Original Research Article

Nutritional Potential of Watermelon (*Citrullus lanatus* (Thunb.) Matsum. & Nakai) Genotypes with Different Flesh Colours

ABSTRACT

Watermelon is a popular and widely consumed fruit that is thirst-quenching and nutritious, containing abundant health-promoting phytonutrients, minerals, and antioxidants. The present study assessed the nutritional potential of twenty watermelon genotypes with different flesh colours, such as red, pink, orange, yellow, and white. This study was conducted in the experimental field of the Department of Vegetable Science at Kerala Agricultural University, Thrissur during two growing seasons (December-March) of 2021-2022 and 2022-2023. A significant variation (p=0.05) was seen in nutritional quality characteristics such as lycopene, beta-carotene, citrulline, and ascorbic acid levels across various watermelon genotypes with different flesh colours. Lycopene and beta-carotene content varied from 0.037 to 66.963 µg/g and 0.037 to 7.423 µg/g, respectively, based on fresh weight. Citrulline content ranged from 843.810 ppm to 2589.750 ppm. Ascorbic acid content ranged from 21.410 to 49.827 mg/kg on a fresh weight basis. The findings indicated that watermelon genotypes with red flesh are good source of lycopene and ascorbic acid. While the highest beta-carotene content was found in orange flesh genotypes. Both orange and yellow flesh watermelon genotypes exhibited supremacy of citrulline content compared to those with red and pink flesh. White-fleshed watermelon genotypes exhibited the lowest levels of lycopene and beta-carotene content. There were significant differences in the yield per plant among various flesh-coloured genotypes of watermelon. Therefore, the findings of this study are crucial for the development of nutritionally enhanced watermelon varieties. This will also help consumers in selecting different flesh-coloured watermelons based on their dietary preferences.

Keywords: *Watermelon; fruit quality; lycopene; beta-carotene; citrulline; ascorbic acid*.

1. INTRODUCTION

Watermelon (*Citrullus lanatus*), a major cucurbitaceous vegetable crop with a chromosome number of 2n=2X=22, is primarily cultivated for its fresh and nutritious fruit. It is largely consumed as a refreshing summer fruit, much appreciated because of its refreshing capability, attractive colour, delicate taste, and high water content to quench the summer thirst (Asfaw, 2022). The fruit is abundant in lycopene and possesses a total antioxidant capacity comparable to that of tomatoes (Perkins-Veazie *et al*., 2001). Additionally, the fruits serve as an excellent source of beta-carotene, vitamins (B, C, and E), minerals (K, Mg, Ca, and Fe), amino acid (citrulline) and phenolic compounds.

Flesh colour is a key quality trait that determines attractiveness and signifies the health-promoting benefits of watermelon (Bang *et al*., 2010). A variety of flesh colours are available in watermelon including white, yellow (pale, canary, salmon), orange and red (King *et al*., 2009). These diverse flesh colours not only add visual appeal but also have nutritional significance, as they are based on the carotenoid composition and content (Song *et al*., 2023).

Among carotenoids, beta-carotene is an important dietary source of vitamin A, which is essential for good eyesight. Generally, higher beta- carotene content would enhance the nutritive value of the fruits (Venkatesan *et al*., 2016). Lycopene imparts red colour in watermelon and has received much scientific attention in recent years due to its strong antioxidant properties (Edwards *et al*., 2003). Research indicates that lycopene is beneficial in human diet for the prevention of cardiovascular diseases as well as certain types of cancer and it may protect the skin from ultraviolet light damage. Many of these advantageous effects have been linked to the presence of phytochemicals with antioxidant effects (Perera and Yen, 2007).

Citrulline is the most abundant amino acid found in ripe watermelon (Joshi et al., 2019; Zhong et al., 2019). This non-essential amino acid were generated as an intermediate in the urea cycle (Bahri et al., 2013). Citrulline acts as a precursor to arginine, another important amino acid present in watermelon (Joshi et al., 2019; Song et al., 2020). This vital amino acid has a substantial role in the immune, gastrointestinal, respiratory, pulmonary, renal, and hepatic systems, and it also supports wound healing (Wu *et al*., 2000; Flynn *et al*., 2002; Collins *et al*., 2007). Additionally, citrulline may contribute to vasodilation and cardiovascular functions, as arginine is a conditionally essential amino acid linked to these processes (Levine *et al*., 2012; Hong *et al*., 2015). Studies suggest that the profiles of citrulline and arginine are crucial in fighting cancer (Lam *et al*., 2009; Di Sano *et al*., 2022), heart disease (Tang *et al*. 2009; Hong *et al*., 2015), acute hydrocephalus (Perez-Neri *et al*., 2007), minor intestinal disorders, blood poisoning, trauma, and pulmonary hypertension (Beyer *et al*., 2008; Santarpia *et al*., 2008), indicating their utility in healing various ailments.

Ascorbic acid is the active form of vitamin C that can impart a sour taste and its concentration differs across various species of fruits and vegetables (Manchali *et al*., 2021; Soumya and Rao, 2014). From nutritional point, it is important due to its antioxidant properties (Dhillon *et al*., 2019). Humans and other primates can no longer synthesize vitamin C, making it necessary to obtain it through diet. The suggested daily consumption (SDC) of ascorbic acid for non-smoking adults is established at 75 mg/day for women and 90 mg/day for men (Monsen, 1996). Hence, the current study was undertaken to assess the nutritional composition levels of lycopene, beta-carotene, citrulline, and ascorbic acid in watermelon fruits with varying flesh colours.

2. MATERIALS AND METHODS

The current research titled "Nutritional potential of watermelon (*Citrullus lanatus* (thunb.) Matsum. & nakai) genotypes with different flesh colours" was conducted in the experimental field of the Department of Vegetable Science at Kerala Agricultural University, Thrissur, situated at 10.5º North latitude and 76.2 º East longitude, with an elevation of 11.13 m above mean sea level. This region experiences a warm and humid tropical climate. The results presented here represent the mean of two growing seasons (December – March) of 2021-2022 and 2022-2023. A total of twenty watermelon genotypes exhibiting various flesh colours (Fig. 1), such as red (Arka Manik, Arka Muthu, Asahi Yamato, CL-4, Sugar baby, and AHW/BR-43), pink (AHW/BR-5, AHW/BR-6, AHW/BR-7, AHW-19, and AHW-65), orange (CL-17, CL-18, CL-19 and CL-14), yellow (CL-5, CL-7, and CL-10), and white (AHW/BR-9 and AHW/BR-13), were included in this investigation (table 1).

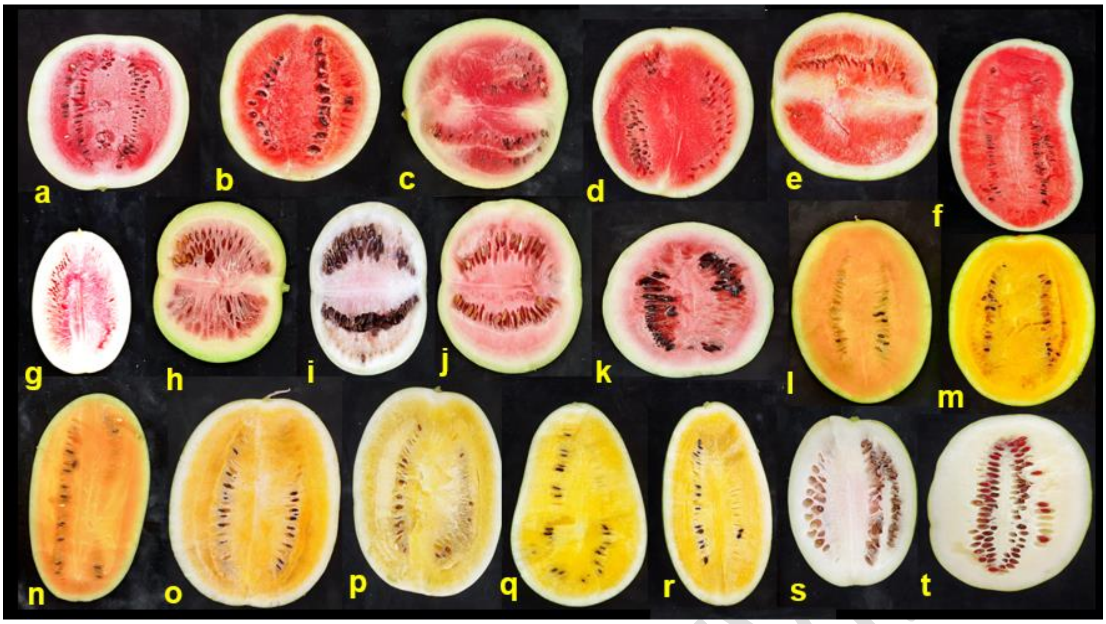

Fig. 1. Watermelon genotypes with various flesh colours – red [a) Arka Manik; b)Arka Muthu; c) Asahi Yamato; d) CL-4; e) Sugar baby; f) AHW/BR-43], pink [g) AHW/BR-5; h) AHW/BR-6; i) AHW/BR-7; j) AHW-19; k) AHW-65], orange [l) CL-17; m) CL-18; n) CL-19; o) CL-14], yellow [p) CL-5; q) CL-7; r) CL-10], and white [s) AHW/BR-9; t) AHW/BR-13].

Table 1. Source of watermelon genotypes with different flesh colours

Sl. No.	Watermelon genotype	Flesh colour	Source
1	Arka Manik	Red	IIHR
2	Arka Muthu	Red	IIHR
3	Asahi Yamato	Red	IIHR
4	CL-4	Red	KAU
5	Sugar Baby	Red	KAU
6	AHW/BR-43	Red	CIAH
7	AHW/BR-5	Pink	CIAH
8	AHW/BR-6	Pink	CIAH
9	AHW/BR-7	Pink	CIAH
10	AHW-19	Pink	IIHR
11	AHW-65	Pink	IIHR
12	CL-17	Orange	KAU
13	CL-18	Orange	KAU
14	CL-19	Orange	KAU

15	CL-14	Orange	KAU
16	CL-5	Yellow	KAU
17	CL-7	Yellow	KAU
18	CL-10	Yellow	KAU
19	AHW/BR-9	White	CIAH
20	AHW/BR-13	White	CIAH

IIHR- Indian Institute of Horticultural Sciences, Bengaluru, KAU – Kerala Agricultural University, Thrissur, CIAH – Central Institute of Arid Horticulture, Bikaner.

The seeds of selected watermelon genotypes underwent a water bath treatment for 3 hours at 40°C and were soaked overnight in 1% KNO_3 before sowing in portrays filled with cocopeat, vermiculite and perlite in a 3:1:1 ratio. Two weeks old seedlings were transplanted into the main field at a spacing of 2m x 1m. The experiment was laid out in a randomized block design with three replications, containing six plants in each replication. Three fruits from each treatment replication were randomly harvested 30-35 days after pollination and the following biochemical analyses were performed.

The lycopene and beta-carotene content in individual fruits were assessed using a spectrophotometer set at wavelengths of 452 nm and 503 nm, respectively (Ranganna, 1986). The citrulline concentration in the dried juice powder of the watermelon samples were measured using gradient HPLC as described by Ridwan *et al.* (2018). Initially, the fruit juice was lyophilized and freeze-dried to obtain the dried form. A sample weighing 14–26 mg of the freeze-dried substance was used, with 10 ml of deionized filtered water to dissolve it. Meanwhile, a 1 mg/ml stock solution for the citrulline standard was prepared by dissolving it in deionized filtered water. The analysis was conducted using an Agilent Technologies 1200 infinity Series HPLC system. Ascorbic acid content in fresh watermelon samples were determined by volumetric method (Sadasivam and Manickam, 1992). Yield per plant was recorded as the average of five randomly tagged plants per accession from each replication.

The data obtained from the various nutritional quality parameters and yield per plant were analyzed using analysis of variance (ANOVA) and statistical evaluation was conducted through Least Square Design (LSD) with KAU GRAPES software version 1.1.1 at a 5% significance level.

3. RESULTS AND DISCUSSION

The findings regarding different nutritional quality parameters of watermelon genotypes with varying flesh colours are shown in Table 2. A significant variation (P=0.05) was found among the watermelon genotypes concerning their lycopene, beta-carotene, citrulline, and ascorbic acid levels. The findings revealed that the lycopene content in watermelon flesh exhibited a considerable variation among the tested genotypes, ranging from 0.037 to 66.963 µg/g. The red-fleshed watermelon varieties showed the highest lycopene content, followed by pink-fleshed types, whereas white-fleshed genotypes had the lowest levels, trailed by yellow-fleshed types. Several studies have recorded similar results regarding lycopene content in watermelon flesh. Lycopene is the main carotenoid present in watermelons with red and pink flesh (Tadmor *et al*., 2005; Kang *et al*., 2010). Naz *et al*. (2014) reported that watermelon is a potential source of lycopene and red-fleshed watermelons have a lycopene concentration that is over 40 per cent greater than that of tomatoes. Choo and Sin (2012) evaluated the lycopene levels in red and yellow-fleshed seeded watermelons and noted that red-fleshed varieties contained the highest lycopene (9.5 mg/kg) compared to yellow-fleshed ones (0.04 mg/kg). Perkins-Veazie *et al*. (2006) also found that lycopene content varied significantly among cultivars; in red-fleshed varieties, it ranged from 33.9 to 75.7 µg g^{-1} (mean value 50 µg g^{-1}), while in the two yellow-fleshed varieties, it was below 5 µg g^{-1}. According to Tadmor *et al*. (2005), red-fleshed watermelons are rich in lycopene and have very little beta-carotene (less than 5 percent). Commercial red-fleshed watermelons have been reported to contain lycopene levels of 45.1-53.2 µg g^{-1} fresh weight (FW), with a mean value of 48.2 µg g^{-1} (Zhao *et al*., 2013). Perkins-Veazie *et al*., (2007) reported that only red-fleshed watermelons contained significant amounts of lycopene, while yellow and orange-fleshed types contained less than 6 mg/kg. Shonima, a red-fleshed seedless watermelon released from Kerala Agricultural University exhibited highest lycopene content which was on par with red fleshed seeded Durgapur Lal, whereas the lowest (0.03 mg/100g) was found in the yellow-fleshed seedless watermelon Swarna (Kaladhar *et al*., 2024).

Beta-carotene serves as a crucial dietary source of vitamin A (Haskell, 2012; Tang, 2012). Higher beta- carotene content would enhance the nutritional value of the fruits (Venkatesan *et al*., 2016). Significant differences in beta-carotene among the different watermelon genotypes were recorded, with levels ranging from 0.037 to 7.423 µg g^{-1}. The highest beta-carotene content was recorded in orange-fleshed watermelon genotypes, while the lowest levels were recorded in white-fleshed genotypes. Distinct carotenoid patterns were observed in red-fleshed and yellow-fleshed watermelons. The red-fleshed watermelon varieties contain high lycopene and varying amounts of beta-carotene (Tadmor *et al*., 2005). The flesh of immature white watermelons contains only minimal quantities of carotenoids as a result of the differentiation of chromoplasts from non-photosynthetic plastids, which probably develop directly from undifferentiated proplastids (Wang *et al*., 2019). The accumulation of carotenoids is linked to the development of flesh colour (Tadmor *et al*., 2005; Bang *et al*., 2007, 2010). Yellow-fleshed watermelon primarily contains violaxanthin and neoxanthin, while orange-fleshed varieties are mainly composed of beta-carotene (Tadmor *et al*., 2005; Lewinsohn *et al*., 2006; Bang *et al*., 2007, 2010; Liu *et al*., 2012). White-fleshed watermelons accumulate colourless phytofluene and light-yellow ζ-carotene (Kang *et al*., 2010; Grassi *et al*., 2013).

The findings indicated that there were statistically significant differences in citrulline content among watermelon genotypes, ranging from 843.810 ppm to 2589.750 ppm. The highest citrulline content was noted in orange-fleshed genotypes followed by yellow-fleshed types, while the lowest content was observed in pink and red-fleshed genotypes. These findings are in line with Rimando and Perkins-Veazie (2005), who stated that citrulline, a non-essential amino acid, is found abundantly in watermelon, particularly in yellow and orange varieties, which have higher concentrations compared to red ones. According to Kaladhar *et al*. (2024), Swarna, a yellow-fleshed seedless watermelon hybrid released from Kerala Agricultural University, exhibited higher citrulline content compared to the red-fleshed seedless hybrid Shonima. Therefore, the current study indicates the supremacy of citrulline content in orange and yellow-fleshed watermelon genotypes compared to red and other fleshed genotypes.

A significant variation in ascorbic acid content among different watermelon genotypes was recorded, with values ranging from 21.410 to 49.827 mg/kg of fresh watermelon. The highest ascorbic acid levels were noted in red-fleshed genotypes, while the lowest were found in white-fleshed genotypes. Comparable results regarding ascorbic acid levels in watermelon genotypes with varying flesh colours were reported by Sultana *et al*. (2023) and Choo and Sin (2012), who found that red-fleshed watermelons had a higher ascorbic acid content than yellow-fleshed types.

A significant variation in yield per plant was recorded among different flesh coloured watermelon genotypes with values ranging from 4.468 to 12.734 kg. The highest yield of 12.734 kg/plant was recorded in red fleshed AHW/BR-43. The lowest yield of 4.468 kg/plant was recorded in pink fleshed AHW/BR-7. These findings are in line with Aiswarya *et al*. (2023) and Pavithra & Nisha (2023), who reported significant differences in yield per plant the among different flesh coloured watermelon genotypes.

Table 2. Nutritional quality parameters and yield of watermelon genotypes with different flesh colours

Sl. No.	Watermelon genotypes	Lycopene (µg/g)	Beta-carotene (µg/g)	Citrulline (ppm)	Ascorbic acid (mg/kg)	Yield/plant (kg)
1	Arka Manik	60.517	6.030	2014.430	49.827	9.808
2	Arka Muthu	66.963	6.397	1791.677	49.010	5.372
3	Asahi Yamato	49.167	6.153	1968.610	43.717	9.095
4	CL-4	47.200	2.630	1531.617	38.580	8.849
5	Sugar Baby	45.880	4.110	1403.710	37.670	8.010
6	AHW/BR-43	58.297	4.677	2248.297	42.527	12.734
7	AHW/BR-5	43.273	2.837	843.810	33.903	5.400
8	AHW/BR-6	32.707	1.173	1607.337	32.510	5.729
9	AHW/BR-7	31.723	1.373	1490.747	30.237	4.468
10	AHW-19	39.697	2.210	1472.273	34.603	7.073
11	AHW-65	36.233	2.230	1463.320	32.160	6.410
12	CL-17	17.350	7.390	2348.930	43.680	10.876
13	CL-18	15.033	7.163	2240.023	40.603	9.876
14	CL-19	19.443	7.423	2589.750	44.467	10.877
15	CL-14	16.237	6.910	2310.337	38.553	9.696
16	CL-5	3.447	4.290	2313.883	33.727	7.591
17	CL-7	4.213	4.653	2290.803	33.863	7.793
18	CL-10	4.553	4.583	2121.063	36.870	8.267
19	AHW/BR-9	0.086	0.173	1357.057	26.640	5.733
20	AHW/BR-13	0.037	0.037	1750.617	21.410	6.807
	SE(m)	0.681	0.055	27.908	0.952	0.193
	CD (0.05)	1.951	0.157	79.898	2.725	0.554
	CV (%)	3.987	2.297	2.602	4.429	4.174

Pearson's correlation matrix revealed the relationships among nutritional quality attributes and yield per plant in watermelon fruits (Table 3). In this analysis, the lycopene content in watermelon exhibited a significant positive correlation ($p=0.01$) with the ascorbic acid content. At the same time, it showed a weak positive correlation with the beta-carotene content and a slight negative correlation with the citrulline content. Furthermore, the beta-carotene content showed a strong positive correlation with both citrulline and ascorbic acid contents. Yield per plant showed a weak positive correlation with nutritional quality attributes like ascorbic acid, citrulline and beta carotene contents and a very weak negative correlation with the lycopene content.

Table 3. Pearson's correlation coefficients between nutritional quality attributes and yield per plant in watermelon

Attributes	Ascorbic acid	Citrulline	Beta- carotene	Lycopene
Citrulline	0.449			
Beta- carotene	0.845**	0.714**		
Lycopene	0.596**	-0.302	0.162	
Yield per plant	0.179	0.291	0.284	-0.174

** Correlation is significant at 0.01 level (two tailed)

4. CONCLUSION

Nutritional quality parameters such as lycopene, beta- carotene, citrulline and ascorbic acid content of twenty watermelon genotypes with five different flesh colours (red, pink, orange, yellow and white) were assessed, leading to the following conclusions drawn from the findings. The red flesh of cultivated watermelons is due to lycopene accumulation, while orange flesh results from beta-carotene accumulation. Watermelons with orange and yellow flesh exhibit higher levels of citrulline content. In contrast, red-fleshed genotypes exhibit higher levels of ascorbic acid. Thus, watermelon genotypes with diverse flesh colours could be utilized for developing new hybrids with enhanced nutritional qualities.

Disclaimer (Artificial intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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