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Quality characteristics and antioxidant properties changes during ripening stage of muskmelon cultivars

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Abstract

The quality of melon is often associated to physicochemical properties and phytonutrient accumulation. The determination of optimum harvest time and selection of genotype are important for maximising the health benefits for melon consumers. The goal of the present work was to study the changes of physicochemical, bioactive compounds, and antioxidant activity of five muskmelon cultivars (Maazoun, Galaoui, Stambouli, Trabelsi, and Asli) at three ripening stages (unripe, ripe, and overripe). The main antioxidant compounds namely carotenoid, total phenol, flavonoid, and vitamin C content were measured. The hydrophilic and lipophilic antioxidant activity (HAA and LAA, respectively) analyses and their correlation with functional compounds were also performed. The result showed that the ripening stage significantly influenced the melon fruit quality depending on cultivars. The transition from the unripe to the overripe melon led to an increase in pH, °Brix, carotenoids, and phenols in all cultivars, except for Stambouli and Trabelsi, where the °Brix value decreased. The levels of flavonoids (except Maazoun, Stambouli, and Asli), vitamin C, HAA, and LAA (except Stambouli) reached a peak at the ripe stage, and decreased thereafter. At the ripe stage, the orange flesh colour melon Galaoui was distinguished by a higher level of carotenoid (54.28 mg/kg fw), phenolic (1290 mg GAE/kg fw), flavonoid (400.12 mg RE/kg fw), vitamin C contents (197.56 mg/kg fw), as well as a higher hydrophilic and lipophilic antioxidant activity (296.77 and 155.82 µM Trolox/100 g fw, respectively). A significant correlation between hydrophilic antioxidant activity and phenolic contents was found (r = 0.98, p < 0.01), suggesting that phenolics were the major contributors to the hydrophilic antioxidant capacity. These findings highlighted the effect of genetic factor and ripeness in determining the physicochemical properties, phytonutrient accumulation, and antioxidant potential of melon fruit. Melon fruits examined can be considered a promising source of functional compounds and antioxidant potential, in both ripe and overripe stages.

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Introduction

Muskmelon (*Cucumis melo* L.), also known as cantaloupe, is one of the most consumed and exported fruits worldwide. The fruit is essentially appreciated for its sweetness, and consumed fresh as a cooling dessert. Muskmelon has different flesh colours ranging from white, light green, to orange, depending on cultivars (Tzuri *et al*., 2015). Consumer preference for muskmelon is mainly determined by sweetness, nutritional factors, and texture (Farcuh *et al.*, 2020). Muskmelon is recommended in healthy diet as it is low in calories and cholesterol (Girelli *et al.*, 2018). Muskmelon also has several beneficial effects for health due to its richness in a multitude of antioxidant compounds and biofunctional properties (Vishwakarma *et al.*, 2017). Muskmelon also has potential health-promoting effects in reducing several diseases (Ayseli and Ayseli, 2016). Thus, these compounds have been included in cultivar breeding objective programs (İzli, 2017; Dhiman *et al*., 2020).

A number of factors such as environmental conditions, genetic aspects, and degree of ripening affect and determine bioactive compound levels and

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quality properties in muskmelon (Torres *et al*., 2020). Physicochemical and phytonutrient accumulation vary during muskmelon ripening stage (Menon and Rao, 2014; Belwal *et al*., 2019). Hence, the optimum harvest is important to determine for consumer health benefits and safety (Menezes Ayres *et al*., 2019). Despite the great influence of maturity stage on the functional quality in muskmelon, few studies have covered the transition from unripe to overripe stage (Khoshnam *et al.*, 2016; Vella *et al*., 2021). Selection of muskmelon genotypes with high antioxidant potential may further enhance health benefits for muskmelon consumers. The relationship between bioactive compounds and antioxidant activity in different hydrophilic and lipophilic fractions of muskmelon during maturity stage is also less investigated. Therefore, the present work focused on the changes of some physicochemical characteristics and functional compounds (carotenoids, phenols, vitamin C, and flavonoids) at unripe, ripe, and overripe stages of maturity, in five muskmelon cultivars (Galaoui, Maazoun, Stambouli, Trabelsi, and Asli). The hydrophilic and lipophilic antioxidant potentials, as well as their correlation with the different classes of bioactive compounds, were also determined.

Materials and methods

Plant materials

Five muskmelon cultivars, previously selected as part of the horticulture laboratory breeding programs based on their superior powdery mildew resistance at the National Agricultural Research Institute of Tunisia, were utilised. These cultivars at the ripe stage exhibit the following flesh colours: Galaoui (orange), Stambouli (light orange), Trabelsi (very light green), Maazoun (light green), and Asli (cream).

Plant culture

The experiments were carried out at the support station of the inter-professional vegetable group located in the Northeast of Tunisia (36°48’28’’N 10°6’4’’E). Muskmelon seeds were sown in plug-seedling trays. The muskmelon plants were transplanted on mid-April with an in-row and between row spacing of 100 and 150 cm, respectively. The experimental design was a randomised complete block. Three blocks (replicates) were used with ten plants per cultivar. The cultivation methods recommended by the National Agricultural Research Institute of Tunisia comprised chemical fertilisers (85 kg/ha N, 70 kg P_2O_5/ha, 130 kg KNO_3/ha, and 80 kg $MgSO_4$/ha), drip irrigation, and hand-weeding control. Synthetic chemical pesticides: Imidacloprid (Promochimie, Tunis, Tunisia; 200 g/L), Acetamiprid (SEPCM, Tunis, Tunisia; 200 g/L), and Triforine (Saprol, BASF Agro SAS; 18 g/L) were used once in the cycle for pathogen treatments.

Fruit sampling and preparation

Muskmelon fruits were harvested at different ripening stages during July 2019. The fruits from each block and variety were grouped into three ripening stages (unripe, ripe, and overripe).

i. The unripe stage (120 days after sowing): Skin fruit was varying from light to dark green, and the flesh was white.
ii. The ripe stage (129 days after sowing): Colour change of the pulp and skin of fruit occurred based on the studied melon cultivars: Maazoun was distinguishable by pale green predominant skin, dark green secondary skin, and light green flesh colour. Galaoui was characterised by cream predominant skin, brown secondary skin, and orange flesh colour. Trabelsi and Stambouli had a light-yellow predominant fruit skin colour with secondary green. Trabelsi had a very light green flesh colour, while Stambouli had a light orange flesh colon. Asli was characterised by light-yellow fruit skin colour and cream flesh colour.
iii. The overripe stage (134 days after sowing): more intense skin colour: Galaoui displayed a deeper shade of orange, while Maazoun adopted a more pronounced greenish tint. Stambouli and Asli melons both had a darker combination of yellow and green skin colours, with a more pronounced intensity for Stambouli. Asli's skin, in particular, turned into a dark yellow hue.

Fruit maturity was assessed in the field based on their ease of separation from vine with a slight twist, leaving clean cavity (Figure 1). The sampling, including five fruits of each ripening stage for five muskmelon cultivars, yielded a total of 75 muskmelons, which were quickly transported to the

laboratory for analysis. The fruits were cut longitudinally, and the samples were taken from the central part of each sample fruit. The flesh of the muskmelons was sliced into pieces, and homogenised using a mixer (Waring Laboratory and Science, Torrington, CT, US). The homogenates were then rapidly covered with aluminium in order to avoid photo-oxidation, and kept at -80°C for the analysis of physicochemical characteristics (°Brix, pH), carotenoids, phenolics, flavonoids, vitamin C, and antioxidant activities, which were performed in triplicates for each sample.

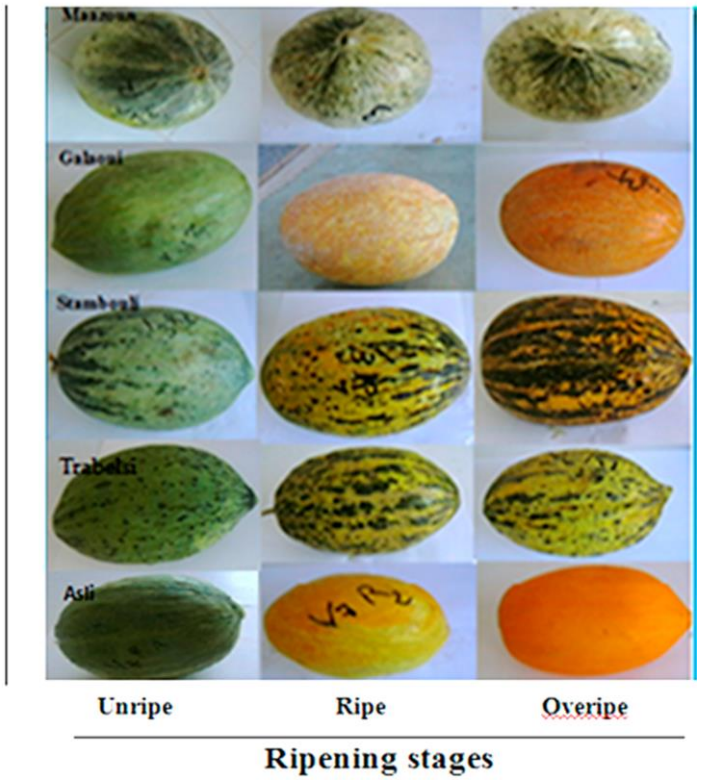

Figure 1. Appearance of muskmelon cultivars at different ripening stages.

Physicochemical trait determination

The fruit water soluble dry matter content was estimated using a digital refractometer (Atago PR-100, NSG Precision Cells, Inc., Farmingdale, NY, USA) by applying the single juice drops on its surface, and was expressed as °Brix. The fruit juice pH was determined using a pH meter (WTW, Microprocessor pH Meter, PH 539, Weilheim, Germany).

Carotenoid content determination

The muskmelon's carotenoid content was measured according to Henane *et al*. (2016). The extraction included a combination of hexane-ethanol-acetone (2-1-1) and 0.05% butylated hydroxytoluene. Carotenoid contents were quantified by measuring the absorbance at 450 nm using a Cecil BioQuest CE 2501 spectrophotometer (Cecil Instruments Ltd., Cambridge, UK), and the data were expressed as milligrams of carotenoid equivalents per kg fresh weight (mg/kg fw).

Total phenolic content determination

The total phenolic content of muskmelon was determined by the Folin-Ciocalteu formula. On 0.3 g aliquot of each fraction, phenolics were extracted as defined by Martinez-Valverde *et al.* (2002). Each sample was given 5 mL of 80% aqueous methanol and 50 mL of 37% HCl. For 2 h, the mixture was held at 4°C with continuous stirring (300 rpm). The samples were centrifuged for 15 min at 10,000 *g*. Finally, 50 µL of the extract was combined with 50 µL of Folin-Ciocalteu reagent and 450 µL of distilled water. The mixture was then allowed to stand at a 4°C for 5 min. Subsequently, 500 µL of 7% sodium carbonate solution was added, along with 200 µL of distilled water. After 90 min of reaction, the absorbances were measured using a BioQuest CE 2501 spectrophotometer (Cecil Instruments Ltd., Cambridge, UK) at a wavelength of 750 nm. Gallic acid was used to generate a linear calibration curve, and the values were represented in milligrams of gallic acid equivalents per kilograms of fresh weight (mg GAE/kg fw).

Flavonoid content determination

The flavonoid content in 0.3 g aliquot of the homogeneous juice was analysed according to Zhishen *et al*. (1999). The methanolic extract was mixed with distilled water, and diluted to a final volume of 0.5 mL. Afterward, it was vigorously shaken with 30 µL of 5% $NaNO_2$. After 5 min, 60 µL of 10% $AlCl_3$ solution were applied, followed by 200 µL of 1 M NaOH after 6 min. The absorbances of the mixtures were measured at 510 nm using a Cecil BioQuest CE 2501 spectrophotometer. A standard Rutin calibration solution was used, and data were expressed as milligrams of rutin equivalent per kg fresh weight (mg RE/kg fw).

Vitamin C content determination

The method used to determine vitamin C (ascorbic acid content) was described by Kampfenkel *et al*. (1995) on 0.1 g sample of homogeneous juice. Vitamin C extraction was assayed using 6%

metaphosphoric acid, and determined by absorbance at 525 nm using a Cecil BioQuest CE 2501 spectrophotometer. The standard curve's linear range spanned from 0 to 700 mmol AsA (ascorbic acid). Data were expressed milligrams of vitamin C per kg fresh weight (mg/kg fw).

Hydrophilic and lipophilic antioxidant activity determination

The ABTS radical scavenging capacities were measured according to Miller and Rice-Evans (1997). The Trolox equivalent antioxidant capacity (TEAC) assay was applied for measurement of the antioxidant activities of hydrophilic and lipophilic fractions (HAA and LAA, respectively). These fractions were extracted from three replicated samples of 0.3 g homogeneous juice using 50% methanol for HAA, and 50% acetone for LAA for 12 h. Centrifugation was then done at 10,000 *g* for 7 min, and the supernatant was collected prior its utilisation for antioxidant activity measurements. Absorbances of the samples were consequently measured at 734 nm using a Cecil BioQuest CE 2501 spectrophotometer (Cecil Instruments Ltd., Cambridge, UK). A linear calibration curve was determined with Trolox solution (0 - 16 µM Trolox), and data were expressed as µM of Trolox per 100 g of fresh weight (µM Trolox/100 g fw).

Statistical analysis

SAS Version 9.1 program was used to statistically analyse all data using One-way analysis of variance (ANOVA) (SAS Institute, Cary, NC, USA). The least significant difference (LSD) procedure was used to compare the mean values ($p < 0.05$). Correlations among parameters were evaluated using Pearson's correlation coefficient (r).

Results and discussion

Soluble solids and pH

Changes in soluble solids and pH are of special importance in fruit taste. Therefore, muskmelon maturity was determined on the basis of the soluble solids (°Brix) and pH of the pulp (Parveen *et al*., 2012; Tristán *et al*., 2022). The °Brix and pH values of muskmelons harvested at different ripening stages are shown in Table 1. The results indicated significant differences among the total soluble solids and pH of the studied muskmelon cultivars during the various stages of ripening ($p < 0.01$). The °Brix in muskmelon fruit increased significantly during ripening for Galaoui, Asli, and Maazoun. °Brix values varied from 4° in Maazoun to 13.2° in Asli, at unripe and overripe stages, respectively. The obtained values for the soluble solids were in line with those reported by Bianchi *et al*. (2016) and Fundo *et al*. (2018), ranging from 4.8° to 14°Brix for different muskmelon cultivars. These data also agreed with Villanueva *et al.* (2004), who reported that soluble solids increased with maturity stage of muskmelon, showing that sucrose was the predominant sugar in ripe fruits, while glucose and fructose were higher in immature fruits. Our results were also in accordance with those of Simandjuntak *et al*. (1996), who reported an increase in soluble solids at overripe stage in muskmelon from 8.45° to 10.10°Brix. During fruit ripening, sugar accumulation plays an important role in taste, and thus consumer acceptance (Durán-Soria *et al.*, 2020). According to Liu *et al*. (2010), sugar compositions changes during fruit development are related to the increase in sucrose phosphate synthase, sucrose synthase, and invertase activities.

For pH, the results showed significant differences in all cultivars during muskmelon ripening stage. Higher pH values were recorded in overripe stage compared to unripe and full ripe stages. The highest pH value was detected in Galaoui (5.6), followed by Mazzoun (6.2) and Asli (6.7), at unripe, ripe, and overripe stages, respectively. The obtained pH values were comparable to those found by Fundo *et al*. (2018) at the ripe stage in muskmelon (6.14). Recently, similar results were reported in muskmelon overripe stage by Vella *et al*. (2021). The present results were also in agreement with the findings of Beaulieu and Lea (2007), who showed that the flesh melon had the lowest pH value (5.25) just before maturity stage, then increased gradually during ripening, reaching 6.79. This increase may be attributed to gradual synthesis of organic acids during the fruit maturation (Koubala *et al*., 2016).

Carotenoids

The variations in carotenoid content during the different stages of ripening in the studied muskmelon cultivars are illustrated in Table 1. The total carotenoids markedly increased during fruit ripening in all cultivars. The values varied among ripening stages, and from one cultivar to another. At the ripe stage, the carotenoid contents ranged from 5.16 mg/kg fw in light green-flesh colour cultivar Stambouli to 54.28 mg/kg fw in orange-flesh colour

Table 1. pH, soluble solids, carotenoids, total phenols, flavonoids, and vitamin C contents in muskmelon cultivars harvested at three different ripening stages.

	pH	Soluble solid (°Brix)	Carotenoid (mg/kg fw)	Phenolic (mg GAE/kg fw)	Flavonoid (mg RE/kg fw)	Vitamin C (mg/kg fw)
Galaoui						
Unripe	5.60 ± 0^{c}	5.30 ± 0.2^{c}	10.30 ± 0.3^{c}	141.34 ± 1.2^{c}	219.44 ± 2.2^{c}	123.76 ± 4.3^{c}
Ripe	5.85 ± 0.1^{b}	10.50 ± 0.7^{b}	54.28 ± 0.1^{b}	1290 ± 1.00^{b}	400.12 ± 1.4^{a}	197.56 ± 5.1^{a}
Overripe	5.90 ± 0^{a}	10.70 ± 0.1^{a}	75.81 ± 0.2^{a}	1330.33 ± 2.1^{a}	360.55 ± 3.1^{b}	175.23 ± 2.3^{b}
Maazoun						
Unripe	5.55 ± 0.2^{c}	4.00 ± 0^{c}	1.06 ± 0.0^{c}	128.71 ± 3.00^{c}	205.55 ± 5.7^{c}	35.20 ± 0.1^{c}
Ripe	6.20 ± 0.3^{b}	12.30 ± 0.8^{b}	5.16 ± 0.3^{b}	439.00 ± 1.8^{b}	255.53 ± 3.1^{b}	175.31 ± 3.0^{a}
Overripe	6.50 ± 0.1^{a}	12.50 ± 0.5^{a}	22.63 ± 0.1^{a}	808.33 ± 1.4^{a}	413.88 ± 9.1^{a}	92.45 ± 4.6^{b}
Stambouli						
Unripe	4.58 ± 0.4^{c}	5.94 ± 0.1^{c}	4.50 ± 0.2^{c}	1120 ± 5.1^{c}	247.22 ± 2.1^{c}	124.21 ± 2.3^{c}
Ripe	5.45 ± 0^{b}	9.50 ± 0.7^{a}	38.57 ± 0.1^{b}	1030 ± 3.3^{b}	264.00 ± 1.1^{b}	180.42 ± 4.0^{a}
Overripe	6.15 ± 0.5^{a}	8.00 ± 0.9^{b}	46.54 ± 0.5^{a}	1390.03 ± 6.2^{a}	369.44 ± 5.3^{a}	172.51 ± 1.1^{b}
Trabelsi						
Unripe	4.49 ± 0.1^{c}	5.00 ± 0.1^{c}	0.00 ± 0.0^{c}	396.17 ± 2.2^{c}	188.88 ± 2.1^{c}	28.30 ± 3.0^{c}
Ripe	5.60 ± 0.7^{b}	10.00 ± 0.2^{a}	6.50 ± 0.4^{b}	665.00 ± 4.5^{b}	384.13 ± 3.3^{a}	143.25 ± 2.4^{a}
Overripe	6.00 ± 0.2^{a}	9.60 ± 0^{b}	31.22 ± 0.1^{a}	716.78 ± 6.1^{a}	351.88 ± 4.1^{b}	130.88 ± 4.0^{b}
Asli						
Unripe	5.00 ± 0.1^{c}	7.50 ± 0.3^{c}	1.50 ± 0.3^{c}	65.48 ± 1.4^{c}	222.22 ± 2.2^{c}	81.50 ± 6.1^{c}
Ripe	6.10 ± 0.3^{b}	13.00 ± 0.2^{b}	8.52 ± 0.6^{b}	800.50 ± 2.00^{b}	263.40 ± 3.0^{b}	132.15 ± 9.1^{a}
Overripe	6.70 ± 0.0^{a}	13.20 ± 0^{a}	25.45 ± 0.0^{a}	1136.24 ± 3.00^{a}	338.88 ± 3.3^{a}	122.43 ± 7.0^{b}

Values are mean ± standard error of triplicate analyses. Lowercase superscripts indicate mean separation within ripening stages of each cultivar; means with different lowercase superscripts are significantly different at $p < 0.05$ by LSD test.

cultivar Galaoui. The values were close to the range previously reported by Henane *et al*. (2016). Total carotenoid content of Galaoui at orange-flesh colour were significantly higher than other at all ripening stages. Generally, highest values of carotenoids were obtained for orange pulp cultivars (Esteras *et al*., 2018; Vanoli *et al*., 2023). This finding was in agreement with some studies which confirmed that orange-fleshed muskmelon is a better source of carotenoids than green fleshed muskmelon (Menon and Rao, 2014). These data also confirmed that muskmelon is a rich source of carotenoids.

The highest amount of total carotenoids was detected in overripe stage in Galaoui (75.81 mg/kg fw), followed by Stambouli (46.54 mg/kg fw), Trabelsi (31.22 mg/kg fw), Asli (25.45 mg/kg fw), and Maazoun (22.63 mg/kg fw). At the unripe stage, carotenoids were detected at a very low level in Maazoun (1.06 mg/kg fw) and Asli (1.5 mg/kg fw). The content of total carotenoids increased progressively from 6- to 31-fold in the subsequent stages of maturation with a minimum value in unripe stage. These results were in line with the findings of Menon and Rao (2014) and Wulandari *et al*. (2017), who reported that the quantity of carotenoids increased during ripening stage of muskmelon. Ionica *et al*. (2015) also reported the increased levels of β-carotene in the ripening stage, especially at the orange-coloured pulp cultivar.

A small amount of carotenoids in unripe stage indicated a low expression of enzymes implicated in carotenogenesis. Our results confirmed that the biosynthesis of carotenoids compounds was related to fruit colour in muskmelon during maturity process, contributing to various chemical parameters changes. The chlorophyll molecules are degraded with a

concomitant increase in the biosynthesis of pigment compounds, including anthocyanins and carotenoids (Fenn and Giovannoni, 2021).

This highest level of synthesis and accumulation of carotenoids detected at ripe and overripe stages might have been due to progressive activation of several enzymes at the early ripening stage implicated in carotenoid compounds biosynthesis. Lv *et al*. (2015) showed that the accumulation of great amounts of carotenoids during ripening fruits is due to the upregulation of carotenoid biosynthetic genes.

Phenolics and flavonoids

Another major group of functional antioxidant compounds that occur in fruits are phenolics and flavonoids. Phenolic compounds in fruits contribute to their quality, nutritional value, aroma, and flavour (Vella *et al*., 2021). The total phenolics and flavonoids of muskmelon cultivars during ripening are shown in Table 1. The results showed that the phenolic and flavonoid contents were significantly different between the ripening stages studied ($p < 0.01$). Results also revealed that the phenolics in muskmelon increased significantly during ripening for all cultivars. Total phenolics at unripe stage were significantly less than those of both ripe and overripe stages.

At the ripe stage, the muskmelon contained 2 to 12 times more phenolics than in the unripe stage. Similar results were reported previously by Henane *et al*. (2015). At the mature stage, the highest phenolic levels were detected in orange-fleshed melon Galaoui and Stambouli (1290 and 1030 mg GAE/kg fw, respectively). The results regarding high accumulation of phenols in orange-fleshed muskmelon were in line with the findings of Menon and Rao (2014), who reported that orange-fleshed muskmelon were richer in phenolics than the green-fleshed ones. Total phenolic levels in the present work were considerably higher than those reported by Fundo *et al*. (2018) of 101.90 ± 14.99 mg GAE/kg fw in the pulp of muskmelon.

Likewise, a significant increase in the amount of phenolic was reported by Menon and Rao (2012), with the advance of the maturation process in muskmelon. However, opposite results were obtained by Wulandari *et al*. (2017) and Tristán *et al*. (2022), who reported that the levels of phenolics decreased as maturation progressed. These findings also indicated the differential synthesis of phenolics during the ripening. Study by Ozkan *et al*. (2012) showed that the phenolic contents increased depending on the ripening of fruits.

Flavonoid contents increased gradually and consistently as the maturity of muskmelon advanced, and showed significant ($p < 0.05$) accumulation in the overripe stage, with the exception for Galaoui and Trabelsi cultivars. The highest amount of flavonoids was detected in Maazoun cultivar (413.88 mg RE/kg fw) at the overripe stage, whereas the lowest content was measured in Trabelsi at the unripe stage (188.88 mg RE/kg fw). At the ripe stage, Galaoui ranked first for flavonoids (400.12 mg RE/kg fw), followed by Trabelsi (384.13 mg RE/kg fw), Stambouli (264 mg RE/kg fw), Asli (263.4 mg RE/kg fw), and Maazoun (255.53 mg RE/kg fw). These results were considerably higher compared to those reported by Ibrahim and El-Masry (2016), who found that the flavonoids content in muskmelon was 2.05 mg RE/kg fw. Few studies are devoted to the determination of flavonoid content in muskmelon cultivars during ripening. Wulandari *et al*. (2017) reported that the flavonoid content of muskmelon cv. Hikapel did not change during ripening. According to Manach *et al*. (2004), it is well known that phenolic acid levels decreased as the fruit ripens, while flavonoid levels increased. Such varying results can depend on the studied cultivars. The differences in genotypes will amplify this variability. Based on our data, muskmelon can be considered a good source of phenolics in the Tunisian diet. Due to its availability and high consumption, this fruit may considerably contribute to the daily intake of phenols.

Vitamin C content

Vegetables and fruits are the primary sources of vitamin C for humans. High amounts of vitamin C are fundamental for human health. In the present work, significant differences were detected during muskmelon maturation ($p < 0.01$) (Table 1). These data are among the first reports on vitamin C content in muskmelon cultivars during overripe stage. The lowest level of vitamin C was detected at unripe stage in the cultivar Trabelsi (28.3 mg/kg fw), and the highest level was observed at ripe stage in the cultivar Galaoui (197.56 mg/kg fw). As the muskmelon ripened, it was found that the vitamin C levels increased at ripe stage, and subsequently decreased at the overripe stage. This increase in vitamin C content can be explained by its antioxidant function, which increases as the respiration rate of climacteric fruits

increases (Markus *et al*., 1999). While the decrease in the amount of vitamin C during the transition from ripe to overripe may result from its oxidation. These results indicated that these variations in vitamin C depend on both maturity stage and genotype. The decrease in vitamin C at overripe stage could have been due to the deterioration of fruit tissues. Villanueva *et al.* (2004) and Wulandari *et al*. (2017) also confirmed this. In contrast to the variations in vitamin C found in the present work, Menon and Rao (2014) demonstrated that young muskmelon contained higher vitamin C content than the fully ripened fruit.

In the flesh of ripe muskmelon, vitamin C values ranged from 132.15 mg/kg fw in Asli cultivar to 197.56 mg/kg fw in Galaoui cultivar. The obtained vitamin C values were in line with those reported for muskmelon varieties ranging from 100 to 300 mg/kg fw (Pandey *et al*., 2021). Ionica *et al*. (2015) focused on the variation traits throughout maturity, and reported similar values to those obtained in the present work. At the ripe stage, the authors reported that vitamin C content varied between 106.82 and 297.21 mg/kg fw for Kemer and Raymond cultivars, respectively.

The variations in vitamin C content are often ascribed to differences in genotypes, cultural practices, environmental conditions, cultivars, and temperatures (Bernal *et al*., 2014). The selection of the genotype is the main factor to consider when high vitamin C concentrations are desired (Lee and Kader, 2000). Our results confirmed that muskmelon could be a relevant source of vitamin C. It is, therefore, advisable to increase the consumption of muskmelon due to their high amounts of vitamin C.

Antioxidant activity

The antioxidant activities in both hydrophilic (HAA) and lipophilic (LAA) fractions of muskmelon cultivars were determined using TEAC assays, since the presence of lipophilic compounds, such as carotenoids and hydrophilic compounds, phenols, and vitamins contribute to the total antioxidant activity of fruits and vegetables. To our knowledge, this is the first study on the variations of HAA and LAA in muskmelon cultivars during ripening. The HAA and LAA in muskmelon cultivars at three different ripening stages are shown in Table 2. Significant differences ($p < 0.05$) were found among ripening stages of all cultivars. Following an increase in antioxidant activity from unripe to ripe, a decrease occurred at the overripe stage. In all varieties, HAA and LAA (except Stambouli cultivar) of ripe muskmelon were significantly higher than that of unripe and overripe muskmelon. HAA was higher than LAA at three ripening stages, and for all muskmelon cultivars. A peak in HAA and LAA values were reached at the ripe stage of maturity in Galaoui cultivar with 296.77 and 155.82 µM Trolox/100 g fw, respectively. However, lower values of hydrophilic and lipophilic antioxidant activity were detected at unripe stage in Maazoun cultivar with 25.15 and 9.1 µM Trolox/100 g fw, respectively.

The total antioxidant activity (HAA + LAA) varied from 34.25 µM Trolox/100 g fw in the green-fleshed cultivar Maazoun to 452.59 µM Trolox/100 g fw in the orange-fleshed cv Galaoui. This variability

Table 2. Hydrophilic and lipophilic antioxidant activities in muskmelon cultivars harvested at three ripening stages.

TEAC assay (µM Trolox/100 g Fw)		
Cultivar	**Hydrophilic**	**Lipophilic**
Maazoun		
Unripe	25.15 ± 0.1^{c}	9.10 ± 3.1^{c}
Ripe	123.31 ± 0.5^{a}	42.00 ± 0.2^{a}
Overripe	112.16 ± 2.1^{b}	10.43 ± 1.1^{b}
Galaoui		
Unripe	130.56 ± 1.4^{c}	77.40 ± 0.5^{c}
Ripe	296.77 ± 2.2^{a}	155.82 ± 0.2^{a}
Overripe	225.54 ± 0.1^{b}	130.33 ± 0.8^{b}
Stambouli		
Unripe	176.70 ± 1.1^{c}	70.60 ± 3.1^{c}
Ripe	222.17 ± 0.1^{a}	98.23 ± 2.3^{a}
Overripe	189.76 ± 3.2^{b}	100.20 ± 4.1^{b}
Trabelsi		
Unripe	84.79 ± 6.2^{b}	21.21 ± 2.2^{c}
Ripe	133.28 ± 4.1^{a}	125.11 ± 0.1^{a}
Overripe	98.11 ± 2.2^{c}	60.34 ± 4.2^{b}
Asli		
Unripe	109.79 ± 10.2^{b}	11.54 ± 6^{c}
Ripe	172.78 ± 4.3^{a}	116.23 ± 2.5^{a}
Overripe	146.18 ± 1.9^{c}	56.13 ± 10.1^{b}

Values are mean ± standard error of triplicate analyses. Lowercase superscripts indicate mean separation within ripening stages of each cultivar; means with different lowercase superscripts are significantly different at $p < 0.05$ by LSD test.

might have been due to the genetic factors that play an important role in determining antioxidant capacity in muskmelon. A similar result has been found by Ionica *et al*. (2015), who also reported that the highest antioxidant capacity was reached in fully ripe muskmelon. Menon and Rao (2012) and Vella *et al*. (2021) reported that the total antioxidant activity decreased with the advancement of maturation. Furthermore, our results were higher than those reported for different muskmelon cultivars ranging from 40.7 to 75 µM Trolox 100/g fw (Ionica *et al*., 2015). Our results showed that ripening stage and cultivar were important parameters for determining the hydrophilic (HAA) and lipophilic (LAA) antioxidant activities.

Correlation

The antioxidant capacity of fruits can vary depending on the total phenolic content, flavonoids, carotenoids, and vitamins C and E (Souza *et al*., 2012). The Pearson's correlation coefficients between hydrophilic, lipophilic, antioxidant activity, phenolics, carotenoids, vitamin C, and flavonoids are presented in Table 3. Based on the results, no significant correlation was found between HAA values and both total vitamin C (r = 0.96) and flavonoids (r = 0.41). Meanwhile, they well correlated with total phenolics (r = 0.98; p < 0.01). This suggested that phenolic compounds may be responsible for presenting the most important contributions to the HAA of muskmelon. Tristán *et al*. (2022) found similar correlation in muskmelon using total antioxidant activity and phenolics. In contrast, Koubala *et al*. (2016) found no correlation in muskmelon between antioxidant capacity and total phenolic, and suggested that macromolecules with antioxidant activity might not only be phenolic compounds. It should be noted that the relationship between the antioxidant activity and total phenolics depended on several factors, such as the chemical structure of the individual component, synergistic interaction among them, and specific conditions applied in different assays (Wulandari *et al*., 2017).

The LAA depends also on the synergistic interaction among all the lipophilic compounds, and specific conditions applied in the antioxidant activity assay. In the present work, no significant correlation between LAA and carotenoids was detected (r = 0.89). Similar results were reported by Benmeziane *et al*. (2018), who showed that flavonoids and carotenoids did not correlate significantly with total antioxidant activity. Tristán *et al*. (2022) found similar correlation in muskmelon using total antioxidant activity and carotenoids. The results of the present work implied that the decrease in LAA during overripe stage could be due to the decrease in other lipophilic contents in muskmelon. It seemed that LAA was mainly impacted by the presence of other lipophilic antioxidant compounds.

Table 3. Pearson correlation coefficients (r) and related significance between antioxidant content and antioxidant activities; n = 45; ns = no significant correlation.

Compound	TEAC assay	
	r	***p***
HAA		
Total Phenolics	0.98	< 0.01
Vitamin C	0.96	ns
Flavonoids	0.41	ns
LAA		
Carotenoids	0.89	ns

Conclusion

The results provided valuable information on the change in the contents of physicochemical properties, functional compounds, and antioxidant activity (HAA and LAA) affected by the ripening process (unripe to overripe stage), as well as the important effect of genotype in determining the antioxidant potential of melon fruit. The results also revealed that the biosynthesis of carotenoids compounds was related to fruit colour in melon, along with maturity process, contributing to various chemical parameters changes. The pH, carotenoids, and phenols increased during ripening stage in all melon cultivars. While a decrease in the levels of vitamin C, HAA, and LAA was recorded progressing from ripe to overripe stage. For flavonoids, the highest values were reached at the overripe stage for all cultivars, except Trabelsi and Galaoui. The °Brix and the total flavonoid content were affected by fruit ripening in a cultivar-dependent way. The orange flesh colour melon showed high level of carotenoids, vitamin C, lipophilic, and hydrophilic antioxidant activities compared to other cultivars. A positive correlation was found between phenolics and hydrophilic antioxidant activity in all muskmelon cultivars during ripening, suggesting that they are the main contributors to the hydrophilic activity in

melon. Finally, the results highlighted the importance of recognising the optimal ripening stage of melon fruit, to guarantee high fruit quality standards, and provide useful data for marketers and consumers of melon fruit.

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