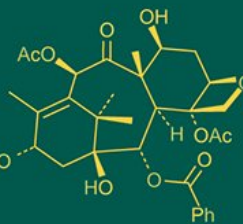
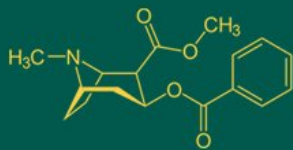


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Destructive evaluation of key physicochemical and textural quality attributes of tomato fruit

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Abstract

Tomato (*Solanum lycopersicum* L.) is a globally significant vegetable crop prized for its culinary versatility and dense concentration of health-promoting antioxidants like lycopene and vitamin C. To meet the rigorous demands of both fresh markets and industrial processing a comprehensive destructive evaluation of physico-chemical and textural attributes is essential. Such analysis provides critical insights into the internal quality dynamics that non-destructive visual inspections cannot capture. This study evaluated ten distinct tomato genotypes (RHRT 20-4 to RHRT 20-13) across eight maturity stages from immature green to overripe. The methodology integrated standardized laboratory protocols for physical (firmness moisture shape index) chemical TSS pH TA lycopene ascorbic acid) and organoleptic (5-point hedonic scale) assessments. Physical results revealed a significant sigmoidal decline in firmness with elongated genotypes RHRT 20-7 and 20-11 exhibiting superior structural retention (> 12 N at red ripe) indicating excellent shelf-life potential. Chemical analysis highlighted a linear increase in TSS (3.5 to 7.8 °Brix) and a peak in ascorbic acid at the red stage where RHRT 20-5 emerged as the nutritional leader. Lycopene accumulation strongly correlated with a* colour coordinates peaking at maturity. Organoleptic evaluation by 200 participants confirmed that genotypes with a balanced sugar-acid ratio and firm texture specifically RHRT 20-5 and 20-11 received the highest overall acceptability scores (>4.5). These findings identify these specific lines as premier candidates for cultivation and future breeding programs aimed at optimizing the nutritional and commercial value of tomatoes.

Keywords: *Solanum lycopersicum* post-harvest quality lycopene firmness sensory evaluation genotype characterization.

1. Introduction

The tomato (*Solanum lycopersicum* L.) is a globally important vegetable valued for its nutritional economic and social benefits. Its antioxidant characteristics make it especially vital for human health (Stoleru and Inculet *et al.* 2020 Heuvelink 2018). It is one of the most popular and widely consumed vegetable crops worldwide globally after potato (Rahman *et al.* 2017 Costa and Heuvelink 2018 Padmanabhan *et al.* 2016) [12 33 34]. Additionally tomatoes and potatoes (*Solanum tuberosum*) share more than 8% of their genomes (Sato *et al.* 2012) [41]. One of the most significant and abundantly cultivated crops on Earth tomatoes are also an incredible source of nutrients that might improve health offering vitamins minerals phenolic compounds dietary fiber and antioxidants (Tolasa *et al.* 2021) [45].

Tomatoes originated in South America's Andes. The cultivated tomato was brought to Europe by the Spanish conquistadors in the sixteenth century and eventually spread to Southern and Eastern Asia Africa and the Middle East. Recently wild tomatoes have spread to other parts of South America and Mexico (Naika *et al.* 2005) [32]. It is a popular vegetable crop of Maharashtra both in fresh and processed form. Global consumption of fresh and processed tomatoes is estimated at 6.4 million tons per year. More than 10 000 tomato varieties are available in the world market differing in their fruit size shape and color (Tiware *et al.* 2022) [44]. Tomatoes are the most frequently produced crop and constitute the primary non-grain commodity in the world agricultural system (Bai and Lindhout 2007 Testa *et al.* 2014) [42]. Tomatoes are a globally significant crop that is grown extensively all over the world. Tomato production and cultivation area have increased during the last 20

The dry matter content of tomatoes typically ranges from 5.0% to 7.5%. (Heuvelink 2005) ^[22]. Dry matter content estimates ranged from 4.2% to 6.6% based on irrigation and fertilization (Heuvelink E 1995 Das *et al.* 2021) ^[14 21]. Fruit quality depends on dry matter levels and component proportions. Some studies have discovered that lower nitrogen levels hinder plant growth and increase the dry matter content of fruits thus boosting fruit quality (Bénard *et al.* 2009) ^[9]. Tomato fruits are packed with vitamins and minerals all of which are beneficial for human health. On the other hand they are rich in trace elements including copper manganese zinc selenium and vitamins C B6 E and folic acid (Borguini *et al.* 2009 Luthria *et al.* 2006) ^[11 27]. It was observed that by neutralizing free radicals these trace elements play a critical role in protective mechanisms (Fernández-Ruiz *et al.* 2011) ^[17]. Ascorbic acid is one of the best chemical compounds found in tomatoes in terms of essential organic acids and nutritional values in fruits and vegetables (Ali *et al.* 2021 Antonious *et al.* 2019 Rosales *et al.* 2011) ^[2 38]. Organic acids contribute to plant nutrients and sugars influencing tomato quality and customer preferences (Zhao *et al.* 2016) ^[51]. Tomato fruit quality is influenced by a variety of factors including genotypes (cultivars) plant growing conditions (ecological and technological) harvest timing physiological and biochemical changes and other agronomic commercial nutritional and gustatory aspects (Felföldi *et al.* 2021 Fortis Hernandez *et al.* 2021 Bădulescu *et al.* 2020) ^[6 18]. Tomato fruit harvested at the right maturity have the highest quality and sensory parameters (Thumula 2006) ^[43]. Fruit cells continue to function after harvest and the quality and storage life of the fruit are determined by maturity. In this regard ripeness is an important property that might influence the organoleptic aspects of the fruits and the final perceptions of consumers (Harker *et al.* 2003) ^[19].

Tomato quality like that of other vegetables and fruits is determined by a variety of factors including commercial appeal physical-morphological qualities organoleptic properties and nutritional as well as health benefits of tomato fruits (Felföldi *et al.* 2021 Harker *et al.* 2003 Dan *et al.* 2015) ^[16 19]. Consequently sensory perceptions of the consumers are the product of the integration of various fruit sensory attributes including vision (shape color appearance) olfactory (odour sweet pungent floral) gustatory (sweet salt sharp bitter flavor) touch (smooth rough) temperature firmness and trigeminal perception (heat astringency) (Vindras *et al.* 2018) ^[47] while certain quality attributes can be quantified objectively using suitable instruments and techniques (e.g. color firmness juiciness total soluble solids chemical composition etc.) numerous others necessitate sensory evaluation which may entail a significant level of subjectivity. Tomato maturity represents the developmental stage that culminates in physiological or horticultural maturity (Li *et al.* 2019). Physiological maturity refers to the developmental stage at which a tomato fruit can continue its ontogeny independently of the plant (Li *et al.* 2019). Horticultural maturity refers to the developmental stage at which a tomato fruit meets the necessary criteria for consumer use for a specific purpose (Elevitch Ragone & Cole 2014) ^[15]. The maturity at harvest is the primary factor influencing storage life and the final quality of fruit. Immature tomatoes are more susceptible to shrivelling mechanical damage and a lack of flavour (Kader 1999) ^[23]. Overripe tomatoes tend to exhibit a soft mealy texture and a

bland flavour shortly after harvest (Sangkasanya *et al.* 2014) ^[40]. Fruit harvested either prematurely or too late in its season is more prone to physiological disorders and exhibits a reduced storage life compared to fruit harvested at optimal maturity.

Based on the above considerations the present study is aimed at performing a complex analysis of the overall qualities of some tomato genotypes represented by ten commercial hybrids as per maturity stages of tomatoes i.e. immature green breaker turning pink red red ripe and overripe based on the reviews and observations. This research mainly aims to highlight critical points of tomato maturity stages from harvesting to processing state of tomato fruit undergoing physical and physicochemical changes that will be mostly beneficial for tomato processing industries for the right selection of proper maturity level ensuring the presence of high- quality attributes will be a key parameter for processing purposes as well as obtaining high yield

2. Materials and Methods

2.1 Plant Materials and cultivation conditions

The present investigation on “Destructive evaluation of physicochemical and textural quality attributes of numerous hybrid genotypes of tomato fruits” was evaluated at “Tomato Improvement Scheme Department of Horticulture and Department of Agricultural Process Engineering Mahatma Phule Krishi Vidyapeeth Rahuri. The plant materials were represented by ten genotypes of the tomatoes i.e. RHRT 20-4 RHRT 20-5 RHRT 20-6 RHRT 20-7 RHRT 20-8 RHRT 20-9 RHRT 20-10 RHRT 20-11 RHRT 20-12 and RHRT

20-13 and subjected to sensory physical and chemical analysis. Visual observations of tomato hybrids such as fruit color fruit firmness and overall acceptability of ten genotypes were monitored as per the maturity stages of immature green to overripe stages.

In research trials tomato cultivation follows standardized agronomic practices to ensure reproducibility and optimal plant performance. The seed rate is typically maintained at 120 g/ha with nursery sowing timed according to the cropping season mid-June to mid-July for Kharif and mid-September to mid-October for Rabi to synchronise plant development with favourable climatic conditions. Transplanting is conducted in the second fortnight of July and October to match nursery readiness and field conditions. Experimental plots use a spacing of 90 x 30 cm to provide adequate plant density for uniform growth and to minimise inter-plant competition. Nutrient management includes the application of a balanced fertilizer regimen consisting of 300:150:150 kg/ha of N: P₂O₅:K₂O along with 20 tons/ha of farmyard manure to enhance soil fertility and structure. Irrigation scheduling is based on crop water requirements applied as needed to avoid water stress. Harvesting typically occurs 60-65 days after transplanting which coincides with the fruit's physiological maturity ranging from immature green to overripe stages. These practices are widely adopted in research to maintain controlled conditions for evaluating cultivar performance postharvest traits and the impact of experimental treatments on growth and yield.

2.2 Sampling and Analysis of the Qualitative Traits of Tomatoes: For the sampling and analysis a total of eight harvestings were performed as per the maturity stages of

different genotypes such as immature green green breaker turning pink red red ripe and overripe. For each harvesting sampling and sample size the same rules were followed for the homogeneity and equality between genotypes. A hundred fruits from each genotype were used after reaching physiological maturity. In the samples of each genotype the same fruits were analyzed for fruit weight height diameter volume and fruit shape index and the data were finally reformed as the means of all the values. The tomato fruits were rigorously sent to the laboratory after the harvest. The peduncles were removed and discarded collectively tomato samples were washed (first with running water and then using distilled water) to remove field heat and residual moisture was evaporated at room temperature and cleaned by using a clean and dry cloth.

2.2 Measurement of Fruit Physical Parameters

A hundred fruits of each genotype were selected to evaluate the fruit firmness shape index and moisture content of the tomato variety.

2.2.1 Evaluation of Fruit Shape Index

The transverse and longitudinal diameters of each tomato fruit were measured with the Vernier caliper and the vertical direction was re-measured. The tomato fruit shape index was determined from the ratio of longitudinal and transverse diameters of the fruits (Xiaoxi *et al.* 2017) ^[49].

2.3.1 Evaluation of Fruit Firmness

The degree of tomato fruit firmness has been used as an indication of fruit quality and texture is influenced by flesh firmness and skin strength. A Texture Analyzer (Food Technology Corporation USA TMS- PRO) having a capacity of 500 N was used for firmness measurement of the tomato sample. The analyzer was connected to the computer for recording the data via a software program and converted into a graphical representation (texture profile) and prepared the report of the individual test. The texture analyzer was equipped with a needle probe and a probe carrier to assess firmness. A tomato fruit was put on a flat plate and then a 6 mm diameter plunger tip penetrated the tomato about 20 mm at a velocity of 1 mm/s. This test was carried out till the needle passed through the tomato sample and returned back to its original position. The force-deformation curve obtained from software gives the maximum force needed to puncture the tomato sample (Bagher 2005) ^[7]. During the measurement three measuring points were selected on the equatorial plane and the average values of the three measuring points were taken as the measured value of tomato firmness.

The following setting was reported for computing the firmness of tomato sample by using texture analyser.

- **Pre-test speed:** 2.00 mm/s
- **Post Test Speed:** 2.00 mm/s
- **Stop plot:** Start position
- **Test Speed:** 0.1 mm/s
- **Trigger:** Auto Trigger
- **Distance:** 20 mm
- **Force:** 50.00 g
- **Probes:** Needle probe for firmness test

For each test the required quantity of tomato test samples was loaded between two parallel plates of the analyzer and punctured gradually recording the force and the

corresponding deformation that occurred until the sample rupture was initiated.

2.3.3 Determination of Moisture Content

Tomato fruit moisture content was determined by the oven-drying method where fresh tomato samples were weighed (W1) dried at 105 °C for 3 hours and dried at 80 °C to constant weight (W2) and moisture content was calculated using the formula (Ranganna 1986)

$$\text{Moisture Content (\%)} = [(W1 - W2) / W1] \times 100$$

2.3.4 Determination of Colour

The color of tomato fruit of two cultivars was analyzed with the help of color scan instruments (Premier Colorscan Instruments Pvt. Ltd. Mumbai India). The color was expressed in dimensions of L* a* and b* values. It works on the principle of focusing the light and measuring the energy reflected from the sample across the entire visible spectrum. The instrument was calibrated before placing the tomato sample by placing calibration plates provided with the instrument. The instrument was calibrated. It was cross-checked by placing the white tile which has been provided with the L* a* and b* values.

In CIE L *a *b* uniform color space L* indicates luminosity or lightness a* chromacity on a green (-)-to-red (+) axis and b* chromacity on a blue (-)-to-yellow (+) axis with chroma (C) indicating intensity or saturation of the color and hue (H) angle that indicates the pure spectrum color. Measurements were taken for three sides and the average value was determined.

2.4 Analysis of Chemical Attributes

2.4.1 Determination of Total Soluble Solid and pH Total soluble solids as °Brix of tomato pulp were measured by using a digital refractometer (SKU: HI96801 Hanna Instruments Pvt. Ltd. Mumbai India). The pulp of the tomato was extracted and filtered and a droplet of the resultant tomato juice about 0.3 mL was loaded on the prism plate of the refractometer to measure the total soluble solid content. The total soluble solid measurement was carried out in triplicate and the average value of the three measurements was calculated to represent the TSS (°Brix) value of the tomato fruit. The prism was thoroughly cleaned before the next sample was measured (AOAC 2005 Kumar *et al.* 2017) ^[25].

The pH of the fresh filtered tomato juice was measured by using a pH meter (Li-120 ELICO Pvt. Ltd. and Hyderabad India) (AOAC 2005 Mahajan *et al.* 2012) ^[28].

2.4.2 Determination of Titrable Acidity

Titrateable acidity of tomato samples was determined by acid-base titration (Yang *et al.* 2010) ^[50]. Ten grams of the tomato sample will be ground and transferred to a 100 ml volumetric flask. The volumetric flask was filled with deionized water to the desired volume. Then the liquid in the volumetric flask was filtered out into a conical flask. A drop of 1% phenolphthalein indicator was added to the filtrate and the filtrate was titrated with 0.1 mol/L NaOH (Ranganna 1986) ^[35]. When the color of the filtrate turns slightly pink and remains unchanged for half a minute the titration is completed. The value was expressed in terms of citric acid as a percentage of acidity of tomato juice (A.O.A.C. 2005). The titrateable acidity was carried out in triplicate and the average value of the three measurements

was used as the titratable acids (%) value of the tomato sample.

2.4.3 Determination of Lycopene Content

Lycopene content within tomato samples was determined by selective extraction colorimetry (Mehrtens *et al.* 2005) [31]. Lycopene from unfiltered whole tomato puree was extracted with absolute ethanol absolute methanol and petroleum ether with 2% dichloromethane. The lycopene content was measured with an ultraviolet spectrophotometer (ELITE BioEra's Life Sciences Pvt. Ltd. Pune and Maharashtra). Petroleum ether was placed in one cuvette as a control and the tomato extract was placed in the other cuvette. The absorbance at 503 nm was calculated as the lycopene (mg/100 g) content of the tomato sample (Zhao *et al.* 2023) [52].

2.4.4 Determination of Vitamin C

The vitamin C (ascorbic acid) content of tomato juice was determined by using reference standard methods of biochemical analysis (AOAC 2005) with the help of reagents such as 4% dry oxalic acid dye solution stock standard solution and working standard solutions. Research studies have employed a titrimetric method for the quantification of ascorbic acid in tomato fruit juice. Typically 5 ml of the working standard solution was pipetted into a 100 ml conical flask followed by the addition of 10 ml of 4% oxalic acid. This solution was then titrated against a dye until a persistent pink coloration was observed indicating the endpoint. The volume of dye consumed (V_1 ml) corresponds to the ascorbic acid content. For sample analysis 0.5-5 g of tomato fruit was extracted with 4% oxalic acid and diluted to a known volume of 100 ml before centrifugation. 5 ml of the clear supernatant was taken mixed with 10 ml of 4% oxalic acid and titrated against the

dye similarly. The ascorbic acid concentration was calculated and expressed as milligrams per gram of tomato fruit juice.

Amount of Ascorbic acid (mg/100g sample) =

$$(0.5/V_1 \text{ ml}) \times (V_2/15 \text{ ml}) \times (100 \text{ ml/Wt. of sample}) \times 100 \dots (2)$$

2.5 Organoleptic Evaluation of Fruit Quality

Tomatoes free from disease insect pests or mechanical damage exhibiting uniform maturity and size were selected and randomly presented for sensory evaluation following cutting. The interim review panel consisted of faculty and students aged 21 to 52 from the College of Horticulture Rahuri who had received prior training in the quantitative assessment of tomato attributes. Attributes of appearance and flavor were selected to characterise the fruit. Each descriptor received a score on a 5-point scale with higher scores indicating a superior index (Azodanlou *et al.* 2003) [5]. Three sessions were conducted in a sensory analysis laboratory with 200 participants involved in the evaluation.

3. Results and discussion

3.1 Fruit shape index

The morphological characterization of tomato genotypes revealed significant diversity in fruit architecture with Fruit Shape Index (FSI) values ranging from 0.771 to 1.600. Based on the standard classification the genotypes were categorized into three distinct groups: Oblate (RHRT 20-4 RHRT 20-9) Round (RHRT 20-5 20-6 20-8 20-10 20-12 20-13) and Ovate/Elongated (RHRT 20-7 20-11). The lowest FSI was recorded in RHRT 20-9 (0.771±0.005) indicating a significantly flattened or oblate profile while the highest was observed in RHRT 20-7 (1.600±0.036) exhibiting a prominent elongated structure (Table 1).

Table 1. Fruit shape index of tomato genotypes and their coefficient of variability (CV %) based on shape classification.

Genotypes	Mean±SEM	CV %	Shape classification
RHRT 20-4	0.939±0.009	1.61	Oblate
RHRT 20-5	1.037±0.007	1.12	Round
RHRT 20-6	0.952±0.016	2.93	Round
RHRT 20-7	1.600±0.036	3.94	Ovate
RHRT 20-8	1.006±0.010	1.69	Round
RHRT 20-9	0.771±0.005	1.18	Oblate
RHRT 20-10	1.005±0.014	2.34	Round
RHRT 20-11	1.405±0.025	3.13	Ovate
RHRT 20-12	1.001±0.010	1.69	Round
RHRT 20-13	0.976±0.018	3.17	Round

A key finding in this study is the high degree of morphological uniformity within each genotype as evidenced by the exceptionally low Coefficient of Variation (CV %) with almost all samples remaining below 4%. This suggests that fruit shape in the RHRT series is a highly stable phenotypic trait with minimal environmental influence likely governed by the strong expression of shape-regulating genes. From a post-harvest perspective a strong positive correlation was observed between the ovate shape (high FSI) and fruit firmness. Genotypes RHRT 20-7 and 20-11 which possessed the highest FSI values also maintained superior firmness at full maturity. This correlation is likely due to the structural arrangement of the pericarp and a reduction in locular space often found in elongated varieties which enhances resistance to mechanical deformation. Consequently these elongated genotypes

represent the most promising candidates for long-distance transport and industrial processing where structural integrity is a priority.

3.2 Fruit firmness

The assessment of fruit firmness (N/cm²) across ten tomato genotypes revealed a progressive and significant decline ($P<0.05$) as the fruit transitioned from the immature green to the overripe stage. At the initial immature green stage firmness values were highest ranging from 38.50±1.250 N/cm² (RHRT 20-9) to 52.40±0.208 N/cm² (RHRT 20-7). As ripening progressed through the Breaker and Turning stages a sharp reduction in resistance to compression was observed across all genotypes indicating the onset of rapid textural modification. By the Red Ripe stage the critical point for fresh consumption RHRT 20-11 (13.40±0.300

N/cm²) and RHRT H 20-7 (12.50 ± 0.375 N/cm²) exhibited the highest retention of structural integrity. Conversely RHRT H 20-9 showed the lowest firmness at 6.40 ± 0.252 N/cm². The Coefficient of Variation (CV %) remained low during the early stages but exhibited an increasing trend in

the overripe phase (reaching up to 41.96% in RHRT H 20-6) reflecting the inherent biological variability in tissue senescence at advanced maturity (Table 2.) Figure 1. Shows the graphical representation of firmness as per maturity stages of total ten tomato genotypes.

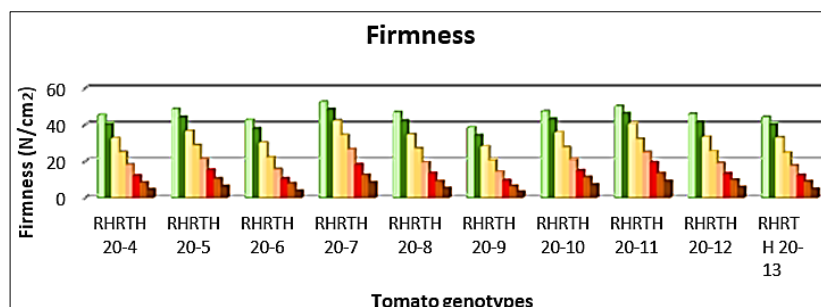


Fig 1: Graphical representation of firmness as per maturity stages of tomato genotypes.

The systematic softening observed in this study is a classic physiological hallmark of climacteric ripening in tomato. This process is primarily governed by the coordinated enzymatic degradation of cell wall polysaccharides. The initial high firmness in the green stages is attributed to a rigid primary cell wall and middle lamella rich in insoluble protopectin. The rapid softening observed between the Breaker and Pink stages suggests a peak in the activity of wall-degrading enzymes. These enzymes facilitate the depolymerization and solubilization of pectin leading to a loss of middle lamella integrity and a reduction in turgor pressure. Genotypes RHRT H 20-11 and RHRT H 20-7 demonstrated superior textural stability likely due to a lower rate of pectin solubilization or a higher initial concentration of calcium-pectate cross-links which fortify the cell wall. These "firm-fleshed" genotypes are of high commercial value. In contrast the rapid softening of RHRT H 20-9 makes it less suitable for long-distance logistics but potentially favorable for processing industries where ease of pulp extraction is required.

3.3 Moisture content

The moisture content (% w.b.) of the ten evaluated tomato genotypes remained consistently high throughout all maturation stages typically ranging between 89.63% and 95.27%. A gradual but statistically significant reduction ($P < 0.05$) in moisture percentage was observed as the fruits progressed from the immature green to the overripe stage. At the initial harvest stage RHRT H 20-9 exhibited the highest moisture content ($95.27 \pm 0.120\%$) while the lowest initial moisture was recorded in RHRT H 20-11 ($92.67 \pm 0.033\%$) (Table 3). By the red ripe stage moisture levels stabilized across genotypes with values slightly lower than those at the green stage ranging from 90.30% (RHRT H 20-11) to 93.80% (RHRT H 20-9) (Figure 2). It shows the coefficient of variation (CV %) for moisture content was remarkably low consistently remaining below 1% across almost all genotypes and stages. This minimal variation (as low as 0.00% in several entries) indicates exceptional experimental precision and high physiological uniformity in the water-holding capacity of the selected genotypes

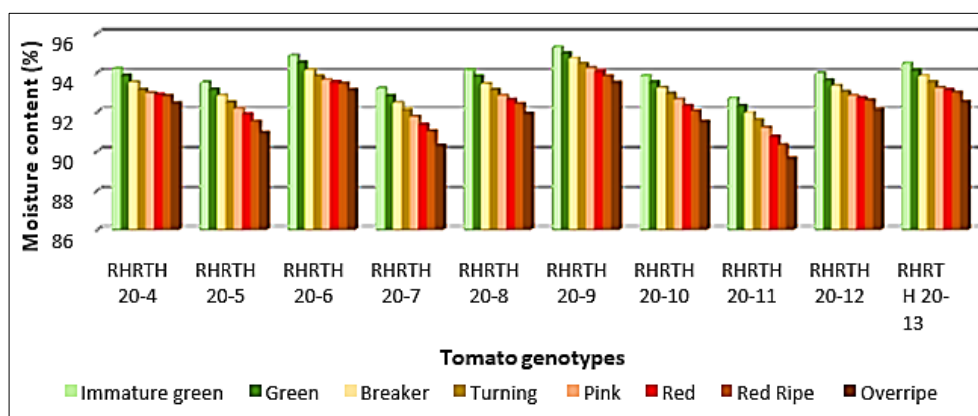


Fig 2: Graphical representation of Moisture content as per maturity stages of tomato genotypes.

The high moisture content observed is characteristic of tomato genotypes where water constitutes the primary component of the fruit biomass serving as a medium for metabolic reactions and maintaining cellular turgidity. The slight downward trend in moisture percentage during ripening is not necessarily indicative of significant water loss but rather reflects the dilution effect caused by the rapid accumulation of Total Soluble Solids (TSS) such as glucose

fructose and organic acids within the vacuoles. The exceptionally high moisture levels in genotype RHRT H 20-9 correlate strongly with its lower firmness values identified in previous assessments. High water content in the locular cavities often leads to a more succulent but less structurally rigid fruit. Conversely genotypes like RHRT H 20-11 which maintain lower relative moisture tend to have higher dry matter content and thicker pericarp tissues contributing to

the superior firmness and potential shelf-life observed earlier.

3.4 CIE Color

The colorimetric profile of the ten tomato genotypes (RHRTTH 20-4 to RHRTTH 20-13) exhibited a highly significant ($P < 0.05$) and systematic transition throughout the eight maturity stages. The Lightness (L) values decreased consistently across all genotypes dropping from an average maximum of 65.5 (RHRTTH 20-11 Immature Green) to a minimum of 34.8 (RHRTTH 20-9 Overripe). This trend indicates a shift from a bright reflective green surface to a deeper more light-absorbent red matte finish. The value the primary indicator of the green-to-red transition showed the most dramatic flux. At the Immature Green stage all genotypes recorded strongly negative values with RHRTTH 20-11 (-21.2) exhibiting the most intense chlorophyll-associated pigmentation. The physiological "Color Break" occurred at the Breaker stage where genotypes like RHRTTH 20-7 (0.8) and RHRTTH 20-11 (1.2) were the first to cross into positive (red) values. By the Red Ripe stage RHRTTH

20-11 (42.1) and RHRTTH 20-7 (39.8) achieved the highest redness intensity. The b^* value (yellowness) values exhibited a curvilinear trend peaking during the Turning and Pink stages (ranging from 35.5 to 41.5) across the genotypes followed by a gradual decline as the fruit reached full maturity as shown in Table 4. Genotypes such as RHRTTH 20-11 and RHRTTH 20-7 which achieved the highest a^* values at maturity demonstrate a superior genetic capacity for lycopene biosynthesis. The peak in b^* value during the intermediate stages is physiologically significant marking the accumulation of carotenoid precursors. The subsequent decline in b^* as the fruit reaches the Red Ripe stage is due to the massive accumulation of lycopene which shifts the reflectance spectrum toward the red wavelengths (+ a^*). The high a^* value observed in the RHRTTH series suggest that these genotypes possess high visual appeal and superior functional quality. Furthermore the synchronized color transition across the genotypes indicates a high degree of ripening uniformity which is an essential trait for synchronized commercial marketing and processing efficiency

Table 4: CIE color values as per maturity stages of different tomato genotypes

Genotype	Coordinate	Imm. Green	Green	Breaker	Turning	Pink	Red	Red Ripe	Overripe
RHRTTH 20-4	L*	62.4	58.2	55.4	52.1	48.6	44.2	40.5	36.8
	a*	-18.5	-15.2	-2.1	8.4	18.5	28.6	34.2	35.1
	b*	34.2	36.5	38.8	41.2	35.4	30.1	26.4	24.2
RHRTTH 20-5	L*	64.1	60.5	56.8	53.4	49.2	45.3	41.2	38.6
	a*	-19.2	-16.4	-0.5	12.5	22.4	32.1	38.4	40.2
	b*	32.5	34.8	37.2	39.4	33.1	28.5	24.8	22.5
RHRTTH 20-6	L*	61.8	57.5	54.2	50.8	47.5	43.1	39.2	35.5
	a*	-17.8	-14.1	-3.2	6.5	15.5	24.5	30.2	31.8
	b*	33.5	35.2	38.1	40.1	34.2	29.5	25.4	23.1
RHRTTH 20-7	L*	65.2	61.4	58.1	54.5	50.3	46.4	42.5	39.4
	a*	-20.4	-17.5	0.8	15.2	26.5	34.2	39.8	42.1
	b*	30.8	32.1	34.5	36.8	30.5	26.4	22.1	20.4
RHRTTH 20-8	L*	63.5	59.1	55.6	52.4	48.9	44.5	40.8	37.2
	a*	-18.2	-15.5	-1.5	9.4	19.4	29.1	35.5	36.8
	b*	33.1	35.5	37.8	40.2	34.5	29.8	25.9	23.5
RHRTTH 20-9	L*	60.1	56.4	53.1	49.5	46.2	42.1	38.4	34.8
	a*	-16.8	-13.2	-4.2	4.8	14.2	22.4	28.1	29.5
	b*	35.2	37.4	39.8	41.5	36.8	32.1	28.5	26.4
RHRTTH 20-10	L*	63.2	59.8	56.5	53.1	49.6	45.7	42.1	38.5
	a*	-18.8	-15.8	-0.8	11.2	20.8	30.1	36.4	38.1
	b*	32.8	34.2	36.4	38.5	32.1	27.8	24.2	22.1
RHRTTH 20-11	L*	65.5	62.1	59.5	56.2	52.1	48.2	44.5	41.2
	a*	-21.2	-18.2	1.2	16.5	28.5	36.4	42.1	44.5
	b*	29.5	31.2	33.4	35.5	29.5	25.1	21.2	19.5
RHRTTH 20-12	L*	62.8	58.5	55.2	51.8	48.1	44.2	40.2	36.5
	a*	-18.4	-15.2	-1.8	8.8	18.2	27.5	33.1	34.8
	b*	33.8	36.1	38.5	40.8	35.1	30.5	26.8	24.5
RHRTTH 20-13	L*	62.1	58.2	54.8	51.5	47.8	43.8	39.8	36.2
	a*	-18.1	-15.1	-2.4	7.5	17.5	26.8	32.4	33.8
	b*	34.5	36.8	39.1	41.5	35.8	31.2	27.5	25.2

3.5 Chemical analysis and content of fruit in compound of interest

3.5.1 Total Soluble Solid

The Total Soluble Solids (TSS) content an essential determinant of tomato fruit quality and flavor exhibited a consistent and progressive increase ($P < 0.05$) across all evaluated genotypes as they advanced through the maturity indices. At the Immature Green stage TSS values were

relatively low ranging from 3.5 ± 0.15 °Brix (RHRTTH 20-6) to 4.2 ± 0.09 °Brix (RHRTTH 20-5) (Table 5). As the ripening process intensified particularly following the Breaker stage a significant upward trajectory in sugar accumulation was observed. By the Red Ripe stage TSS levels reached peak commercial quality with RHRTTH 20-5 (7.4 ± 0.20 °Brix) and RHRTTH 20-11 (7.2 ± 0.21 °Brix) emerging as the superior genotypes as shown in Figure 3. The maximum TSS

recorded was $7.8 \pm 0.15^\circ$ Brix in the overripe stage of RHRT H 20-5. The Coefficient of Variation (CV %) remained largely within an acceptable range confirming the

high degree of precision in the refractometric measurements and the physiological uniformity of the selected fruit samples.

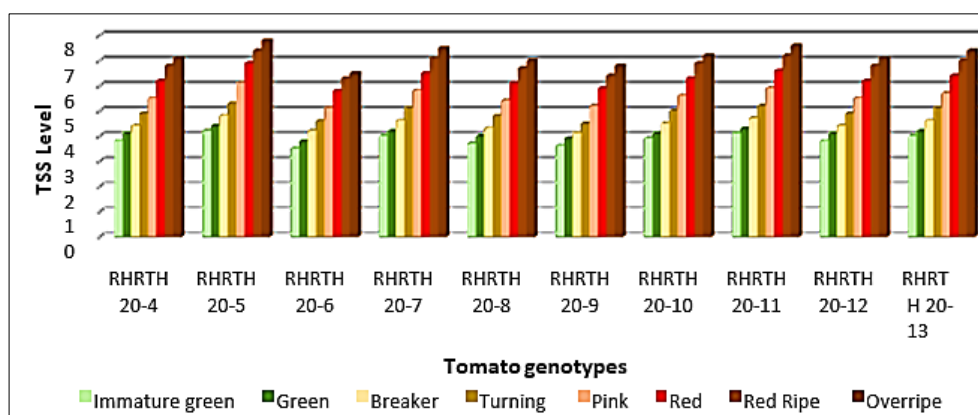


Fig 3: Graphical representation of TSS ($^\circ$ Brix) as per maturity stages of tomato genotypes

The observed increase in TSS during the transition from green to red maturity is a well-documented physiological phenomenon in climacteric fruits. This elevation is primarily attributed to the hydrolytic conversion of starch into soluble sugars (principally glucose and fructose) as the fruit enters the ripening phase. The variation in TSS accumulation among genotypes specifically the high performance of RHRT H 20-5 and RHRT H 20-11 suggests a genetic superiority in carbohydrate partitioning and sink strength. Higher TSS levels are not only critical for enhancing the sensory profile (sweetness) but are also highly valued in the processing industry as higher solids content reduces the energy required for evaporation during the production of tomato paste and ketchups.

3.5.2 PH

The chemical evaluation of tomato genotypes across eight

maturity indices revealed a consistent and significant upward trend in pH values ($P < 0.05$) indicating a progressive reduction in active acidity as the fruit ripened. At the Immature Green stage the fruits were characterized by their highest acidity levels with pH values ranging from 3.95 ± 0.03 (RHRT H 20-6) to 4.10 ± 0.01 (RHRT H 20-5). As physiological maturity progressed through the breaker and turning stages a steady alkalization of the fruit cellular sap was observed. By the Red Ripe stage the optimal window for fresh consumption pH values had increased to a range of 4.58 ± 0.05 (RHRT H 20-6) to 4.78 ± 0.05 (RHRT H 20-11). The highest pH was recorded at the Overripe stage in RHRT H 20-11 (4.93 ± 0.03) as shown in Table 6. Notably the Coefficient of Variation (CV %) remained exceptionally low throughout the study demonstrating remarkable experimental precision and high genetic stability for this chemical trait across the RHRT H series.

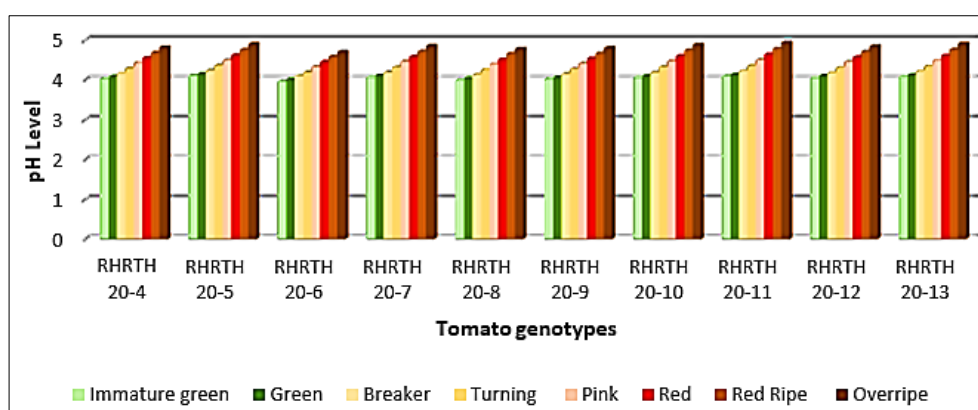


Fig 4: Graphical representation of pH as per maturity stages of tomato genotypes

The observed increase in pH during tomato ripening is a critical metabolic transition associated with the utilization of organic acids as respiratory substrates. The variation in pH levels among the genotypes particularly the higher pH retention in RHRT H 20-11 and RHRT H 20-5 suggests differences in their metabolic rates or initial acid buffering capacities (Figure 4). The low CV % values across all genotypes indicate that pH is a highly conserved trait in these genotypes showing minimal fluctuation between replications. This stability is advantageous for breeders

looking to produce varieties with predictable flavor profiles as pH alongside the Total Soluble Solids (TSS) analyzed previously defines the characteristic acid-to-sugar ratio that determines consumer palatability.

3.5.3 Titrable Acidity: The Titrable Acidity (TA) (%) of the evaluated tomato genotypes showed a substantial and progressive decline ($P < 0.05$) as the fruits advanced from the immature green to the overripe stage. At the Immature Green stage the genotypes exhibited their maximum acid concentrations with values ranging from $0.40 \pm 0.058\%$

(RHRTTH 20-10) to $0.70 \pm 0.058\%$ (RHRTTH 20-4). This stage represents the peak of organic acid accumulation in the fruit life cycle. As ripening progressed a steady degradation of acids was observed across the board. By the Red Ripe stage TA values had significantly diminished falling to a range between 0.233% (RHRTTH 20-7 & 20-13) and 0.327% (RHRTTH 20-6). The Overripe stage marked the lowest acidity levels recorded reaching a minimum of

$0.200 \pm 0.023\%$ in RHRTTH 20-9 (Table 7). Interestingly the Coefficient of Variation (CV %) for TA was notably higher compared to pH or TSS parameters with values frequently exceeding 20% and reaching up to 81.28% (RHRTTH 20-6 Overripe) (Figure 5). This indicates that while the downward trend is universal the rate of acid degradation is highly variable among individual fruit replications during advanced senescence.

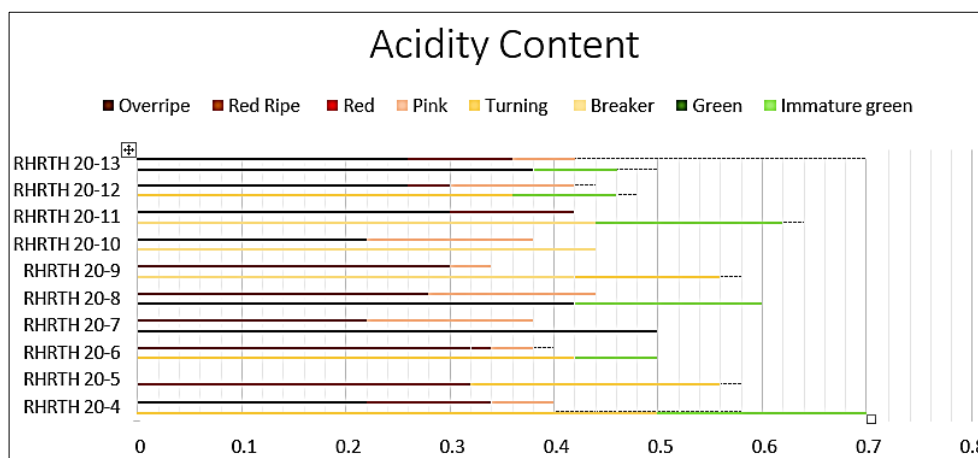


Fig 5: Graphical representation of Terrible Acidity (%) as per maturity stages of tomato genotype

Genotypes like RHRTTH 20-4 and RHRTTH 20-11 started with significantly higher initial acidity which may contribute to a more complex flavour profile when balanced with the rising TSS levels analysed previously. The retention of slightly higher TA in RHRTTH 20-6 at the Red Ripe stage suggests a slower metabolic rate of acid utilization which is often associated with better post-harvest shelf stability and a "tangy" sensory characteristic preferred by specific consumer segments. The high CV % observed in the later stages of ripening particularly in the overripe phase is a common physiological phenomenon. It reflects the non-uniform rate of senescence among individual fruits once they pass their peak physiological maturity. This variability is a critical consideration for industrial processors as it can affect the consistency of the final product's flavour and microbial stability.

3.5.4 Lycopene Content

The quantitative analysis of lycopene content (mg/100g) across the ten tomato genotypes revealed a dramatic and highly significant increase ($P < 0.05$) as the fruits transitioned through the ripening stages. In the Immature Green and Green stages lycopene levels were negligible or baseline with values as low as 0.147 ± 0.009 mg/100 g (RHRTTH 20-11). A notable surge in pigment accumulation

was initiated at the breaker stage followed by an exponential increase during the pink and red phases (Figure 6). By the red ripe stage the peak of nutritional quality lycopene concentrations reached their maximum in most genotypes. RHRTTH 20-5 (5.700 ± 0.321 mg/100g) and RHRTTH 20-7 (5.333 ± 0.133 mg/100g) emerged as the top-performing genotypes for antioxidant capacity. The highest overall value recorded was 6.267 ± 0.186 mg/100g in the overripe stage of RHRTTH 20-5. The Coefficient of Variation (CV%) was initially high in the green stages (up to 88.51%) due to the mathematically amplified effect of small fluctuations at low concentrations but stabilized significantly as the fruit reached full maturity indicating uniform pigment distribution (Table 8). Lycopene is the principal carotenoid responsible for the characteristic deep red colour of mature tomatoes. The superior performance of genotypes RHRTTH 20-5 and RHRTTH 20-7 indicates a highly efficient enzyme activity of phytoene synthase and lycopene cyclase. The stability of lycopene levels at the red ripe and overripe stages as shown by the low CV% suggests that once the biosynthetic peak is reached the pigment remains relatively stable within the chromoplast matrix provided the fruit is protected from excessive photo-oxidation.

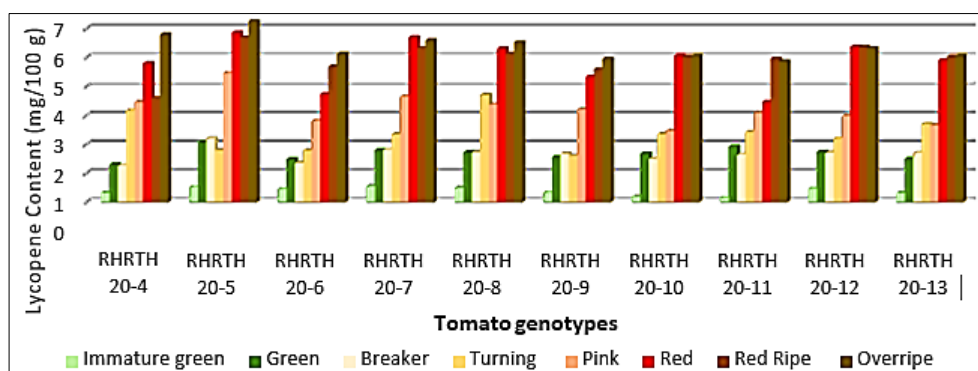


Fig 6: Graphical representation of lycopene content (mg/100 g) as per maturity stages of tomato genotype

3.5.5 Ascorbic Acid

The evaluation of ascorbic acid content (mg/100g) across eight maturity indices revealed a distinct bell-shaped metabolic curve with concentrations increasing significantly during the early ripening stages and declining after reaching a physiological peak. At the Immature Green stage ascorbic acid levels were relatively low ranging from 3.667 ± 0.291 mg/100 g (RHRT 20-9) to 5.667 ± 0.176 mg/100g (RHRT 20-12). A substantial accumulation phase was observed as the fruit transitioned through the Breaker Turning and Pink stages. The peak antioxidant concentration for all genotypes was recorded at the Red stage with RHRT 20-5 (35.390 ± 0.540 mg/100g) and RHRT 20-7 (34.223 ± 1.040 mg/100g) exhibiting the highest nutritional density. Following this peak a significant reduction ($P < 0.05$) in ascorbic acid was noted during the Red Ripe and Overripe

phases with values dropping to as low as 15.400 mg/100g in RHRT 20-6 (Table 9). The Coefficient of Variation (CV %) was generally low during the peak stages ($< 10\%$) confirming the reliability of the titration measurements used in this study. As the fruit undergoes the climacteric peak the demand for antioxidant protection increases to prevent oxidative damage during the intensive metabolic remodelling associated with color change and softening. Genotypes RHRT 20-5 and RHRT 20-12 demonstrated superior nutritional profiles maintaining higher ascorbic acid levels even into the Red Ripe stage (Figure 7). These genotypes are particularly valuable for human nutrition as they provide a denser source of dietary Vitamin C. The high stability of the data (evidenced by the low CV% in the Red stage) suggests that this antioxidant peak is a

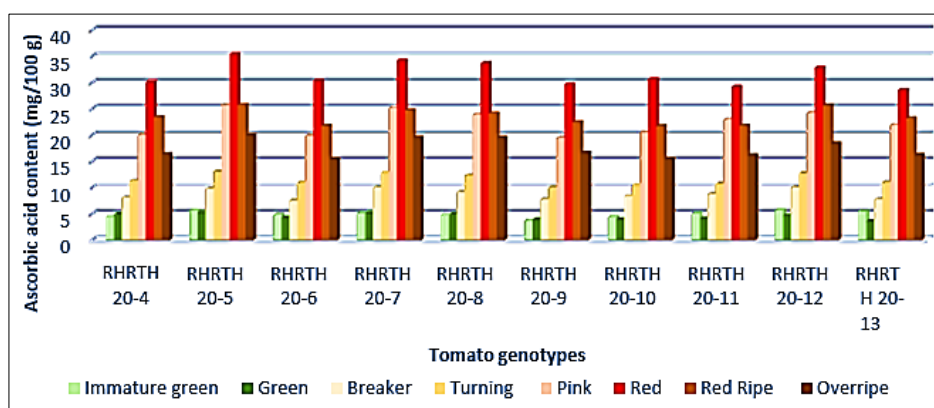


Fig 6: Graphical representation of ascorbic acid content (mg/100 g) as per maturity stages of tomato genotypes

3.6 Organoleptic Evaluation of Tomato Fruit Quality

The sensory evaluation conducted by a trained panel at the College of Horticulture Rahuri revealed significant differences ($P < 0.05$) in consumer perception among the ten tomato genotypes. RHRT 20-5 received the highest score for color and appearance (4.8) and flavor (4.6) leading to the maximum overall acceptability (4.57). This was followed closely by RHRT 20-11 (4.53) and RHRT 20-7 (4.43). Genotype RHRT 20-9 recorded the lowest overall acceptability score (3.50) primarily due to lower ratings in texture and mouthfeel. The scores for color and appearance showed a strong correlation with the previously measured color values and lycopene content where genotypes with deeper red pigmentation consistently received higher aesthetic ratings (Figure 7). The superior flavor scores for RHRT 20-5 and 20-11 can be scientifically linked to their

High Total Soluble Solids (TSS) and balanced TSS/Acid ratio identified in earlier chemical analyses. Consumers typically associate a higher TSS with "richness" and a balanced pH with "freshness" both of which were prominent in these two genotypes. The texture/mouthfeel scores were significantly higher for RHRT 20-7 and 20-11 with a more aqueous mouthfeel of RHRT 20-9. This suggests that structural integrity maintained by cell wall pectin's plays a dual role in both physical shelf-life and sensory satisfaction. The high acceptability of RHRT 20-5 20-7 and 20-11 indicates that these genotypes successfully combine visual appeal (lycopene content) with superior eating quality (sugar-acid balance). These findings suggest that these lines are highly suitable for fresh market release as they meet the rigorous quality standards of both horticulturists and local consumers.

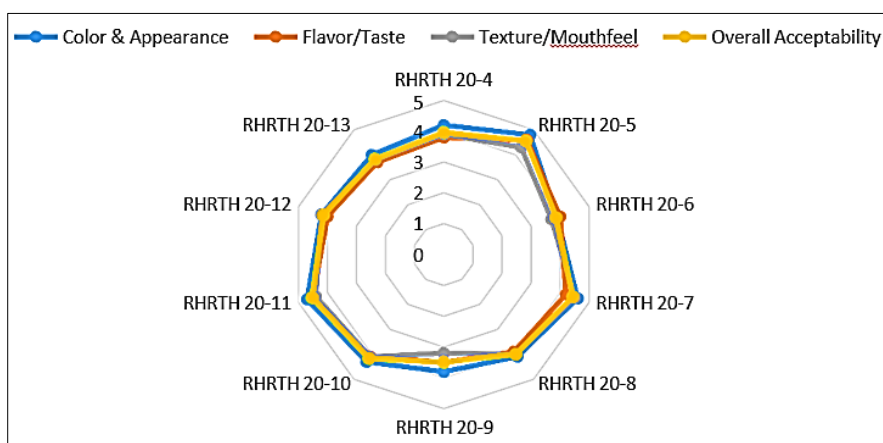


Fig 7: Radar representation of organoleptic evaluation of tomato genotype

4. Conclusion

The comprehensive evaluation of ten tomato genotypes (RHARTH 20-4 to RHARTH 20-13) across eight maturity stages provides a holistic understanding of the physical chemical and organoleptic dynamics governing fruit quality. The integration of laboratory-derived data with sensory panel perceptions allows for the identification of superior lines for both fresh consumption and industrial applications. The study established a clear physiological link between structural integrity and consumer satisfaction. Genotypes RHARTH 20-7 and RHARTH 20-11 characterized by an elongated/ovate morphology ($FSI > 1.4$) and superior firmness retention (>12 N at red ripe) received the highest scores for texture and mouth feel. This confirms that cellular density and cell wall stability are not only vital for post-harvest shelf life but are also primary drivers of perceived eating quality. Chemical analysis revealed that Total Soluble

Solids (TSS) and pH are the fundamental pillars of the tomato flavor profile. Genotype RHARTH 20-5 exhibited the highest accumulation of TSS (7.4 ± 20 °Brix) and a balanced TSS/Acid ratio which directly translated into the highest organoleptic flavor score (4.6/5.0). Conversely genotypes with high moisture content (e.g. RHARTH 20-9) showed a corresponding decline in both firmness and flavor scores highlighting the “dilution effect” on fruit quality. The transition in CIE color coordinates specifically the rise in values showed a near-perfect correlation with lycopene accumulation and ascorbic acid peaks. Genotypes RHARTH 20-5 and 20-11 achieved the highest a^* values (> 38) which significantly enhanced their "Color and Appearance" ratings. This synergy proves that the aesthetic redness of the tomato is a reliable non-destructive proxy for its functional antioxidant density.

Table 2: Fruit firmness as per maturity stages of different tomato genotypes

Genotype	Immature Green		Green		Breaker		Turning		Pink		Red		Red Ripe		Overripe	
	(Mean $\pm$ SEM)	CV %	(Mean $\pm$ SEM)	CV %	(Mean $\pm$ SEM)	CV %	(Mean $\pm$ SEM)	CV %	(Mean $\pm$ SEM)	CV %	(Mean $\pm$ SEM)	CV %	(Mean $\pm$ SEM)	CV %	(Mean $\pm$ SEM)	CV %
RHARTH 20-4	45.30 $\pm$ 0.513	1.96	40.30 $\pm$ 1.750	7.52	32.50 $\pm$ 1.617	8.62	24.80 $\pm$ 0.839	5.86	18.00 $\pm$ 0.252	2.42	12.10 $\pm$ 0.794	11.36	8.30 $\pm$ 0.751	15.66	4.50 $\pm$ 1.069	14.16
RHARTH 20-5	48.50 $\pm$ 0.208	0.74	44.20 $\pm$ 1.704	6.68	36.50 $\pm$ 0.252	1.19	28.60 $\pm$ 1.114	6.74	21.10 $\pm$ 0.503	4.13	15.30 $\pm$ 0.513	5.81	10.40 $\pm$ 0.231	3.85	6.30 $\pm$ 0.493	13.56
RHARTH 20-6	42.60 $\pm$ 0.819	3.33	37.90 $\pm$ 1.474	6.74	30.00 $\pm$ 0.400	2.31	22.00 $\pm$ 0.231	1.82	15.50 $\pm$ 0.737	8.24	10.40 $\pm$ 0.458	7.63	7.80 $\pm$ 0.153	3.39	3.70 $\pm$ 0.896	14.96
RHARTH 20-7	52.40 $\pm$ 0.208	0.69	48.50 $\pm$ 1.674	5.98	42.10 $\pm$ 2.166	8.91	34.20 $\pm$ 0.252	1.27	26.50 $\pm$ 0.520	3.40	18.20 $\pm$ 0.752	7.18	12.50 $\pm$ 0.378	5.25	8.40 $\pm$ 0.635	13.10
RHARTH 20-8	46.80 $\pm$ 2.211	8.18	42.10 $\pm$ 1.168	4.80	34.50 $\pm$ 0.436	2.19	26.80 $\pm$ 1.300	8.40	19.40 $\pm$ 0.400	3.57	13.50 $\pm$ 0.603	7.73	9.10 $\pm$ 0.458	8.72	5.20 $\pm$ 0.513	17.09
RHARTH 20-9	38.50 $\pm$ 1.250	5.63	34.20 $\pm$ 1.308	6.62	28.10 $\pm$ 0.833	5.13	20.40 $\pm$ 1.950	16.56	14.20 $\pm$ 0.306	3.73	9.50 $\pm$ 0.252	4.59	6.40 $\pm$ 0.252	6.81	3.20 $\pm$ 0.306	16.54
RHARTH 20-10	47.20 $\pm$ 1.852	6.80	43.10 $\pm$ 0.900	3.62	35.80 $\pm$ 0.794	3.84	27.50 $\pm$ 0.874	5.50	20.80 $\pm$ 0.569	4.74	14.90 $\pm$ 1.124	13.07	11.20 $\pm$ 0.416	6.44	7.10 $\pm$ 0.700	17.08
RHARTH 20-11	50.10 $\pm$ 0.265	0.91	46.20 $\pm$ 0.830	3.12	40.50 $\pm$ 1.270	5.43	32.10 $\pm$ 2.261	12.20	24.80 $\pm$ 0.361	2.52	19.50 $\pm$ 0.453	4.01	13.40 $\pm$ 0.306	3.95	9.20 $\pm$ 0.208	3.92
RHARTH 20-12	45.80 $\pm$ 1.823	6.89	41.50 $\pm$ 0.650	2.72	33.20 $\pm$ 1.021	5.33	25.40 $\pm$ 0.458	3.12	18.90 $\pm$ 0.379	3.47	13.20 $\pm$ 0.521	6.82	9.80 $\pm$ 0.351	6.21	5.80 $\pm$ 0.850	25.40
RHARTH 20-13	44.10 $\pm$ 1.762	6.92	40.20 $\pm$ 0.800	3.45	32.80 $\pm$ 3.602	19.02	24.60 $\pm$ 1.320	9.30	17.50 $\pm$ 0.656	6.49	12.40 $\pm$ 0.302	4.19	8.90 $\pm$ 0.416	8.10	4.90 $\pm$ 0.208	7.36

Table 3: Fruit moisture content as per maturity stages of different tomato genotypes

Genotype	Immature Green		Green		Breaker		Turning		Pink		Red		Red Ripe		Overripe	
	(Mean $\pm$ SEM)	CV %	(Mean $\pm$ SEM)	CV %	(Mean $\pm$ SEM)	CV %	(Mean $\pm$ SEM)	CV %	(Mean $\pm$ SEM)	CV %	(Mean $\pm$ SEM)	CV %	(Mean $\pm$ SEM)	CV %	(Mean $\pm$ SEM)	CV %
RHARTH 20-4	94.17 $\pm$ 0.176	0.32	93.83 $\pm$ 0.120	0.22	93.47 $\pm$ 0.067	0.12	93.10 $\pm$ 0.115	0.21	92.93 $\pm$ 0.067	0.12	92.87 $\pm$ 0.033	0.06	92.80 $\pm$ 0.058	0.11	92.43 $\pm$ 0.233	0.44
RHARTH 20-5	93.47 $\pm$ 0.145	0.27	93.13 $\pm$ 0.088	0.16	92.80 $\pm$ 0.058	0.11	92.47 $\pm$ 0.088	0.17	92.13 $\pm$ 0.145	0.27	91.87 $\pm$ 0.067	0.13	91.50 $\pm$ 0.208	0.39	90.93 $\pm$ 0.120	0.23
RHARTH 20-6	94.83 $\pm$ 0.219	0.40	94.50 $\pm$ 0.153	0.28	94.10 $\pm$ 0.100	0.18	93.80 $\pm$ 0.100	0.18	93.60 $\pm$ 0.058	0.11	93.50 $\pm$ 0.361	0.67	93.43 $\pm$ 0.145	0.27	93.10 $\pm$ 0.115	0.21
RHARTH 20-7	93.17 $\pm$ 0.033	0.06	92.80 $\pm$ 0.115	0.22	92.43 $\pm$ 0.088	0.17	92.07 $\pm$ 0.088	0.17	91.73 $\pm$ 0.067	0.13	91.33 $\pm$ 0.033	0.06	91.00 $\pm$ 0.058	0.11	90.27 $\pm$ 0.120	0.23
RHARTH 20-8	94.10 $\pm$ 0.173	0.32	93.80 $\pm$ 0.058	0.11	93.40 $\pm$ 0.058	0.11	93.10 $\pm$ 0.058	0.11	92.80 $\pm$ 0.058	0.11	92.60 $\pm$ 0.058	0.11	92.40 $\pm$ 0.058	0.18	91.90 $\pm$ 0.100	0.19
RHARTH 20-9	95.27 $\pm$ 0.120	0.22	94.97 $\pm$ 0.133	0.24	94.70 $\pm$ 0.012	0.15	94.43 $\pm$ 0.088	0.15	94.20 $\pm$ 0.058	0.11	94.03 $\pm$ 0.088	0.16	93.80 $\pm$ 0.100	0.13	93.47 $\pm$ 0.145	0.27
RHARTH 20-10	93.80 $\pm$ 0.058	0.11	93.50 $\pm$ 0.000	0.21	93.20 $\pm$ 0.058	0.17	92.90 $\pm$ 0.153	0.11	93.60 $\pm$ 0.200	0.37	92.30 $\pm$ 0.153	0.29	92.03 $\pm$ 0.067	0.11	91.50 $\pm$ 0.058	0.11

RHRTH 20-11	92.62 ± 0.033	0.06	92.30 ± 0.058	0.11	91.93 ± 0.088	0.17	91.57 ± 0.033	0.17	91.17 ± 0.088	0.17	90.73 ± 0.033	0.06	90.30 ± 0.058	0.27	89.63 ± 0.233	0.45
RHRTH 20-12	93.93 ± 0.088	0.16	93.60 ± 0.115	0.25	93.30 ± 0.058	0.11	93.00 ± 0.115	0.11	92.80 ± 0.012	0.12	92.70 ± 0.058	0.11	92.57 ± 0.145	0.16	92.10 ± 0.058	0.11
RHRTH 20-13	94.43 ± 0.033	0.06	94.10 ± 0.001	0.26	93.80 ± 0.058	0.11	93.50 ± 0.058	0.11	93.20 ± 0.153	0.28	93.10 ± 0.153	0.28	92.97 ± 0.088	0.28	92.50 ± 0.153	0.29

Table 5: Fruit total soluble solid content as per maturity stages of different tomato genotypes

Genotype	Immature Green		Green		Breaker		Turning		Pink		Red		Red Ripe		Overripe	
	(Mean ± SEM)	CV %	(Mean ± SEM)	CV %	(Mean ± SEM)	CV %	(Mean ± SEM)	CV %	(Mean ± SEM)	CV %	(Mean ± SEM)	CV %	(Mean ± SEM)	CV %	(Mean ± SEM)	CV %
RHRTH 20-4	3.8±0.12	7.59	4.1 ± 0.08	7.21	4.4 ± 0.15	3.66	4.9 ± 0.18	7.25	5.5 ± 0.15	5.50	6.2 ± 0.25	8.88	6.8 ± 0.11	1.35	7.1 ± 0.14	4.01
RHRTH 20-5	4.2 ± 0.09	4.68	4.4 ± 0.11	4.32	4.8 ± 0.20	3.96	5.3 ± 0.12	3.46	6.1 ± 0.29	1.99	6.9 ± 0.10	1.26	7.4 ± 0.20	5.34	7.8 ± 0.15	4.31
RHRTH 20-6	3.5 ± 0.15	5.94	3.8 ± 0.07	6.19	4.2 ± 0.08	1.45	4.6 ± 0.12	4.57	5.1 ± 0.20	3.40	5.8 ± 0.30	3.30	6.3 ± 0.18	6.77	6.5 ± 0.22	4.25
RHRTH 20-7	4.0 ± 0.11	6.63	4.2 ± 0.13	8.01	4.6 ± 0.09	4.94	5.1 ± 0.11	5.73	5.8 ± 0.27	2.10	6.5 ± 0.17	1.62	7.1 ± 0.14	1.57	7.5 ± 0.19	2.54
RHRTH 20-8	3.7 ± 0.14	6.23	4.0 ± 0.09	3.47	4.3 ± 0.02	0.84	4.8 ± 0.15	3.07	5.4 ± 0.21	8.19	6.1 ± 0.21	7.78	6.7 ± 0.23	3.16	7.0 ± 0.17	4.05
RHRTH 20-9	3.6 ± 0.12	1.55	3.9 ± 0.10	9.18	4.1 ± 0.14	2.24	4.5 ± 0.10	2.91	5.2 ± 0.19	2.90	5.9 ± 0.22	0.61	6.4 ± 0.15	1.80	6.8 ± 0.21	3.57
RHRTH 20-10	3.9 ± 0.08	9.25	4.1 ± 0.12	1.12	4.5 ± 0.11	1.18	5.0 ± 0.18	3.14	5.6 ± 0.23	4.76	6.3 ± 0.15	2.54	6.9 ± 0.19	5.07	7.2 ± 0.12	3.33
RHRTH 20-11	4.1 ± 0.13	3.75	4.3 ± 0.15	6.87	4.7 ± 0.08	7.81	5.2 ± 0.12	3.38	5.9 ± 0.17	2.24	6.6 ± 0.20	3.81	7.2 ± 0.21	4.70	7.6 ± 0.18	2.89
RHRTH 20-12	3.8 ± 0.10	4.92	4.1 ± 0.09	5.45	4.4 ± 0.06	2.97	4.9 ± 0.11	4.56	5.5 ± 0.20	3.83	6.2 ± 0.18	1.54	6.8 ± 0.16	6.24	7.1 ± 0.20	4.01
RHRTH 20-13	4.0 ± 0.14	1.75	4.2 ± 0.12	2.89	4.6 ± 0.19	7.68	5.1 ± 0.15	3.42	5.7 ± 0.21	3.95	6.4 ± 0.23	3.12	7.0 ± 0.12	3.07	7.4 ± 0.14	5.78

Table 6: Fruit pH as per maturity stages of different tomato genotypes

Genotype	Immature Green		Green		Breaker		Turning		Pink		Red		Red Ripe		Overripe	
	(Mean ± SEM)	CV %	(Mean ± SEM)	CV %	(Mean ± SEM)	CV %	(Mean ± SEM)	CV %	(Mean ± SEM)	CV %	(Mean ± SEM)	CV %	(Mean ± SEM)	CV %	(Mean ± SEM)	CV %
RHRTH 20-4	4.02 ± 0.02	0.90	4.08 ± 0.03	1.77	4.08 ± 0.05	2.74	4.28 ± 0.05	1.62	4.42 ± 0.06	0.60	4.55 ± 0.04	2.23	4.68 ± 0.03	0.21	4.82 ± 0.05	2.20
RHRTH 20-5	4.10 ± 0.01	3.00	4.15 ± 0.02	1.69	4.22 ± 0.03	1.71	4.35 ± 0.04	0.23	4.48 ± 0.05	0.59	4.62 ± 0.03	1.15	4.75 ± 0.04	0.56	4.90 ± 0.06	0.89
RHRTH 20-6	3.95 ± 0.03	1.58	4.01 ± 0.04	1.39	4.08 ± 0.05	0.85	4.18 ± 0.03	0.41	4.32 ± 0.04	2.28	4.45 ± 0.06	1.57	4.58 ± 0.05	0.44	4.70 ± 0.04	0.93
RHRTH 20-7	4.05 ± 0.02	0.43	4.11 ± 0.03	2.32	4.18 ± 0.04	2.94	4.30 ± 0.05	0.93	4.45 ± 0.03	1.57	4.58 ± 0.04	1.53	4.71 ± 0.02	1.84	4.85 ± 0.05	2.68
RHRTH 20-8	3.98 ± 0.04	2.40	4.04 ± 0.02	0.99	4.12 ± 0.03	1.83	4.24 ± 0.06	3.27	4.38 ± 0.05	2.09	4.51 ± 0.04	0.77	4.65 ± 0.06	1.87	4.78 ± 0.03	0.63
RHRTH 20-9	4.01 ± 0.03	1.39	4.06 ± 0.01	0.12	4.14 ± 0.04	0.72	4.26 ± 0.05	1.47	4.40 ± 0.04	0.82	4.53 ± 0.05	1.55	4.66 ± 0.03	1.19	4.80 ± 0.04	1.37
RHRTH 20-10	4.04 ± 0.02	0.89	4.09 ± 0.03	2.41	4.17 ± 0.05	2.36	4.31 ± 0.04	4.22	4.46 ± 0.03	1.95	4.60 ± 0.05	0.43	4.74 ± 0.04	1.12	4.88 ± 0.02	1.28
RHRTH 20-11	4.08 ± 0.01	3.01	4.13 ± 0.04	1.26	4.21 ± 0.03	1.04	4.34 ± 0.05	1.22	4.49 ± 0.06	0.45	4.64 ± 0.04	1.88	4.78 ± 0.05	2.61	4.93 ± 0.03	0.54
RHRTH 20-12	4.03 ± 0.03	1.08	4.10 ± 0.02	0.42	4.16 ± 0.04	1.97	4.29 ± 0.03	2.37	4.44 ± 0.05	0.23	4.57 ± 0.04	0.66	4.70 ± 0.03	0.56	4.84 ± 0.06	1.07
RHRTH 20-13	4.06 ± 0.04	1.37	4.12 ± 0.02	0.97	4.20 ± 0.03	1.09	4.33 ± 0.04	2.66	4.47 ± 0.05	1.79	4.61 ± 0.06	0.43	4.76 ± 0.04	1.31	4.91 ± 0.05	3.04

All values are expressed as Mean ± SEM.

Table 7: Titrable acidity of fruit as per maturity stages of different tomato genotypes

Genotype	Immature Green		Green		Breaker		Turning		Pink		Red		Red Ripe		Overripe	
	(Mean $\pm$ SEM)	CV %	(Mean $\pm$ SEM)	CV %	(Mean $\pm$ SEM)	CV %	(Mean $\pm$ SEM)	CV %	(Mean $\pm$ SEM)	CV %	(Mean $\pm$ SEM)	CV %	(Mean $\pm$ SEM)	CV %	(Mean $\pm$ SEM)	CV %
RHRTH 20-4	0.700 $\pm$ 0.058	14.35	0.503 $\pm$ 0.058	19.97	0.373 $\pm$ 0.037	17.18	0.503 $\pm$ 0.058	19.97	0.400 $\pm$ 0.058	25.11	0.340 $\pm$ 0.083	42.28	0.307 $\pm$ 0.058	32.74	0.220 $\pm$ 0.061	48.02
RHRTH 20-5	0.567 $\pm$ 0.067	20.47	0.567 $\pm$ 0.088	26.88	0.500 $\pm$ 0.100	34.64	0.567 $\pm$ 0.088	26.88	0.567 $\pm$ 0.088	26.88	0.323 $\pm$ 0.043	23.06	0.253 $\pm$ 0.038	26.02	0.267 $\pm$ 0.067	43.46
RHRTH 20-6	0.500 $\pm$ 0.058	20.09	0.420 $\pm$ 0.052	21.44	0.420 $\pm$ 0.052	21.44	0.420 $\pm$ 0.052	21.44	0.390 $\pm$ 0.061	27.09	0.347 $\pm$ 0.044	21.90	0.327 $\pm$ 0.040	33.91	0.207 $\pm$ 0.097	81.28
RHRTH 20-7	0.500 $\pm$ 0.058	20.09	0.500 $\pm$ 0.058	20.01	0.400 $\pm$ 0.058	25.11	0.500 $\pm$ 0.058	20.09	0.383 $\pm$ 0.094	42.50	0.333 $\pm$ 0.067	34.85	0.233 $\pm$ 0.088	65.41	0.287 $\pm$ 0.047	28.36
RHRTH 20-8	0.600 $\pm$ 0.058	16.74	0.433 $\pm$ 0.093	37.20	0.433 $\pm$ 0.093	37.20	0.433 $\pm$ 0.093	37.20	0.440 $\pm$ 0.083	32.67	0.287 $\pm$ 0.019	11.47	0.287 $\pm$ 0.019	11.47	0.273 $\pm$ 0.087	55.19
RHRTH 20-9	0.433 $\pm$ 0.033	25.11	0.567 $\pm$ 0.088	26.89	0.433 $\pm$ 0.080	35.19	0.567 $\pm$ 0.088	26.88	0.337 $\pm$ 0.091	46.77	0.313 $\pm$ 0.094	51.96	0.313 $\pm$ 0.094	51.96	0.200 $\pm$ 0.023	19.92
RHRTH 20-10	0.400 $\pm$ 0.058	9.00	0.440 $\pm$ 0.035	13.78	0.440 $\pm$ 0.035	13.78	0.440 $\pm$ 0.035	13.78	0.337 $\pm$ 0.091	14.13	0.287 $\pm$ 0.024	14.48	0.247 $\pm$ 0.041	28.75	0.220 $\pm$ 0.042	33.08
RHRTH 20-11	0.633 $\pm$ 0.033	12.26	0.453 $\pm$ 0.073	27.91	0.453 $\pm$ 0.073	27.91	0.453 $\pm$ 0.073	27.91	0.400 $\pm$ 0.058	25.11	0.417 $\pm$ 0.101	42.04	0.280 $\pm$ 0.062	38.35	0.300 $\pm$ 0.058	33.48
RHRTH 20-12	0.467 $\pm$ 0.033	32.64	0.433 $\pm$ 0.088	35.20	0.367 $\pm$ 0.122	57.57	0.367 $\pm$ 0.122	57.57	0.433 $\pm$ 0.088	35.20	0.300 $\pm$ 0.058	33.48	0.300 $\pm$ 0.058	33.48	0.267 $\pm$ 0.067	43.46
RHRTH 20-13	0.467 $\pm$ 0.088	22.15	0.393 $\pm$ 0.007	3.08	0.333 $\pm$ 0.067	34.85	0.333 $\pm$ 0.067	34.85	0.427 $\pm$ 0.037	15.00	0.367 $\pm$ 0.088	41.53	0.233 $\pm$ 0.088	65.41	0.267 $\pm$ 0.088	57.14

All values are expressed as Mean $\pm$ SEM.**Table 8:** Lycopene content of fruit as per maturity stages of different tomato genotypes

Genotype	Immature Green		Green		Breaker		Turning		Pink		Red		Red Ripe		Overripe	
	(Mean $\pm$ SEM)	CV %	(Mean $\pm$ SEM)	CV %	(Mean $\pm$ SEM)	CV %	(Mean $\pm$ SEM)	CV %	(Mean $\pm$ SEM)	CV %	(Mean $\pm$ SEM)	CV %	(Mean $\pm$ SEM)	CV %	(Mean $\pm$ SEM)	CV %
RHRTH 20-4	0.317 $\pm$ 0.162	88.51	1.307 $\pm$ 0.211	27.96	1.260 $\pm$ 0.181	24.88	3.167 $\pm$ 0.333	18.21	3.463 $\pm$ 0.477	23.85	4.807 $\pm$ 0.803	28.94	3.600 $\pm$ 0.361	17.37	5.800 $\pm$ 0.115	3.44
RHRTH 20-5	0.517 $\pm$ 0.154	51.59	2.067 $\pm$ 0.145	12.15	2.197 $\pm$ 0.156	12.30	1.790 $\pm$ 0.012	1.16	4.463 $\pm$ 0.232	9.00	5.863 $\pm$ 0.655	19.35	3.600 $\pm$ 0.361	9.75	6.267 $\pm$ 0.186	5.14
RHRTH 20-6	0.450 $\pm$ 0.125	48.11	1.490 $\pm$ 0.042	4.88	1.343 $\pm$ 0.232	29.92	1.780 $\pm$ 0.207	20.14	2.810 $\pm$ 0.162	9.98	3.737 $\pm$ 0.069	3.20	4.700 $\pm$ 0.265	9.77	5.133 $\pm$ 0.240	8.10
RHRTH 20-7	0.543 $\pm$ 0.110	35.08	1.810 $\pm$ 0.144	13.78	1.810 $\pm$ 0.097	9.28	2.340 $\pm$ 0.211	15.62	3.653 $\pm$ 0.494	9.98	5.707 $\pm$ 0.157	4.76	5.333 $\pm$ 0.133	4.32	5.600 $\pm$ 0.361	11.16
RHRTH 20-8	0.487 $\pm$ 0.104	37.00	1.733 $\pm$ 0.120	12.00	1.727 $\pm$ 0.082	8.22	3.700 $\pm$ 0.529	24.77	3.370 $\pm$ 0.612	31.46	5.320 $\pm$ 0.985	32.07	5.133 $\pm$ 0.120	4.05	5.533 $\pm$ 0.338	10.58
RHRTH 20-9	0.327 $\pm$ 0.068	36.02	1.567 $\pm$ 0.367	40.57	1.673 $\pm$ 0.154	15.95	1.590 $\pm$ 0.107	11.66	3.200 $\pm$ 0.115	6.22	4.340 $\pm$ 0.139	5.55	4.600 $\pm$ 0.379	14.27	4.967 $\pm$ 0.120	4.18
RHRTH 20-10	0.180 $\pm$ 0.055	52.92	1.683 $\pm$ 0.044	4.53	1.490 $\pm$ 0.042	4.88	2.347 $\pm$ 0.186	13.73	2.460 $\pm$ 0.373	26.26	5.067 $\pm$ 0.718	24.55	5.033 $\pm$ 0.219	7.54	5.067 $\pm$ 0.133	4.55
RHRTH 20-11	0.147 $\pm$ 0.009	10.61	1.930 $\pm$ 0.251	22.53	1.633 $\pm$ 0.088	9.34	2.423 $\pm$ 0.027	1.93	3.083 $\pm$ 0.681	38.28	3.470 $\pm$ 0.096	4.79	4.967 $\pm$ 0.120	4.18	4.867 $\pm$ 0.481	17.11
RHRTH 20-12	0.457 $\pm$ 0.069	26.15	1.750 $\pm$ 0.161	15.93	1.700 $\pm$ 0.115	11.71	2.187 $\pm$ 0.318	25.18	2.973 $\pm$ 0.301	17.53	5.380 $\pm$ 0.194	6.25	5.367 $\pm$ 0.233	7.52	5.333 $\pm$ 0.133	4.32
RHRTH 20-13	0.313 $\pm$ 0.063	34.86	1.507 $\pm$ 0.024	2.76	1.693 $\pm$ 0.146	14.94	2.693 $\pm$ 0.032	2.06	2.657 $\pm$ 0.228	14.86	4.913 $\pm$ 0.410	14.45	5.033 $\pm$ 0.233	8.01	5.067 $\pm$ 0.590	20.17

All values are expressed as Mean $\pm$ SEM.**Table 9:** Ascorbic acid content of fruit as per maturity stages of different tomato genotypes

Genotype	Immature Green		Green		Breaker		Turning		Pink		Red		Red Ripe		Overripe	
	(Mean $\pm$ SEM)	CV %	(Mean $\pm$ SEM)	CV %	(Mean $\pm$ SEM)	CV %	(Mean $\pm$ SEM)	CV %	(Mean $\pm$ SEM)	CV %	(Mean $\pm$ SEM)	CV %	(Mean $\pm$ SEM)	CV %	(Mean $\pm$ SEM)	CV %
RHRTH 20-4	4.333 $\pm$ 0.491	19.63	4.920 $\pm$ 0.042	1.48	8.000 $\pm$ 0.902	19.5	11.203 $\pm$ 0.535	8.27	20.000 $\pm$ 0.755	6.54	30.100 $\pm$ 1.189	6.84	23.400 $\pm$ 1.137	8.42	16.400 $\pm$ 0.945	9.98
RHRTH 20-5	5.633 $\pm$ 0.338	10.39	5.220 $\pm$ 0.180	5.97	9.700 $\pm$ 0.153	2.73	13.000 $\pm$ 0.306	4.08	25.667 $\pm$ 0.751	5.07	35.390 $\pm$ 0.540	2.64	25.753 $\pm$ 0.565	3.80	19.953 $\pm$ 0.880	7.64
RHRTH 20-13	4.767 $\pm$ 0.128	12.28	4.267 $\pm$ 0.128	2.72	7.467 $\pm$ 0.128	8.60	10.867 $\pm$ 0.128	3.83	19.833 $\pm$ 0.128	8.22	30.300 $\pm$ 0.128	5.78	21.733 $\pm$ 0.128	7.94	15.400 $\pm$ 0.128	3.44

20-6	0.338		0.067		0.371		0.240		0.941		1.012		0.996		0.306	
RHRTH 20-7	5.067 ± 0.437	14.94	5.160 ± 0.151	5.07	9.933 ± 0.240	4.19	12.733 ± 0.353	4.80	25.167 ± 0.273	1.88	34.223 ± 1.040	5.26	24.687 ± 0.899	6.31	19.567 ± 0.561	4.97
RHRTH 20-8	4.683 ± 0.364	13.46	4.900 ± 0.173	6.11	9.100 ± 0.321	6.11	12.233 ± 0.501	7.09	23.867 ± 0.384	2.79	33.707 ± 0.846	4.35	24.133 ± 0.771	5.53	19.533 ± 1.206	10.70
RHRTH 20-9	3.667 ± 0.291	13.74	3.967 ± 0.088	3.84	7.667 ± 0.240	5.42	9.933 ± 0.240	4.18	19.393 ± 0.462	4.13	29.707 ± 0.893	5.21	22.460 ± 1.168	9.00	16.640 ± 0.266	2.77
RHRTH 20-10	4.367 ± 0.590	23.40	3.967 ± 0.203	8.86	8.233 ± 0.649	13.6	10.400 ± 0.462	7.69	20.467 ± 0.353	2.99	30.667 ± 0.882	4.98	21.700 ± 0.656	5.24	15.447 ± 0.694	7.78
RHRTH 20-11	5.667 ± 0.176	13.86	4.100 ± 0.321	13.56	8.700 ± 0.265	5.28	10.667 ± 0.677	11.00	22.900 ± 1.493	11.30	29.183 ± 0.725	4.30	21.800 ± 1.102	8.75	16.137 ± 0.177	1.90
RHRTH 20-12	5.667 ± 0.176	5.38	4.687 ± 0.356	13.16	9.953 ± 0.237	4.12	12.670 ± 0.369	5.04	24.167 ± 1.688	12.10	32.857 ± 0.759	4.00	25.617 ± 0.489	3.30	18.417 ± 0.526	4.95
RHRTH 20-13	5.400 ± 0.872	28.01	3.633 ± 0.296	14.11	7.667 ± 0.176	3.92	10.933 ± 0.371	5.88	21.867 ± 0.851	6.74	28.633 ± 0.924	5.59	23.200 ± 0.462	3.45	16.233 ± 0.555	5.92

All values are expressed as Mean ± SEM.

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