



RESEARCH ARTICLE

# Variations in the nutritional makeup of tomato and cherry tomato genotypes and their hybrids in both fresh and processed forms

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## Abstract

Tomato improvement is essential for enhancing processing quality and maximizing antioxidant retention in value-added products. This study aimed to evaluate compositional changes and nutrient retention in fresh and thermally processed fruits of diverse tomato genotypes, including double-cross hybrids derived from four single-cross parents and hybrids developed between purple and cherry tomato lines. Fresh tomatoes and thermally processed tomato puree samples were analysed for lycopene,  $\beta$ -carotene, ascorbic acid, anthocyanin, titratable acidity and total soluble solids (TSS). Highly significant genotypic variation was detected for all quality traits, indicating strong genetic control. PAN12023, a single-cross hybrid genotype, exhibited the highest TSS and lycopene content. Thermal processing led to substantial increases in lycopene levels (673.89 %), especially in purple  $\times$  cherry and double-cross hybrids, while other nutrients generally declined. Among the hybrids, Bidhan Purple  $\times$  Cherry Yellow Big Fruit showed the greatest retention of  $\beta$ -carotene, ascorbic acid, anthocyanin and titratable acidity despite processing losses. Standardizing appropriate thermal processing techniques and utilizing multi-parent hybridization can provide genetically diverse germplasm and support the breeding of improved tomato varieties with enhanced nutritional resilience. Overall, the results highlight the importance of genotype selection for developing nutrient-rich processed tomato products having a wide range of health benefits as well as maintaining the consumer preferences.

**Keywords:** cherry tomato; double cross hybrids; processing quality; purple tomato; single cross hybrids

## Introduction

Dietary recommendations based on food are fundamental for preventing chronic diseases. Tomatoes exhibit a distinctive nutritional and bio-chemical profile, rich in vitamin C (ascorbic acids), vitamin A (in the form of carotenoids), fibre, essential macro-nutrient (K), phenolics and antioxidants such as lycopene and  $\beta$ -carotene (1). Lycopene, a carotenoid pigment, primarily found in ripe tomatoes and tomato-based processed products, to their distinctive deep-red color. Research suggests an inverse relationship between serum lycopene levels and the risk of cancer, cardiovascular disease (CVD) and osteoporosis (2-4). Processing enhances lycopene bioavailability by breaking down cell walls, increasing its accessibility and facilitating the conversion of trans-isomers to cis isomers (5). Besides lycopene, tomatoes also possess other carotenoids such as phytonene, phytofluene, g-carotene, z-carotene,  $\beta$ -carotene, eurosporene and lutein.

Vitamin C is crucial for human health, primarily preventing scurvy and maintaining healthy skin and blood vessels (6). Fruit acidity and total soluble solids are crucial not only for consumption but also for various processing

applications. Total soluble solids content (TSS) content is particularly crucial for processes such as dehydration and concentrated pulp preparation. Cherry tomatoes are gaining popularity globally, particularly in Brazil, due to their cultivation in protected environments. This popularity is driven by their high levels of beneficial compounds such as lycopene,  $\beta$ -carotene, flavonoids and vitamin C, their delicious taste and their ability to produce fruit even in high temperatures (7).

Petunidin was identified as the predominant anthocyanidin in *Aft*, followed by malvidin and delphinidin (8). Driven by the health benefits and antioxidant properties of anthocyanins, this study aimed to explore the genetic potential for increasing anthocyanin levels in cherry tomato fruit. The simple inheritance of *Aft* facilitates the incorporation of this gene into existing cherry tomato germplasm (9). Three genes, anthocyanin fruit (*Aft*), aubergine (*abg*) and atroviolacea (*atv*), have been identified that can cause anthocyanin production in fruit peel. The *Aft* gene, responsible for anthocyanin production in fruit, was discovered through crosses involving *Solanum chilense* Dunal. (8).

A high concentration of anthocyanin is crucial for potent antioxidant effects. Incorporating the anthocyanin-producing trait into cherry tomatoes, which are naturally high in carotenoids, allows for the development of novel tomato varieties that are rich in both water-soluble and fat-soluble antioxidants. Increased demand for anthocyanin-rich foods reflects research on their potential to combat chronic diseases (10). Beyond their well-known use in cooking, tomatoes offer nutritional benefits as a low-calorie food packed with unique compounds that may promote good health. The study of the interaction between a crop's genetic diversity and the impact of processing on nutritional retention is gaining attention due to its potential to address global malnutrition and create a more resilient food system.

The present investigation has been outlined with the objectives to evaluate the biochemical variations among tomato genotypes and hybrids in both fresh and processed forms and to identify genotypes suitable for thermal processing with minimal nutrient loss.

## Materials and Methods

The current research programmes were conducted at the Department of Vegetable Science, Bidhan Chandra Krishi Viswavidyalaya (BCKV), Mohanpur, Nadia, West Bengal, India, during two consecutive years (2020-2021 and 2021-2022). The investigation was undertaken to find the differences over biochemical parameters (TSS, ascorbic acid, lycopene,  $\beta$ -carotene, titratable acidity, anthocyanin) of four single cross hybrids, six double cross hybrids, two purple cultivars, three cherry tomato cultivars and six hybrids between purple and cherry tomato cultivars in fresh and processed states (Table 1).

Seeds from the parent lines, having undergone treatment with thiram at a rate of 3 g kg<sup>-1</sup>, were sown in a seedbed during the initial week of October 2020. Seedlings of thirty days old were transplanted to the crossing block in the first week of November 2020, during the afternoon. All the cultural practices were done on time (11). When the female plants were in full bloom, their buds were emasculated and pollinated with the chosen male

plants using a half diallel mating design. Hybrid seed extraction was performed through fermentation method.

The seeds from 12 crosses and 9 parent plants were planted in a prepared nursery bed during the October first week, 2021, using the same methods as before. Thirty-day-old seedlings were transplanted to individual 3.0 × 3.0 m plots in the main field during the first week of November 2021. The average temperature ranges between 9 °C and 25 °C and relative humidity varied between 76 % and 89 % during experimental period. The seedlings were spaced 60 cm apart in both directions. A randomized complete block design with three replications was used for the transplanting.

The recording of fruit quality characteristics was performed using ten fruits selected from each genotype within each replication. Composite samples of ten fruits of 21 genotypes including hybrids, in three replications, were prepared from the cut fruits for the purpose of estimating various fruit quality characteristics. These included total soluble solids (°Brix) (measured with the help of ERMA digital hand refractometer), titratable acidity (% of citric acid concentration), carotenoids such as  $\beta$ -carotene and lycopene (mg100<sup>g</sup> fruit FW) as per the standard method, vitamin C or ascorbic acid (mg 100<sup>g</sup> FW) (indophenol method) and in purple tomatoes and their crosses the anthocyanin content (mg 100<sup>g</sup> FW) following standard methods (12-14).

Tomato puree was prepared by heating one kg each tomato pulp of 21 genotypes/hybrids with addition of salt, sugar and preservative as per the standard method (15). Thermal processing for tomato puree involved a pasteurization step at 98 °C for 40 sec to 100 °C for a few min depending upon the weight and genotype of tomato pulp sample. TSS of final products was 18-22 °Brix. Each puree from 21 genotypes/hybrids was filled up into pre-sterilized bottles having capacity of 200 g. Bottles were sealed tightly capped and stored at ambient temperature. The same biochemical parameters were recorded from puree prepared from each parent and hybrid and the average data across two years was further worked out for statistical analysis.

The data from three replications were pooled over two years and analysed using ANOVA for a randomized complete

**Table 1.** Sources of different tomato and cherry tomato genotypes and their hybrids used as experimental materials

Sl. No.	Genotypes/hybrids	Name of the genotype/crosses	Source of collection
1.	Single cross tomato hybrid	PAN 12023 SW-1504 Devi L-37	Pan Seeds Pvt. Ltd., West Bengal, India US Agriseeds, Telengana, India VNR-Seeds, Chhattisgarh, India Syngenta, Basel, Switzerland
2.	Double cross tomato hybrid	PAN 12023 × SW-1504 PAN 12023 × Devi PAN 12023 × L-37 SW-1504 × Devi SW-1504 × L-37 Devi × L-37	- - - - - -
3.	Purple tomato	Bidhan Purple Alisha Craig Aft	BCKV, West Bengal, India BCKV, West Bengal, India
4.	Cherry tomato	Cherry Yellow Big fruit 2016/Cherry-1 2018/Cherry Tomato-2	BCKV, West Bengal, India ICAR-IIVR, Varanasi, India ICAR-IIVR, Varanasi, India
5.	Purple × Cherry tomato	Bidhan Purple × Cherry Yellow Big fruit Bidhan Purple × 2016/Cherry Tomato-1 Bidhan Purple × 2018/Cherry Tomato-2 Alisha Craig Aft × Cherry Yellow Big fruit Alisha Craig Aft × 2016/Cherry Tomato-1 Alisha Craig Aft × 2018/Cherry Tomato-2	- - - - - -

BCKV = Bidhan Chandra Krishi Viswavidyalaya. ICAR-IIVR = Indian Council of Agricultural Research-Indian Institute of Vegetable Research.

block design (RBD). Tukey's honest significant difference (HSD) test was used to see if the treatment means  $\pm$  SD were significantly different at  $p \leq 0.05$  from each other. Treatment means having different superscripts were determined to be statistically significant by Tukey's post-hoc test. Statistical analysis was done with SAS (ver. 9.3 Professional Version, SAS Institute, Cary, NC).

## Results and Discussion

### Total soluble solids (TSS)

Higher levels of TSS constitute a primary quality attribute with respect to both nutritional value and suitability for processing (16). The highest total soluble solids content (8.90 °Brix) was observed in genotype Cherry Yellow Big fruit, followed by the hybrid Bidhan Purple  $\times$  2018/Cherry Tomato-2 (8.03 °Brix) in fresh fruits (Fig. 1). After processing TSS content was increased to the extent of 439.74 % from the fresh fruits in both PAN 12023 (single cross tomato hybrid) and Bidhan Purple (Purple tomato) (25.53 °brix) among the genotypes (Table 2; Fig. 1).

Quality and flavour of processed products depend on chemical compositions of varieties/hybrids of tomato. TSSs are related to yield of concentrated tomato products in more concentrated form and yield of certain processed products are determined by fruit sugar content. A primary determinant of tomato flavour is the ratio of sugars to acids. Organic processing tomatoes have more TSS than those grown with chemical fertilizers (17). Heat treatment or processing, such as blanching, canning or drying, generally causes water loss in tomatoes, which concentrates the existing soluble solids (sugars and acids) relative to the overall weight (18). This physical effect makes the soluble solids content appear to increase when measured. Additionally, heat can break down cell walls and release previously bound components into the soluble phase, further contributing to the elevated measurable soluble solids content (19). Thus, the increase in TSS during tomato processing is primarily a concentration effect due to moisture loss and, to a lesser extent, the breakdown of complex carbohydrates into simpler soluble sugars.

### Lycopene

Purple tomatoes, especially Alisha Craig *Aft* had highest mean lycopene values (8.81 mg 100<sup>g</sup>) in fresh fruits followed by Bidhan Purple (5.80 mg 100<sup>g</sup>) (Fig. 2). After processing Bidhan Purple  $\times$  Cherry Yellow Big fruit (purple  $\times$  cherry hybrid) showed the maximum lycopene value (20.33 mg 100<sup>g</sup>), followed by cherry tomato genotype 2018/Cherry Tomato-2 (18.51 mg 100<sup>g</sup>) (Fig. 2). Among all the genotypes, Alisha Craig *Aft*  $\times$  2018/Cherry Tomato-2 genotype showed maximum percent increase (673.89 %) in lycopene content (Table 2).

Lycopene is the pigment largely responsible for the characteristic deep-red color of ripe tomato fruit and tomato products. Its biological and physico-chemical characteristics, particularly those pertaining to its functions as a natural antioxidant, have drawn attention. Lycopene in fresh tomato fruits essentially appears in the all-trans configuration. The main causes of tomato lycopene degradation during processing are isomerization and oxidation. Isomerization creates an unstable, energy-rich station by converting all-trans isomers to *cis*-isomers because of greater energy input. Thermal processing typically results in some lycopene loss in dishes derived from tomatoes. Heat causes isomerization of the all-trans to *cis* forms. The *cis* isomers rise depending on temperature and processing time. The bioavailability of *cis* isomers in food is higher than that of all-trans isomers.

The observed increase in lycopene levels is a result of the liberation of lycopene from the tomato matrix cells induced by heat treatment, which weakens bonding forces between lycopene and the tissue matrix making lycopene more accessible and enhancing the *cis* isomerization (20). It was also reported that heat treatment demonstrably enhances the bioavailability of lycopene in tomatoes (21). It is reasonable to believe that the breakdown of protein-carotenoid complexes by heat likely explains both the observed pigment degradation and the increased extractability of the remaining pigments. In the outer most layer, the initial effect is more pronounced due to the tissue's thinness, which makes heat conduction simple and quick. Lycopene content in processed products like juice, sauce, tomato soup and tomato puree has been reported to be increased significantly compared to fresh tomatoes (22).

**Table 2.** Percent increase (+) or decrease (-) of biochemical traits in processed form

Genotypes/Crosses	Percent (%) increase (+) or decrease (-) of traits					
	TSS (°Brix)	Lycopene (mg 100 <sup>-g</sup> FW)	$\beta$ -carotene (mg 100 <sup>-g</sup> FW)	Ascorbic acid (mg 100 <sup>-g</sup> FW)	Titrateable acidity (mg 100 <sup>-g</sup> FW)	Anthocyanin contents (mg 100 <sup>-g</sup> FW)
PAN 12023	+439.74	+132.86	-7.40	-32.55	-23.33	-
SW-1504	+334.09	+121.52	-10.00	-51.45	-19.51	-
Devi	+380.14	+138.72	-16.39	-48.31	-20.45	-
L-37	+338.51	+98.65	-25.80	-75.70	-29.50	-
PAN 12023 $\times$ SW-1504	+343.73	+169.24	-64.51	-42.24	-47.82	-
PAN 12023 $\times$ Devi	+330.18	+144.33	-52.38	-42.85	-37.50	-
PAN 12023 $\times$ L-37	+320.25	+238.98	-30.55	-48.299	-29.03	-
SW- 1504 $\times$ Devi	+264.27	+264.82	-24.44	-65.00	-40.00	-
SW-1504 $\times$ L-37	+351.53	+262.50	-34.14	-81.57	-45.65	-
Devi $\times$ L-37	+316.48	+143.55	-34.28	-35.88	-45.45	-
Bidhan Purple	+439.74	+71.37	-40.65	-59.51	-72.22	-87.53
Alisha Craig <i>Aft</i>	+173.52	+80.24	-33.92	-31.47	-28.57	-87.77
Cherry Yellow Big fruit	+137.75	+90.90	-38.46	-43.01	-40.62	-
2016/Cherry-1	+166.76	+214.11	-11.11	-12.55	-90.90	-
2018/Cherry Tomato-2	+209.43	+274.69	-36.06	-62.47	-34.78	-
Bidhan Purple $\times$ Cherry Yellow Big fruit	+155.89	+261.10	-5.26	-13.30	-48.00	-91.46
Bidhan Purple $\times$ 2016/Cherry Tomato-1	+172.08	+312.82	-14.28	-74.58	-19.04	-85.91
Bidhan Purple $\times$ 2018/Cherry Tomato-2	+188.41	+239.65	-36.11	-59.94	-61.90	-85.70
Alisha Craig <i>Aft</i> $\times$ Cherry Yellow Big fruit	+205.11	+268.86	-41.37	-53.22	-60.86	-83.72
Alisha Craig <i>Aft</i> $\times$ 2016/Cherry Tomato-1	+204.28	+170.37	-25.00	-34.98	-40.00	-87.26
Alisha Craig <i>Aft</i> $\times$ 2018/Cherry Tomato-2	+138.75	+673.89	-19.51	-37.77	-40.90	-83.64

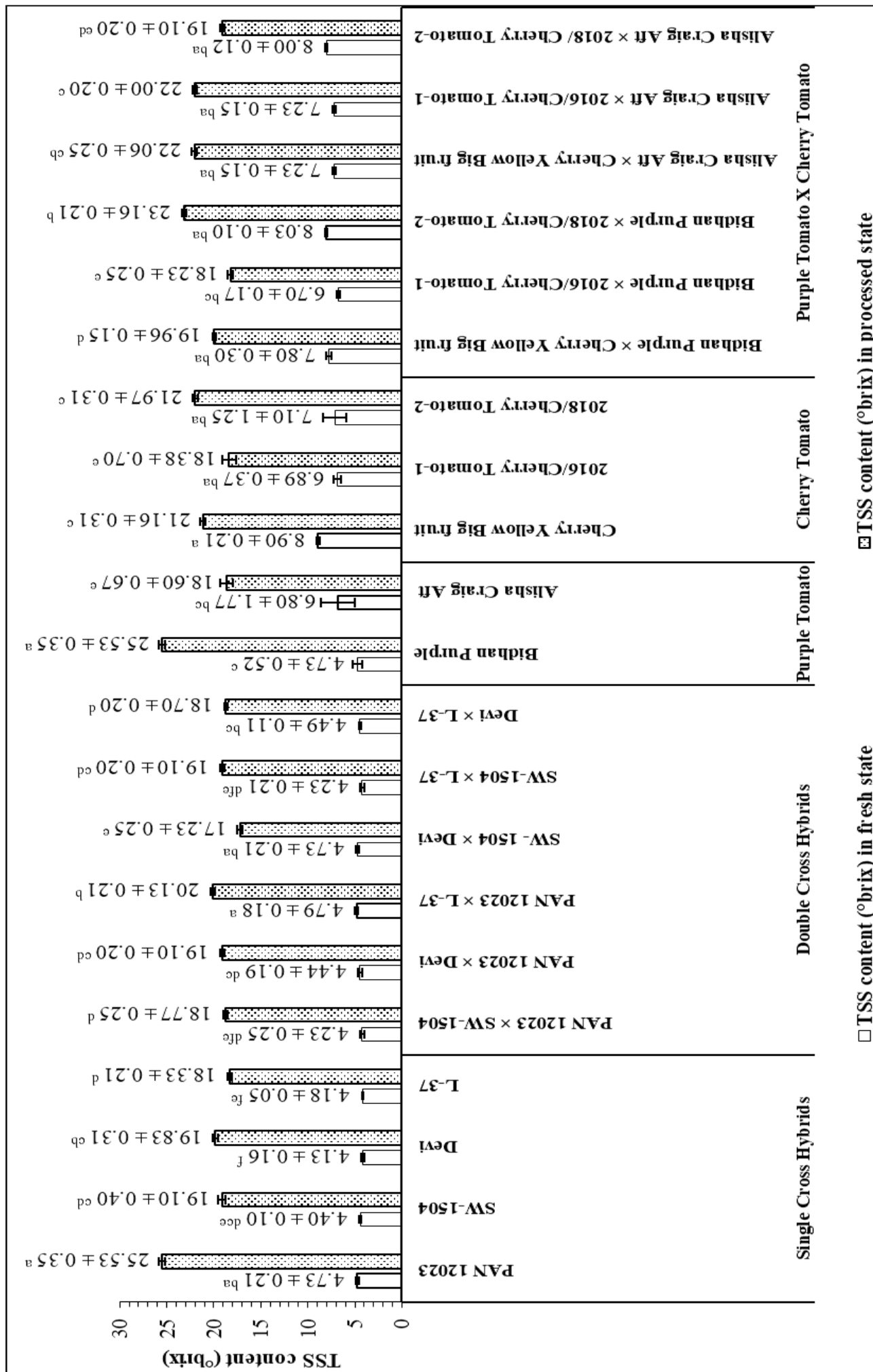


Fig. 1. Total soluble solids (TSS) content (°Brix) of tomato genotypes in fresh and processed states. Values represent mean ± SD of three replications. Mean followed by different letters differ significantly at  $p \leq 0.05$  (Tukey HSD).

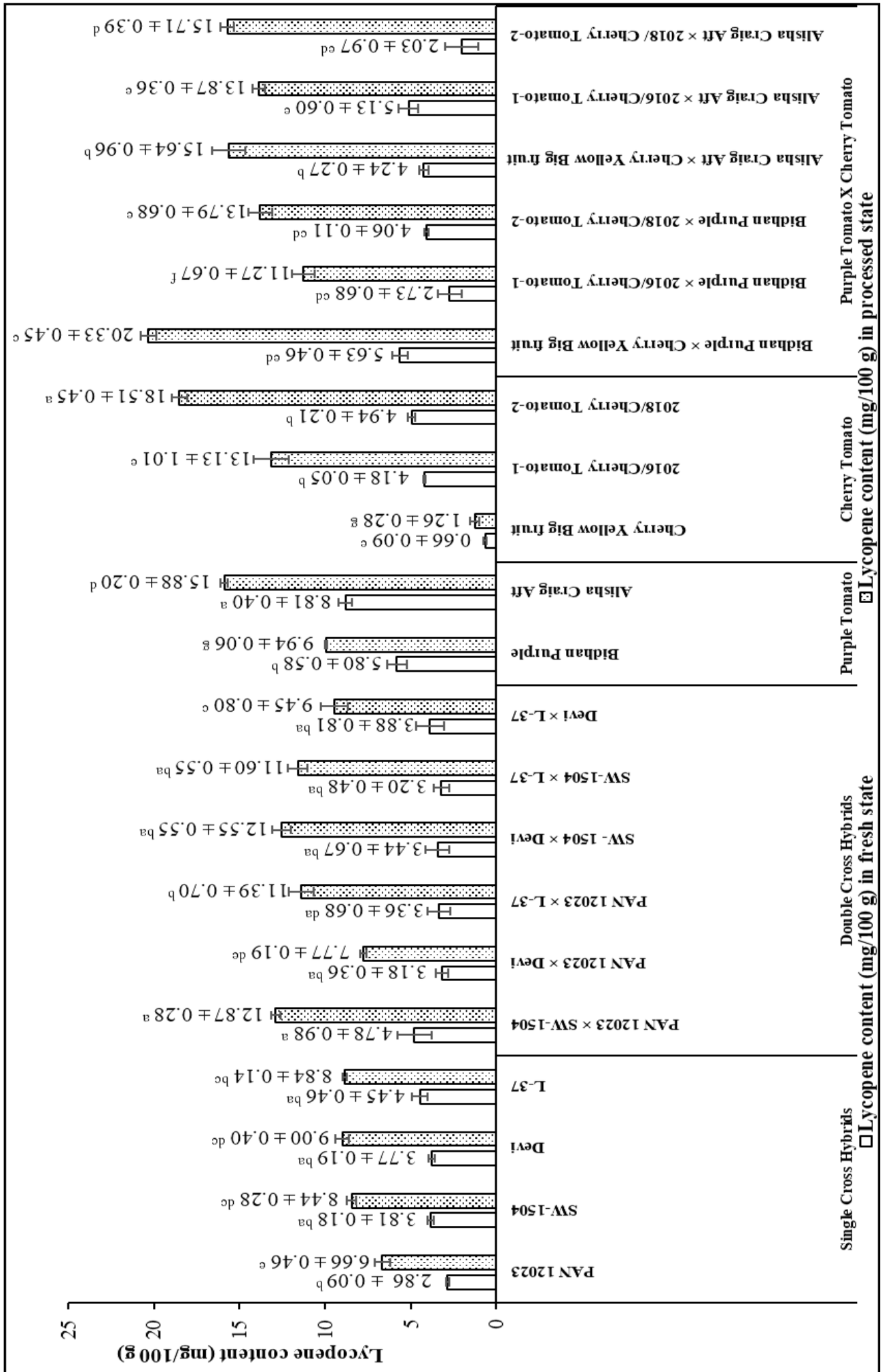


Fig. 2. Lycopene content (mg 100<sup>-1</sup>) of tomato genotypes in fresh and processed states. Values represent mean ± SD of three replications. Mean followed by different letters differ significantly at  $p \leq 0.05$  (Tukey HSD).

## $\beta$ -carotene

The present study demonstrated a sharp reduction in  $\beta$ -carotene content of tomato after processing (Fig. 3). Bidhan Purple (purple tomato) showed the maximum mean  $\beta$ -carotene (0.91 mg 100<sup>g</sup>) in fresh fruits, followed by single cross tomato hybrid PAN 12023 (0.81 mg 100<sup>g</sup>) (Fig. 3). After processing, the percentage loss of  $\beta$ -carotene was found minimum (5.26 %) in purple-cherry hybrid Bidhan Purple  $\times$  Cherry Yellow Big fruit, followed by single cross hybrid PAN 12023 (7.40 %) (Table 2).

The instant reduction in  $\beta$ -carotene content of tomato after processing is primarily due to oxidation and isomerization reactions, which are accelerated by factors such as heat, light and the presence of oxygen.  $\beta$ -carotene has a highly unsaturated structure with many conjugated double bonds, making it very susceptible to oxidation when exposed to oxygen, especially during processing when tissue integrity is lost. This reaction is often accelerated by heat and light and results in degradation products that lack the nutritional benefits and color of intact  $\beta$ -carotene. Thermal processing, such as heating or drying, causes the conversion of the naturally predominant all-*trans*  $\beta$ -carotene form to *cis*-isomers. While *cis*-isomers can be more bioavailable in some cases, the all-*trans* form generally has higher vitamin A activity and the conversion contributes to the overall reduction in the total amount or activity of  $\beta$ -carotene measured.

The  $\beta$ -carotene concentration reduces after heating because free radicals propagate at their optimal rate when  $\beta$ -carotene exposures to heat oxidation reaches their maximum value (23). Degradation rate also depends on the thickness of tomato pulp, oxygen diffusion rate and heating temperature. In previous study, partial degradation of lutein and  $\beta$ -carotene by heat (-29 % and -3 %, respectively), accompanied by a 37 % increase in lycopene extractability has been observed (24).

## Ascorbic acid

The current study discovered that, regardless of genotypes or hybrids, the mean ascorbic acid value dropped following exposure to heat. In general, purple tomatoes, cherry tomatoes and purple-cherry hybrids contained more ascorbic acid contents than other genotypes in both fresh and processed states (Fig. 4). Purple-cherry hybrid Bidhan Purple  $\times$  2018/Cherry Tomato-2 showed the maximum mean ascorbic acid value (71.40 mg 100<sup>g</sup>) in fresh state. After processing, the genotype Alisha Craig *Aft* (purple tomato) had the maximum mean ascorbic acid (38.97 mg 100<sup>g</sup>) (Fig. 4). Double cross tomato hybrid SW-1504  $\times$  L-37 showed the maximum per cent decrease (81.57 %) as against cherry tomato genotype 2016/Cherry-1 resulted the minimum per cent decrease (12.55 %) of ascorbic acid after heating (Table 2).

Ascorbic acid is water soluble and heat labile. When heat is applied, enzymatic activity starts and degradation of ascorbic acid takes place. This thermal degradation can be initiated directly or by triggering enzymes such as ascorbic acid oxidase, which accelerate the breakdown of ascorbic acid, especially when combined with factors such as water and oxygen. More cooking time results more degradation of ascorbic acid, though it also depends on varieties of tomatoes. It is also recorded loss of ascorbic acid in uncontrolled cooking methods and duration (25).

## Titrateable acidity

After processing of fresh tomatoes into puree, titrateable acidity decreased to some extent. Double cross tomato hybrids PAN 12023  $\times$  L-37 had the maximum titrateable acidity (0.62 mg 100<sup>g</sup>) in fresh state (Fig. 5). After processing, PAN 12023 (single cross hybrid) recorded the maximum titrateable acidity content (0.46 mg 100<sup>g</sup>). Overall, single and double cross tomato hybrids exhibited more amount of acidity in both fresh and processed states. Cherry tomato genotype 2016/Cherry-1 showed the maximum per cent reduction (90.90 %) in titrateable acidity and Bidhan Purple  $\times$  2016/Cherry Tomato-1 retained the maximum titrateable acidity with minimum per cent decrease (19.04 %) after processing (Table 2).

The titrateable acidity of tomatoes decreases after processing into a puree primarily due to the degradation or loss of organic acids, especially citric acid, which is the predominant acid in tomatoes. This reduction is mainly caused by thermal processing, enzymatic activity and volatilization. In essence, the processing conditions and the initial quality of the raw fruit lead to a net reduction in the total available free hydrogen ions that contribute to titrateable acidity (26).

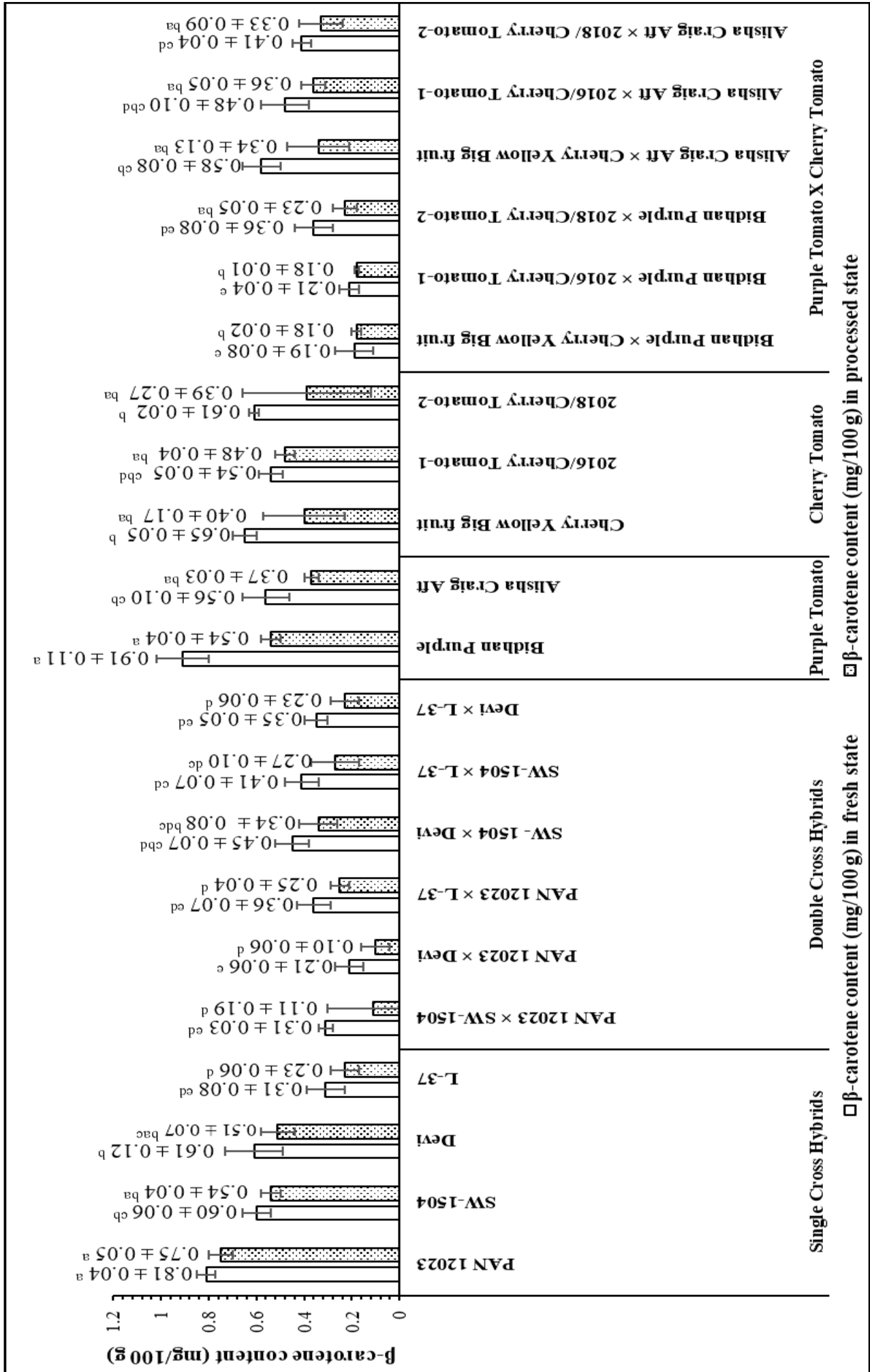
## Anthocyanin

Anthocyanin was synthesized in purple tomatoes and hybrids of purple tomatoes. It was found that purple tomatoes Bidhan Purple contained more amount of anthocyanin in fresh fruits (20.62 mg 100<sup>g</sup>) as well as after processing into puree (2.57 mg 100<sup>g</sup>), over purple-cherry hybrids (Fig. 6). The hybrid Bidhan Purple  $\times$  2018/Cherry Tomato-2 showed the minimum reduction (83.64 %) in anthocyanin content resulting maximum retention of anthocyanin after processing (Table 2).

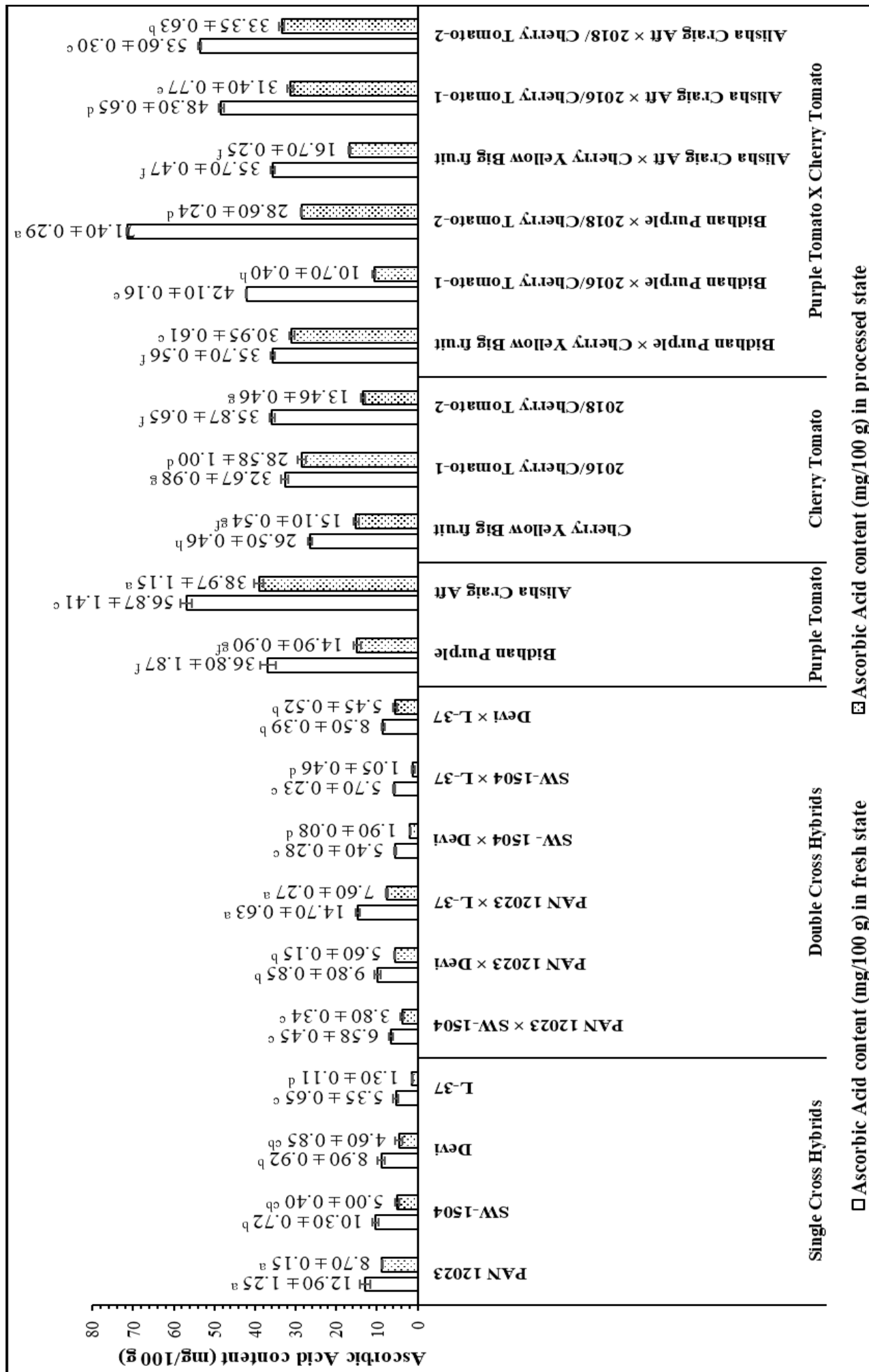
Anthocyanin production is regulated by complex gene networks, notably involving the *Aft* (Anthocyanin fruit) and *CHI* (Chalcone isomerase) genes and is highly sensitive to heat stress which accelerates the degradation kinetics of the pigments. High temperatures negatively impact anthocyanin content by both repressing biosynthesis and accelerating pigment degradation. Heat stress can induce the expression of enzymes like class III peroxidases (Prxs) and polyphenol oxidase, which promote the oxidative degradation of anthocyanins, particularly in the presence of hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>). Anthocyanin levels in developing fruit exhibit a progressive increase, culminating in a maximum concentration immediately preceding the ripening stage and start decreasing when ripening progresses (27).

Anthocyanins break down when exposed to heat primarily because high temperatures accelerate the rate of chemical reactions that degrade the complex molecular structure of the pigment. This process, known as thermal degradation, is influenced by several factors such as molecular instability, hydrolysis, isomerization and cleavage, enzyme activity, pH level and oxygen exposure. Thus, heat provides the necessary energy for the anthocyanin molecule to undergo a series of chemical transformations that result in the loss of its coloured structure. The discoloration of fruits is attributable to either a decrease in anthocyanin biosynthesis, an increase in anthocyanin degradation, or a confluence of both processes.

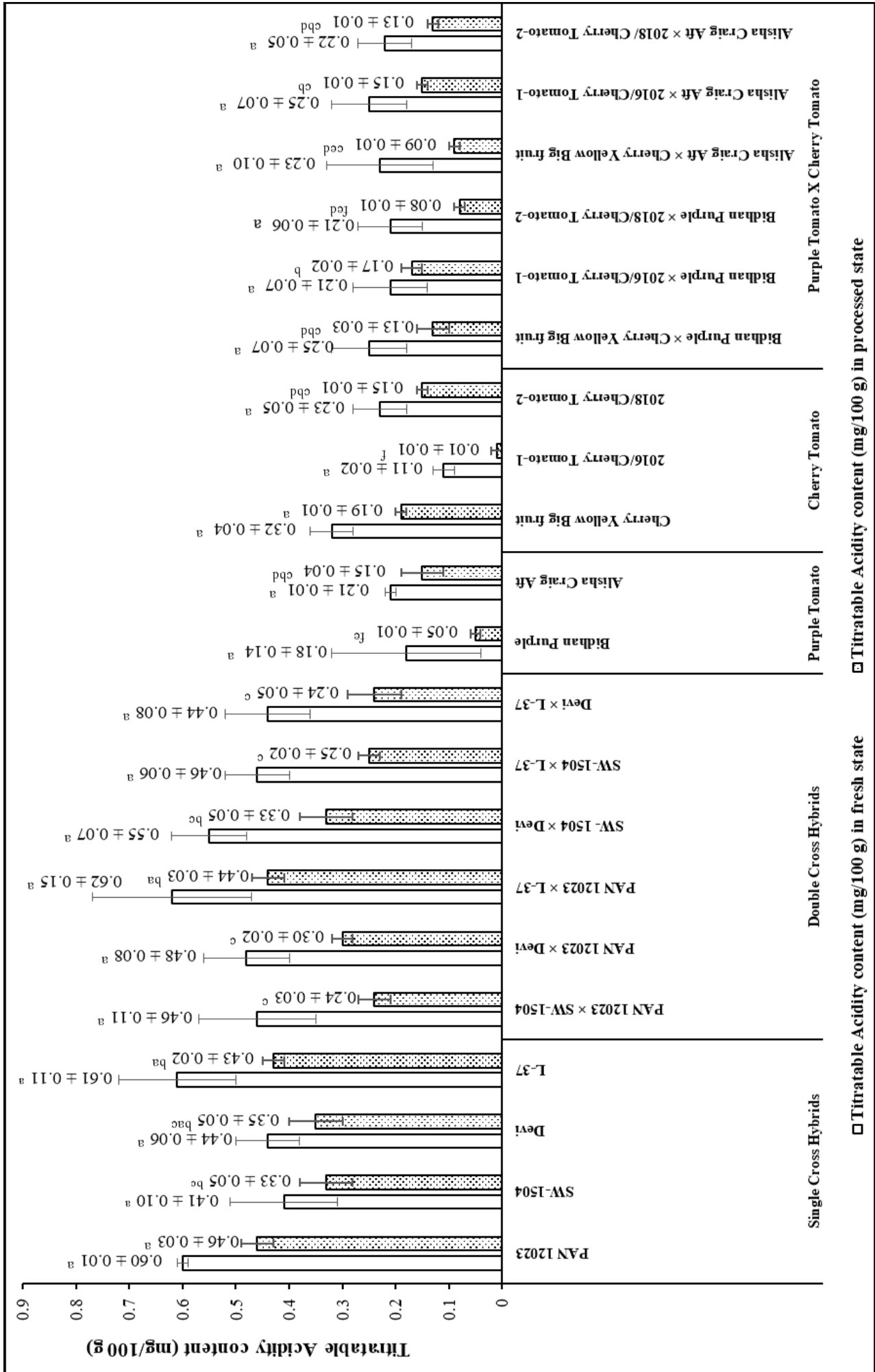
The quantitative variation in anthocyanin content is governed by the expression levels of late biosynthetic genes



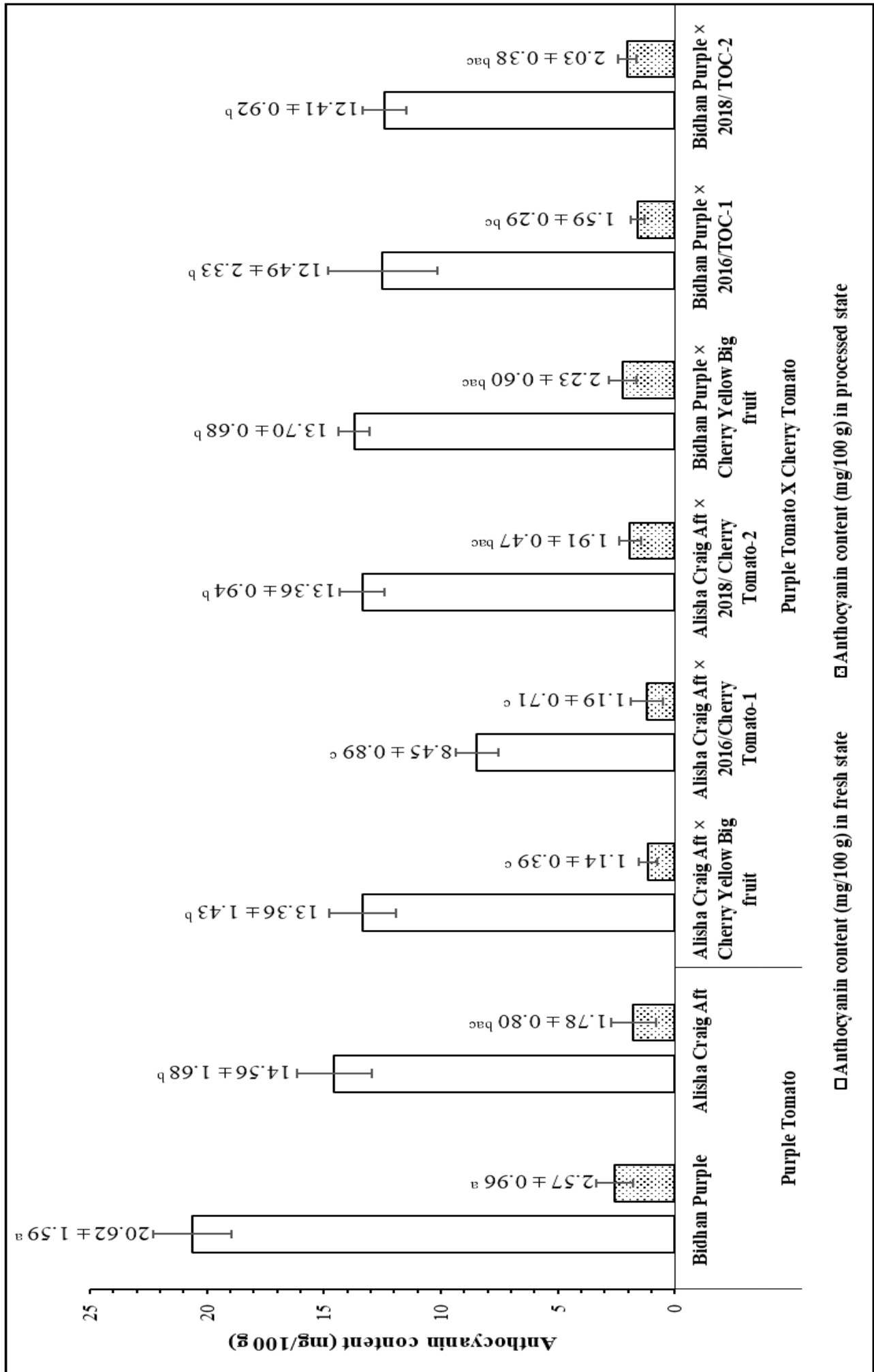
**Fig. 3.**  $\beta$ -carotene content (mg 100<sup>g</sup>) of tomato genotypes in fresh and processed states. Values represent mean  $\pm$  SD of three replications. Mean followed by different letters differ significantly at  $p \leq 0.05$  (Tukey HSD).



**Fig. 4.** Ascorbic acid content (mg 100<sup>-3</sup>) of tomato genotypes in fresh and processed states. Values represent mean ± SD of three replications. Mean followed by different letters differ significantly at  $p \leq 0.05$  (Tukey HSD).



**Fig. 5.** Titratable acidity content (mg 100<sup>-1</sup>) of tomato genotypes in fresh and processed states. Values represent mean ± SD of three replications. Mean followed by different letters differ significantly at p≤0.05 (Tukey HSD).



**Fig. 6.** Anthocyanin content (mg 100<sup>-3</sup>) in purple tomatoes and cherry tomatoes and their crosses in fresh and processed states. Values represent mean ± SD of three replications. Mean followed by different letters differ significantly at  $p \leq 0.05$  (Tukey HSD).

within the anthocyanin biosynthetic pathway. A decrease in the transcript levels of late biosynthetic genes is observed during processing concomitant with the occurrence of discoloration (28). The *Aft* gene in purple tomato is hypothesized to be either a regulatory gene or a promoter region influencing the expression of a structural gene and higher levels of flavonoids, including anthocyanins, are observed in cultivated tomato fruits as a result of the reintroduced *CHI* gene expression (29, 30).

### Limitations and Future Scope

Although diverse genotypes were included, the study examined only a selected set of double-cross, purple and cherry hybrids, which may not represent the full genetic spectrum of tomato germplasm. Only one type of thermal processing was evaluated. Nutrient retention may differ under alternative methods such as microwave heating, high-pressure processing or vacuum evaporation. The study focused on immediate post-processing nutrient levels. It did not assess storage stability, degradation kinetics, or shelf-life behaviour of processed products. The study did not explore the genetic or molecular basis underlying nutrient retention or degradation during processing.

To evaluate diverse processing technologies using non-thermal and mild-thermal methods (HPP, cold-break processing and microwave-assisted extraction) to identify optimum conditions that minimize nutrient losses; to screen a broader panel of tomato genetic resources can help to identify superior alleles for nutrient stability, to conduct studies on colour, flavour, viscosity, consumer liking and market potential of processed tomato products derived from superior genotypes, to apply genomic tools, QTL mapping, transcriptomics and metabolomics to understand the mechanisms that govern antioxidant accumulation and processing stability, to evaluate how nutrient retention changes during storage of tomato products, providing practical insights for commercial processing industries, to assess how processing influences bio-accessibility and bioavailability of antioxidants in human or simulated digestion models.

### Conclusion

The present investigation amply demonstrated significant variation in different quality characters in purple tomato and cherry tomato genotypes and their resulting hybrids. The study suggests that lycopene and other antioxidant vitamins of tomato mostly depend on genetic factors. Lycopene content in the processed product increased many folds in comparison to the fresh tomato because extractability of lycopene increased with heating the product. Anthocyanin content in the processed product decreased considerably when exposed to heat due to breakdown process. Thermal processing requires a balance: it must be sufficiently intense to inactivate microorganisms and degrading enzymes, yet sufficiently gentle to preclude chemical alterations that could negatively impact the food's flavour and nutritional profile.

Precise determination of the kinetic parameters is therefore crucial for predicting quality alterations that may arise during the thermal processing of tomatoes. The colour, anthocyanin content and antioxidant capacity of food are expected to be affected by the specific temperature and time combinations used in different processing steps. Suitable thermal method needs to be standardized for preparation of

several types of processed items with the retention of adequate level of lycopene, ascorbic acid and other antioxidants in different groups of tomatoes.

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### Authors' contributions

SG carried out the experiments and wrote the manuscript; PM carried out the experiments; RGM carried out the analysis and edited the manuscript; PH conceived the research idea and edited the manuscript; AC conceived the research idea, supervised the work, performed statistical analysis and edited the manuscript; IC conceived the research idea, supervised the work and edited the manuscript. All authors read and approved the final version of manuscript.

### Compliance with ethical standards

**Conflict of interest:** Authors do not have any conflict of interest to declare.

**Ethical issues:** None

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