garg, Ph.D., Dean (Retired), College of Basic Sciences & Humanities, G.B. Pant University of Agric. & Tech., Pantnagar, India
Dr. Humnath Bhandari, Ph.D., IRRI Representative for Bangladesh, Agricultural Economist, Agrifood Policy Platform, Philippines
Dr. Indu S Sawant, Ph.D., Director, ICAR - National Research Centre for Grapes, Pune, India
Dr. Kuldeep Singh, Ph.D., Director, ICAR - National Bureau of Plant Genetic Resources, New Delhi, India
Dr. M.P. Pandey, Ph.D., Ex. Vice Chancellor, BAU, Ranchi & IGKV, Raipur and Director General, IAT, Allahabad, India
Dr. Martin Mortimer, Ph.D., Professor, The Centre of Excellence for Sustainable Food Systems, University of Liverpool, United Kingdom
Dr. Muneshwar Singh, Ph.D., Project Coordinator AICRP- LTFE, ICAR - Indian Institute of Soil Science, Bhopal, India
Prof. Omkar, Ph.D., Professor, Department of Zoology, University of Lucknow, India
Dr. P.C. Srivastav, Ph.D., Professor, Department of Soil Science, G.B. Pant University of Agriculture and Technology, Pantnagar, India
Dr. Prashant Srivastava, Ph.D., Cooperative Research Centre for Contamination Assessment and Remediation of the Environment, University of South Australia, Australia
Dr. Puneet Srivastava, Ph.D., Director, Water Resources Center, Butler-Cunningham Eminent Scholar, Professor, Biosystems Engineering, Auburn University, U.S.A.
Dr. R.C. Chaudhary, Ph.D., Chairman, Participatory Rural Development Foundation, Gorakhpur, India
Dr. R.K. Singh, Ph.D., Director & Vice Chancellor, ICAR-Indian Veterinary Research Institute, Izatnagar, U.P., India
Prof. Ramesh Kanwar, Ph.D., Charles F. Curtiss Distinguished Professor of Water Resources Engineering, Iowa State University, U.S.A.
Dr. S.N. Maurya, Ph.D., Professor (Retired), Department of Gynecology & Obstetrics, G.B. Pant University of Agric. & Tech., Pantnagar, India
Dr. Sham S. Goyal, Ph.D., Professor (Retired), Faculty of Agriculture and Environmental Sciences, University of California, Davis, U.S.A.
Prof. Umesh Varshney, Ph.D., Professor, Department of Microbiology and Cell Biology, Indian Institute of Science, Bangalore, India
Prof. V.D. Sharma, Ph.D., Dean Academics, SAI Group of Institutions, Dehradun, India
Dr. V.K. Singh, Ph.D., Head, Division of Agronomy, ICAR-Indian Agricultural Research Institute, New Delhi, India
Dr. Vijay P. Singh, Ph.D., Distinguished Professor, Caroline and William N. Lehrer Distinguished Chair in Water Engineering, Department of Biological Agricultural Engineering, Texas A& M University, U.S.A.
Dr. Vinay Mehrotra, Ph.D., President, Vinlax Canada Inc., Canada

Editor-in-Chief
Dr. Manoranjan Dutta, Head Crop Improvement Division (Retd.), National Bureau of Plant Genetic Resources, New Delhi, India

Managing Editor
Dr. S.N. Tiwari, Ph.D., Professor, Department of Entomology, G.B. Pant University of Agriculture and Technology, Pantnagar, India

Assistant Managing Editor
Dr. Jyotsna Yadav, Ph.D., Research Editor, Directorate of Research, G.B. Pant University of Agriculture and Technology, Pantnagar, India

Technical Manager
Dr. S.D. Samantray, Ph.D., Professor, Department of Computer Science and Engineering, G.B. Pant University of Agriculture and Technology, Pantnagar, India

PANTNAGAR JOURNAL OF RESEARCH

Vol. 21(2) May-August, 2023

CONTENTS

A Review-Tomato quality as influenced by preharvest factors

H.N. PRASAD, BANKEY LAL[2*], SUNITA BHANDARI[2], RAKESH BHARGAVA[2], VIPUL PRATAP SINGH[3] and ANSHU KAMBOJ[3]

[1]*College of Agriculture, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur- 208 002 (Uttar Pradesh),* [2]*School of Agriculture, RNB Global University Bikaner-334601 (Rajasthan),* [3]*Departmentof Agriculture, School of Agricultural Sciences and Technology, RIMT University, Mandi Gobindgarh (Punjab)*

[*]*Corresponding author e-mail Id: bankeylal71@gmail.com*

ABSTRACT: The quality of tomatoes is a complex feature that involves numerous plant and fruit-level processes and is influenced by interactions between social, cultural, and environmental factors. This study focuses on how pre-harvest factors affect tomato quality, and quality is determined from the standpoint of the customer, *i.e.,* by fruit size or fresh mass, colour, taste, flavour, texture, and health value. The research was conducted; Department of Vegetable Science and quality analysis is taken by Biocontrol laboratory of Chandra Shekhar Azad University of Agriculture and Technology Kanpur, (U.P.). The tomato is the second fruit consumed globally and a model plant for biologists. Physiologists and geneticists have studied the mechanisms underlying tomato fruit quality in great detail, and reactions to climatic and cultural practices have been well documented. However, in a time of worldwide change, managing and enhancing fruit quality will depend on our ability to combine knowledge and foresee interactions among genotype, environment, and cultural practices. We might benefit from the recent advancement of process-based models of fruit quality to address this difficult problem. Here, a number of tomato growth and quality models are explored, along with their possible use in creating ideotypes—conceptual plants that are anticipated to function in particular settings.

Key words: Environment, fleshy fruit quality, genetic, Process-based model, *Solanum lycopersicum*

While an overall rise in agricultural output is necessary to feed the growing population, crop quality improvement is a difficult and pressing issue since consumer behavior has recently begun to have a greater impact on the demand for premium quality. One issue with horticulture crops is that there isn't a single definition of quality that incorporates all the many factors. Another issue is that there might be a disconnect between the quality that is instrumentally tested at harvest and the quality that consumers perceive after purchase and storage (Kyriacou and Rouphael, 2017). According to FAO Stat (2015), the tomato (*Solanum Lycopersicum* L.) is the second-most significant vegetable crop after potatoes. It is a model species for biologists, particularly those researching the quality and ripening of fleshy fruits. Numerous characteristics make up quality and stakeholders determine which characteristics are most crucial. Organoleptic quality is based on physical (texture or firmness) and biochemical qualities (mostly the contents in sugars, acids, and volatile chemicals), which determine the overall flavour. Commercial quality is primarily dependent on outward appeal (*e.g.,* colour, form and size), firmness, and shelf life. While the sanitary quality is determined by the absence of pesticide residues or other unhealthy compounds like allergens, mycotoxins, antibiotics, environmental persistent pollutants, and pathogenic microorganisms, the health benefits depend on the composition in vitamins and phytonutrients (lycopene, -carotene, ascorbate, and polyphenol), as well as minerals (potassium, calcium, phosphorus, magnesium).Currently, fruit quality is assessed at harvest; however, it is elaborated during fruit development as a result of numerous interconnected developmental processes and metabolic activities that are controlled by the fruit's ontogenetic programme and environmental factors (Ho, 2003).Fresh farmed tomatoes have very changeable principal characteristics at harvest: fruit fresh weight can vary by 200 times, while contents of dry matter, sugar, acid, or ascorbate might differ by 4 to 5 times. Despite advances in our understanding of the metabolic processes and molecular controls affecting plants and fruits, improving fruit quality and balancing yield and quality remain difficult tasks. Breeding has traditionally prioritized production and fruit shelf life (Bai and Lindhout, 2007), and in recent decades, the productivity of greenhouse tomatoes has doubled as a result of cultivar advancements, climatic control, and crop management (de Gelder *et al.*, 2012).

The identification of the processes underlying each trait is the first step towards understanding and managing fruit quality variations in relation to genetic and environmental conditions; the development of an integrative approach will then help to disentangle the complex network of interactions among these processes in response to external or internal stimuli (Martre *et al.*, 2011).Because of this, fruit ecophysiologists have made it a priority to understand fruit quality in relation to Genetic X Environmental X management (Genetic x Environmental x Management) interactions and to examine correlations between yield and quality traits in order to create novel crop management strategies. In this regard, process-based models of fruit quality, which are mathematical representations of the key processes defining fruit functioning, have shown to be effective tools for defining pertinent policies and designing plant ideotypes adapted to particular environments or crop systems, i.e., genotypes capable of maintaining yield and producing high-quality fruits (Genard *et al.*, 2007).

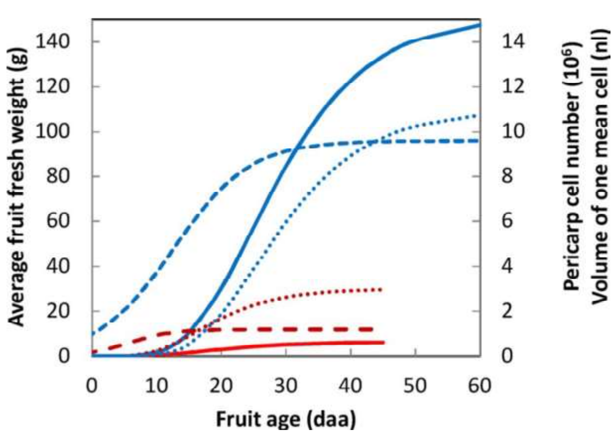

Fig. 1: Dynamics of fruit fresh weight (solid lines), pericarp cell number (dashed lines) and mean cell volume (dotted lines) of cherry (red) and large-fruited (blue) tomatoes. The curves were fitted on several sets of experimental data (adapted from Bertin *et al.*, 2009).

This review aims to offer fresh insight into the evolution of tomato fruit quality with an emphasis on organoleptic quality and nutritional value. We begin by outlining the main characteristics of quality as well as the underlying mechanisms from fruit setting to ripening, or during the preharvest phase. The consequences of environmental and genetic factors involved in quality variations are discussed in the second and third portions.

Tomato quality characteristics

Fruit size and shape

Fruit size and shape are two important quality characteristics that influence consumer purchase. Fruit shape has undergone significant genetic diversification during breeding and is primarily governed by genetics. Fruit size substantially varies in response to GxExM (Genetic x Environmental x Management) interactions, while fruit shape is less dependent on the environment. The development of pericarp tissue, which results in an increase in fruit volume, is accomplished through two crucial processes (Ho, 1996): the production of new cells, which stops about 10–25 days after anthesis (daa), and cell growth and expansion, which typically continue until the start of maturation (Fig. 1) and may be constrained by the extensibility of the epidermis (Thompson, 2001).Even though the majority of the fruit's volume gain occurs during the expansion phase, numerous studies have demonstrated that the final size is highly correlated with the number of cells (Bertin *et al.*, 2003). Endoreduplication, sometimes referred to as the change from a complete to an imperfect mitotic cycle without mitosis, is closely linked to the stop of cell division and a rise in cell size. According to Bertin *et al.* (2007), incomplete cell cycles in cherry tomatoes and large-fruit cultivars result in an increase in cell DNA content up to 256C or even 512C (equivalent to 8 or 9 endocycles, respectively), which has been linked to cell size (Chevalier *et al.*, 2011). Water inflow through xylem and phloem, water outflow through transpiration, and even water backflow to the plant through xylem all work together to balance cell expansion.

Fruit texture

Fruits that are destined for the fresh market or for industrial processing may have a different end-use value depending on their texture. When it comes to tomatoes, texture has a significant impact on consumer acceptance and purchase decisions (Causse *et al.*, 2010). Additionally, it interferes with the perception of flavour and scent (Causse *et al.*, 2003), and it considerably affects the shelf-life and transportability of fruit. Texture includes a number of properties, including firmness, meltiness, mealiness, juiciness, or crunchiness (Harker *et al.*, 2002). These properties can be accessed through sensory analysis and can also be measured objectively using mechanical techniques, near-infrared spectroscopy, or hyper-spectral imaging techniques reviewed by Chen and Opara (2013).

Complex mechanisms underlie the texture of fruit. The molecular and biochemical mechanisms that cause fruit to soften during ripening have received a great deal of attention. These mechanisms include the reduction of intercellular adhesion, depolymerization and solubilization of hemicelluloses and pectic cell wall polysaccharides, and the decline in fruit firmness that occurs at the same time as the middle lamella dissolves (Toivonen and Brummell, 2008). Several cell wall-degrading enzymes, such as hydrolases, transglucosylases, lyases, and other wall-loosening proteins like expansins, are also up-regulated at the same time. However, according to some researchers (Chaib *et al.*, 2007), the texture of the fruit may already be regulated by a number of mechanisms.

Fruit aroma and flavor

Complex interactions between sugars, acids, and volatile aromatic molecules produce flavour. As with other fleshy fruits, tomatoes have a wide range of volatile organic compounds (VOCs) that they produce. Impart a characteristic aroma and influence the taste perception and preferences of consumers (Baldwin *et al.*, 2008; Tieman *et al.*, 2012). Only 30 of the more than 400 VOCs found in fresh tomatoes have been found to be present in amounts more than one ppb and to significantly contribute to the detectable flavour (Buttery, 1993).While some of these volatiles transmit positive attributes, others have negative connotations. The locular gel contributes less to the total synthesis of VOCs during ripening than does the rest of the fruit (Maul *et al.*, 1998). They consist of nitrogen, sulphur, and halogen-containing compounds as well as acyclic, cyclic, and heterocyclic hydrocarbons, alcohols, phenols, ethers, aldehydes, ketones, carboxylic acids, esters, and lactones reviewed by Lewinsohn *et al.*, 2001). Hexanal, cis-3-hexenal, cis-3-hexen-1-ol, 3-methyl-1-butanol, hexyl alcohol, 1-nitro-3-methylbutane, and 2-methyl-1-butane are the most common volatiles found in 152 heirloom tomato cultivars, according to Tieman *et al.* (2012). The aroma of a tomato, however, results from the synergism of several ingredients rather than the presence or absence of a single chemical. The main odour-active aroma volatiles in fresh tomatoes are (Z)- 3-hexenal, hexanal, 1-octen-3-one, methional, 1-penten-3-one, and 3-methylbutanal, while linalool, an acyclic monoterpene alcohol, has a significant impact on tomato flavour (Buttery, 1993). Fruits contain VOCs that are generated in various ways metabolic pathways (Klee and Tieman, 2013), and derived from fatty acids (e.g. cis-3-hexenol and n-hexanal), aliphatic amino acids (e.g. 2-isobutylthiazole and guaiacol), phenolic compounds (e.g. eugenol and methyl salicilate), or longer terpenoids such as β-carotene and lycopene (e.g. β-ionone and geranylacetone). It might be possible to analyse these connections by using electronic sounds to find volatiles in fruit tissue (Maul *et al.*, 1998). According to a recent study, the nearly total elimination of the most prevalent class of volatiles (C6 volatiles) in transgenic fruit has an effect on flavour intensity but has little to no effect on customer preference (Tieman *et al.*, 2012). As a result, odour thresholds alone cannot accurately anticipate how a given volatile would affect flavour. Additionally, these scientists showed that fragrance volatiles, like geranium, contribute to perceived sweetness irrespective of sugar concentration, offering a fresh strategy for enhancing sweetness perception.

Fruit Ascorbate (Vitamin-C)

In plants, ascorbic acid, often known as ascorbate (AsA), serves crucial roles. For example, it affects cell division, cell wall formation, and how plants interact with their surroundings, pathogens, and oxidising agents (Gest *et al.*, 2013). According to Frei *et al.* (2012), it is also a critical micronutrient and a significant antioxidant for human diet. The two biologically active, water-soluble forms of vitamin C found in tomatoes are ascorbate (reduced form) and dehydroascorbic acid (oxidised form). Between tomato species and cultivars, the total amount of vitamin C ranges from 8 to 40 mg 100 g1 and is available in all cell compartments of tissues that are actively growing and developing (CTIFL, 2011) (L-galactose route, Wheeler *et al.*, 1998) The AsA biosynthesis pathway in plants and the multiple enzymes involved have been fully documented. Both leaves and fruits produce AsA by converting D-glucose.

Due to AsA's antioxidant properties, it can quickly oxidise after being produced, making the recycling pathway (reduction of the oxidised form) crucial for preserving AsA levels and redox status in plant cells (Massot *et al.*, 2013). Thus, AsA import (or the import of precursors) from leaves, AsA synthesis and recycling inside the fruit, AsA export, AsA degree of oxidation or degradation, and AsA pool size in fruit are all related to each other (Massot *et al.*, 2013). According to Massot *et al.* (2010), during fruit development, AsA concentration declines throughout the times of cell division and expansion—possibly due to dilution effects—and subsequently rises during ripening with the hexose content. Numerous studies have discovered strong associations between fruit soluble sugar and AsA levels. Recent research, however, has shown that AsA synthesis in tomato fruit is not constrained by sugar concentration (Massot *et al.*, 2010) and that in situ synthesis outperformed AsA transport from leaves (Gautier *et al.*, 2009).

Fruit carotenoids

Due to their antioxidant effects, carotenoids are particularly crucial for the human diet as they give ripe fruits their colour, which is the first quality trait that encourages purchasing (Dorais *et al.*, 2008).In addition, carotenoids play crucial biological roles in plants, such as capturing light in photosynthetic membranes, shielding the photosynthetic apparatus from excessive light, forming pigment protein complexes in thylakoids, acting as precursors of abscisic acid, and acting as pollinator attractants, which aid in seed dispersal (Llorente *et al.*, 2016).Lycopene, which makes up 80–90% of the total carotenoids in ripe fruit, is the most prevalent carotenoid in tomato fruit. It is followed by phytoene, phytofluene, zeta-carotene, gamma-carotene, -carotene (a precursor to vitamin A), neurosporene, and lutein. The most noticeable exterior colour changes from green to red in tomatoes are caused by the loss of chlorophyll and the accumulation of -carotene and lycopene (Fraser *et al.*, 1994). The total carotenoid concentration in tomato fruit increases between 10- and 50-fold during fruit ripening. According to Fraser *et al.* (1994), the fundamental mechanism governing the rise in carotenoid concentrations is based on the differential regulation of the expression of genes encoding enzymes of the carotenoid biosynthesis pathway, such as phytoene synthase and phytoene desaturase. The carotenoid biosynthesis pathway has been extensively studied, and a number of regulatory mechanisms, such as ethylene, light, substrate availability, and metabolic sequestration, have been proposed (Fanciullino *et al.*, 2014). The hypothesis that the final content in carotenoids could be early determined through plastid size and density (Fanciullino *et al.*, 2014) is supported by the fact that carotenoid accumulation and activities of many enzymes involved in the biosynthesis do not correlate during fruit development (Fraser *et al.*, 1994).

Environmental control of fruit quality

Environmental influences may have an impact on fruit quality directly by affecting the production and distribution of primary metabolites among sink organs, but they may also have an impact indirectly through stress-related changes in osmotic and turgor regulation and the stimulation of antioxidant metabolism in the event of induced oxidative stress. Although it is frequently asserted that stress has a negative impact on yield and a positive impact on quality, it would be important to establish this as a paradigm because plant and fruit responses are highly influenced by genotype, stress intensity and duration, plant and organ development stage, and interactions among stress factors (Ripoll *et al.*, 2014). For each of these reasons, a deeper comprehension of the underlying adaptation mechanisms is necessary to exploit stress to enhance fruit quality.

Impact of environmental factors on fruit quality

The key variables that affect fruit mass or composition are light intensity, temperature, and air humidity (Guichard *et al.*, 2001; Biais *et al.*, 2014). These elements change the carbon and water fluxes between source and sink organs by affecting plant growth, leaf expansion, carbon assimilation, and transpiration (Ho, 1996). For instance, in response to changes in stem water potential, increased fruit transpiration and decreased xylem influx would result in a reduction in fruit growth under high vapour pressure deficit (VPD) (Guichard *et al.*, 2001); in the driest parts of the day, a xylem efflux may even take place (Guichard *et al.*, 2005). According to Bertin *et al.* (2000), high VPD also causes more blossom-end rot but less fruit breaking. Cell expansion is the fruit growth step that is most susceptible to assimilate deficiency.

As has been seen in tomato fruit at the tissue (Bertin, 2005; Prudent *et al.*, 2010) and gene (Baldet *et al.*, 2006) levels, severe carbon deficiency may negatively influence cell division. Since many studies only report changes in fruit composition on a fresh weight basis, it is not always clear whether these changes are the result of active solute accumulation, dilution/dehydration effects linked to changes in fruit size and water content, or both (Genard *et al.*, 2014).

Genetic control of fruit quality

Quantitative variables with continuous variation in segregating populations include important aspects of tomato fruit quality like fruit size, appearance, firmness, and shelf life (Causse *et al.*, 2002). Over the past 50 years, breeding has significantly altered them, resulting in a wide range of size, shape, and colour. For example, domestication increases fruit size in cultivated species up to 1000 times more than in their wild relatives (Frary *et al.*, 2000). On the other hand, the genetic enhancement of organoleptic quality or health value has just recently been taken into consideration. Genetic enhancement of tomato quality is challenging since the majority of fruit quality parameters are multi-genic, co-localized QTL/genes with opposing effects, and interactions between QTL/genes, the environment, and cultural practices. Although the use of genetic transformations for commercial gain is strictly controlled, genetic engineering approaches aim to alter the expression of genes controlling quality attributes, particularly during ripening (e.g., to improve the taste, sugar to acid ratios, aroma, and carotenoids levels in tomatoes) (Lewinsohn *et al.*, 2001; Guo *et al.*, 2012). On the other hand, the inherent genetic diversity seen in tomato species or among them presents a significant opportunity to develop novel, enhanced cultivars (Lin *et al.*, 2014). Numerous QTL for fruit weight, shape, sugar and acid contents, firmness, volatiles, and sensory attributes have been discovered through genetic studies on populations derived from interspecific crosses between wild species and processing or fresh tomatoes (review in Labate *et al.*, 2007). Some of them may have positive impacts when incorporated into large fruit genotypes (Lecomte *et al.*, 2004), significant mutations and genes for enhancing tomato fruit quality were reported.

CONCLUSION

Fruit quality is a complex concept with many different parameters. For variables like fruit size or sugar content, as demonstrated in this review, the genetic and environmental controls of tomato quality are partially recognized, but less is known about those controls for qualities related to volatiles. It is obvious that significant advancement is still needed. However, modern technology makes it possible to genotype and phenotype plants and fruits, providing new opportunities for using genetic resources.

For numerous parameters linked to tomato fruit quality, near-isogenic lines, mutants, transgenic, and mapping populations have been generated over the past ten years. These resources allow researchers the chance to assess the theories put forth in PBSMs and to draw attention to crucial regulation loops. PBSMs could assist us in to identify optimal settings of genetic factors to produce a desired phenotype and unravel the relationships between genotypes and phenotypes. However, the emergence of novel cultivars based on ideotypes created by models is still a long way off.

FUTURE PROSPECTS

Tomato fruit, postharvest quality control starts in the field and continues all the way to the ultimate customer. A few preharvest practices used during production have an impact on the fruits' postharvest quality status. Any postharvest handling method or technique can only be used to maintain the quality of any fruit after it has been harvested. Future research in this area should focus on in order to produce good quality fruits at harvest, preharvest factors like genetic factors, environmental factors, and cultural factors all play a crucial role.

REFERENCES

Bai, Y. and Lindhout P. (2007). Domestication and breeding of tomatoes: what have we gained and what can we gain in the future? *Ann. Bot.*, 100:1085–1094.

Baldet, P., Hernould, M., Laporte, F., Mounet, F., Just D., Mouras, A., Chevalier, C. and Rotha, C. (2006). The expression of cell proliferation-related genes in early developing flowers is affected by a fruit load reduction in tomato plants. *Journal of Experimental Botany,* 57: 961–970.

Baldwin, E.A., Goodner, K. and Plotto, A.J. (2008). Interaction of volatiles, sugars, and acids on perception of tomato aroma and flavor descriptors. *Journal of Food Sciences*, 73 (6): S294–307.

Bertin, N. (2005). Analysis of the tomato fruit growth response to temperature and plant fruit load in relation to cell division, cell expansion and DNA endoreduplication. *Ann. Bot.*, 95: 439–447.

Bertin, N., Borel, C., Brunel, B., Cheniclet, C. and Causse, M. (2003). Do genetic makeup and growth manipulation affect tomato fruit size by cell number, or cell size and DNA endoreduplication? *Ann. Bot.*, 92: 415–424.

Bertin, N., Causse, M., Brunel, B., Tricon, D. andGénard, M. (2009). Identification of growth processes involved in QTLs for tomato fruit size and composition. Journal *of Experimental Botany,*60:237–248.

Bertin, N., Guichard, S., Leonardi, C., Longuenesse, J.J.L., Langlois, D. and Navez, B. (2000). Seasonal evolution of the quality of fresh glasshouse tomatoes under Mediterranean conditions, as affected by air vapour pressure deficit and plant fruit load. *Ann. Bot.*, 85: 741–750.

Bertin, N., Lecomte, A., Brunel, B., Fishman, S. and Génard, M. (2007). A model describing cell polyploidization in tissues of growing fruit as related to cessation of cell proliferation. *Journal Experimental Botany,* 58: 1003–1013.

Biais, B., Bénard, C., Beauvoit, B., Colombié, S., Prodhomme, D., Ménard, G., Bernillon, S., Gehl, B., Gautier, H., Ballias, P., Mazat, J.-P., Sweetlove, L., Génard, M. andGibon, Y. (2014). Remarkable reproducibility of enzyme activity profiles in tomato fruits grown under contrasting environments provides a roadmap for studies of fruit metabolism. *Plant Physiology,* 164:(3), 1204–1221 10.1104/pp.113.231241.

Buttery, R.G. (1993). Quantitative and sensory aspects of flavor of tomato and other vegetable and fruits. In: Acree, T.E., Teranishi, R. (Eds.), Flavor Science: Sensible Principles and Techniques. ACS, Wash. DC, Pp. 259–286.

Causse, M., Buret, M., Robini, K. andVerschave, P. (2003). Inheritance of nutritional and sensory quality traits in fresh market tomato and relation to consumer preferences. *Journal of Food Sciences*, 68: 2342–2350.

Causse, M., Friguet, C., Coiret, C., Lépicier, M., Navez, B., Lee, M., Holthuysen, N., Sinesio, F., Moneta, E. andGrandillo, S. (2010). Consumer preferences for fresh tomato at the European scale: a common segmentation on taste and firmness. *Journal of Food Sciences*, 75 (9): S 531–S541.

Causse, M., Saliba-Colombani, V., Lecomte, L., Duffe, P., Rousselle, P. andBuret, M. (2002). QTL analysis of fruit quality in fresh market tomato: a few chromosome regions control the variation of sensory and instrumental traits. *Journal of Experimental Botany*, 53: 2089–2098.

Chaib, J., Devaux, M.-F., Grotte, M.G., Robini, K., Causse, M., Lahaye, M. and Marty, I. (2007). Physiological relationships among physical, sensory, and morphological attributes of texture in tomato fruits. *Journal of Experimental Botany,* 58: 1915–1925.

Chen, L. and Opara, U.L. (2013). Texture measurement approaches in fresh and processed foods—a review. *Food Researcher Int.*, 51 (2): 823–835.

Chevalier, C., Nafati, M., Mathieu-Rivet, E., Bourdon, M., Frangne, N., Cheniclet, C., Renaudin, J.-P., Gévaudant, F. and Hernould, M. (2011). Elucidating the functional role of endoreduplication in tomato fruit development. *Ann. Bot.*, 107 (7): 1159–1169.

CTIFL (2011). Hortipratic Tomate: Qualité et preferences. CTIFL 271p.

De. Gelder, A., Dieleman, J.A., Bot, G.P.A. and Marcelis, L.F.M. (2012). An overview of climate and crop yield in closed greenhouses. *Journal of Horticulture Sciences and Biotechnology*, 87 (3): 193–202.

Dorais, M., Ehret, D.L. and Papadopoulos, A.P. (2008). Tomato (*Solanum lycopersicum*) health components: from the seed to the consumer. *Phytochemistry Rev.,* 7 (2): 231–250.

Fanciullino, A.L., Bidel, L.P.R. and Urban, L. (2014). Carotenoid responses to environmental stimuli: integrating redox and carbon controls into a fruit model. *Plant Cell Environmental*, 37: 273–289.

FAOSTAT (2015). Food and Agriculture Organization of the United Nations. Available online at http://www.fao.org/faostat/

Frary, A., Nesbitt, T.C., Grandillo, S., Knaap, E., Cong, B., Liu, J., Meller, J., Elber, R., Alpert, K.B. and Tanksley, S.D. (2000). fw2.2: a quantitative trait locus key to the evolution of tomato fruit size. *Science*, 289: 85–88.

Fraser, P.D., Truesdale, M.R., Bird, C.R., Schuch, W. and Bramley, P.M. (1994). Carotenoid biosynthesis during tomato fruit development – evidence for tissue-specific gene expression. *Plant Physiology,* 105: 405–413.

Frei, B., Birlouez-Aragon, I. and Lykkesfeldt, J. (2012). Authors' perspective: what is the optimum intake of vitamin C in humans? *Critical Review of Food Sciences and Nutrition,* 52 (9): 815–829.

Gautier, H., Massot, C., Stevens, R., Serino, S. and Genard, M. (2009). Regulation of tomato fruit ascorbate content is more highly dependent on fruit irradiance than leaf irradiance. *Ann. Bot.,* 103: 495–504.

Genard, M., Baldazzi, V. and Gibon, Y. (2014). Metabolic studies in plant organs: don't forget dilution by growth. Front of Plant Sciences, 5: 85.

Genard, M., Bertin, N., Borel, C., Bussières, P., Gautier, H., Habib, R., Léchaudel, M., Lecomte, A., Lescourret, F., Lobit, P. and Quilot, B. (2007). Towards a virtual fruit focusing on quality: modelling features and potential uses. *Journal of Experimental Botany,* 58: 917–928.

Gest, N., Gautier, H. and Stevens, R. (2013). Ascorbate as seen through plant evolution: the rise of a successful molecule? *Journal of Experimental Botany,* 64 (1): 33–53.

Guichard, S., Bertin, N., Leonardi, C., Gary, C. (2001). Tomato fruit quality in relation to water and carbon fluxes. *Agronomie,*21: 385–392.

Guichard, S., Gary, C., Leonardi, C. and Bertin, N. (2005). Analysis of growth and water relations of tomato fruits in relation to air vapor pressure deficit and plant fruit load. *Journal of Plant Growth Regulator,* 24: 1–13.

Guo, F., Zhou, W., Zhang, J., Xu, Q. and Deng, X. (2012). Effect of the citrus lycopene β-cyclase transgene on carotenoid metabolism in transgenic tomato fruits. PLoS One 7 (2), e32221.

Harker, F.R., Maindonald, J., Murray, S.H., Gunson, F.A., Hallett, I.C. and Walker, S.B. (2002). Sensory interpretation of instrumental measurements 1: texture of apple fruit. *Postharvest Biology and Technology,* 24: 225–239.

Ho, L.C. (1996). Tomato. Marcel Dekker Inc., New York.

Ho, L.C. (2003). Improving tomato fruit quality by cultivation. In: Cockshull, K.E., Gray, D., Seymour, G.B., Thomas, B. (Eds.), Genetic and Environmental Manipulation of Horticultural Crops. *CABI Publishing,* UK, Pp. 17–29.

Klee, H.J. and Tieman, D.M. (2013). Genetic challenges of flavour improvement in tomato. *Trends Genetics,* 29 (4): 257–262.

Kyriacou C. and Rouphael Y. (2017). Towards a new definition of quality for fresh fruits and vegetables. Sciences and Horticulture doi:10.1016/j.scienta.2017.09.046.

Labate, J.A., Grandillo, S., Fulton, T., Munos, S., Caicedo, A.L., Peralta, I., Ji, Y.F., Chetelat, R.T., Scott, J.W., Gonzalo, M.J., Francis, D., Yang, W.C., Knaap, E., Baldo, A.M., Smith-White, B., Mueller, L.A.,

Prince, J.P., Blanchard, N.E., Storey, D.B., Stevens, M.R., Robbins, M.D., Wang, J.F., Liedl, B.E., O'Connell, M.A., Stommel, J.R. and Aoki, K. (2007). Tomato. In: Kole, C. (Ed.), Genome Mapping and Molecular Breeding in Plants. Springer, Berlin, Heidelberg, New York, Pp. 1–125.

Lecomte, L., Duffe, P., Buret, M., Servin, B., Hospital, F. and Causse, M. (2004). Marker-assisted introgression of 5 QTLs controlling fruit quality traits into three tomato lines revealed interactions between QTLs and genetic backgrounds. *Theory of Applicable Genetics*, 109: 658–668.

Lewinsohn, E., Schalechet, F., Wilkinson, J., Matsui, K., Tadmor, Y., Nam, K.H., Amar, O., Lastochkin, E., Larkov, O., Ravid, U., Hiatt, W., Gepstein, S. andPicherskyc, E. (2001). Enhanced levels of the aroma and flavor compound S-linalool by metabolic engineering of the terpenoid pathway in tomato fruits. *Plant Physiology*, 127 (3): 1256–1265.

Lewinsohn, E., Schalechet, F., Wilkinson, J., Matsui, K., Tadmor, Y., Nam, K.H., Amar, O., Lastochkin, E., Larkov, O., Ravid, U., Hiatt, W., Gepstein, S. andPicherskyc, E. (2001). Enhanced levels of the aroma and flavor compound S-linalool by metabolic engineering of the terpenoid pathway in tomato fruits. *Plant Physiology,* 127 (3): 1256–1265.

Lin, T., Zhu, G., Zhang, J., Xu, X., Yu, Q., Zheng, Z., Zhang, Z., Lun, Y., Li, S., Wang, X., Huang, Z., Li, J., Zhang, C., Wang, T., Zhang, Y., Wang, A., Zhang, Y., Lin, K., Li, C., Xiong, G., Xue, Y., Mazzucato, A., Causse, M., Fei, Z., Giovannoni, J.J., Chetelat, R.T., Zamir, D., Städler, T., Li, J., Ye, Z., Du, Y. and Huang, S. (2014). Genomic analyses provide insights into the history of tomato breeding. *Nat. Genet*., 46 (November (11)): 1220–1226.

Llorente, B., D'Andrea, L., Ruiz-Sola, M.A., Botterweg, E., Pulido, P., Andilla, J., Loza-Alvarez, P. and Rodriguez-Concepcion, M. (2016). Tomato fruit carotenoid biosynthesis is adjusted to actual ripening progression by a light-dependent mechanism. *Plant Journal,* 85: 107–119.

Martre, P., Bertin, N., Salon, C. and Genard, M. (2011). Modelling the size and composition of fruit, grain and seed by process-based simulation models. New Phytol. *Tansley Rev.,* 191: 601–618.

Massot, C., Bancel, D., Lauri, F., Truffault, V., Baldet, P., Stevens, R. and Gautier, H. (2013). High temperature inhibits ascorbate recycling and light stimulation of the ascorbate pool in tomato despite increased expression of biosynthesis genes. *PLoS One,* 8 (12): e84474.

Massot, C., Génard, M., Stevens, R. and Gautier, H., (2010). Fluctuations in sugar content are not determinant in explaining variations in vitamin C in tomato fruit. *Plant Physiol. Biochem*., 48: 751–757.

Maul, F., Sargent, S.A., Balaban, M.O., Baldwin, E.A., Huber, D.J. and Sims, C.A., (1998). Aroma volatile profiles from ripe tomato fruit are influenced by physiological maturity at harvest: an application for electronic nose technoogy. *J. Am. Soc. Hortic. Sci.,* 123 (6): 1094–1101.

Prudent, M., Bertin, N., Genard, M., Munos, S., Rolland, S., Garcia, V., Petit, J., Baldet, P., Rothan, C. and Causse, M., (2010). Genotype-dependent response to carbon availability in growing tomato fruit. *Plant Cell Environ*., 33: 1186–1204.

Ripoll, J., Urban, L., Staudt, M., Lopez-Lauri, F., Bidel, L.P.R. and Bertin, N., (2014). Water shortage and quality of fleshy fruits – making the most of the unavoidable. Review. *Journal of Experimental Botany,* 65: (15), 4097–4117.

Thompson, D.S. (2001). Extensiometric determination of the rheological properties of the epidermis of growing tomato fruit. *Journal Experimental Botany,* 52: 1291–1301.

Tieman, D., Bliss, P., McIntyre, L.M., BlandonUbeda, A., Bies, D., Odabasi, A.Z., Rodr1´guez, G.R., van der Knaap, E., *et al*. (2012). The chemical interactions underlying tomato flavor preferences. *Curr. Biol.,* 22: 1035–103.

Toivonen, P.M.A. and Brummell, D.A., (2008). Biochemical bases of appearance and texture changes in fresh-cut fruit and vegetables. *Postharvest Biology Technology*,48: 1–14.

Wheeler, G.L., Jones, M.A. and Smirnoff, N. (1998). The biosynthetic pathway of vitamin C in higher plants. *Nature,* 393 (6683): 365–369.

Received: June 26, 2023
Accepted: August 9, 2023