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Development of Thai-taste maoberry (*Antidesma bunius* (L.) Spreng.) vegan sorbet from fruit of different maturities with added inulin: Physicochemical and antioxidant properties

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Abstract

Maoberry (*Antidesma bunius* (L.) Spreng.) is a tropical fruit popularly consumed with Thai-style chili sugar flakes containing sugar, salt, and chili to enhance its flavour, and reduce its sour and bitter taste. The present work aimed to develop a Thai-taste maoberry vegan sorbet using maoberries at different stages of maturity with added inulin, and to evaluate its physicochemical properties, total phenolic and total flavonoid contents, and antioxidant capacities. Results showed that the three different stages of maoberry maturity caused significant changes on pH, total soluble solids, mixture viscosity, overrun, and firmness of the sorbets. The antioxidant activities assessed using ferric-reducing antioxidant power (FRAP), 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging, 3-ethylbenzthiazoline-6-sulphonic acid (ABTS), radical cation decolourisation, and oxygen radical absorbance capacity (ORAC) assays indicated similar trends. Black maoberry sorbet exhibited total flavonoid contents and FRAP values almost twice those of red maoberry sorbet. However, adding inulin significantly increased the melting rate of the product ($p < 0.05$), but improved the mixture viscosity and overrun, which are important attributes of sorbets.

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Introduction

Sorbet is a type of ice cream made from fruit purée, fruit juice, and/or water and sweeteners. Sorbet is low in calories because it contains no fat, cream, or added animal protein (Palka and Skotnicka, 2022). Therefore, sorbet can be a healthy choice for vegans, vegetarians, and consumers who would like to consume an alternative frozen dessert or ice cream. The world market for non-dairy frozen desserts, including sorbets, is expected to expand at an annual growth rate of 8.7% from 2022 to 2030, with an increasing consumer demand for a greater range of plant-based diets, low-calorie snacks, and foods that support healthier blood biochemistry profiles (Grand View Research, 2023).

Inulin, a fructo-oligosaccharide (FOS), is a polysaccharide that cannot be digested by the human digestive system. It has prebiotic properties that decrease constipation and the risk of bowel diseases, and stimulate immune functions (Narala *et al.*, 2022). It has been used as a thickener, stabiliser, and fat replacer in frozen desserts because it can form a gel and trap water in food systems (Akbari *et al.*, 2019). Adding inulin to ice cream desserts has been reported not to affect consumer acceptability even though its inclusion reduces the fat and sugar contents (Da Silva Faresin *et al.*, 2022).

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Maoberry (*Antidesma bunius* (L.) Spreng.) is a tropical fruit locally known as *ma-mao*, and widely cultivated in north-eastern Thailand. It is traditionally consumed with Thai-style chili sugar flakes containing sugar, salt, and chili that enhance its flavour, and reduce its sourness and bitterness. The shape of the fruit is small ovoid, clustered in a bunch. Maoberry is green when young, then turns to red and purple-black when ripened. It can be eaten fresh semi-ripe or ripe. Previous studies have reported that maoberry has antioxidant (Kemsawasd and Chaikham, 2021), anti-obesity (Krongyut and Sutthanut, 2019), anti-diabetes (Aksornchu *et al*., 2021), lipid-lowering (Crieta *et al*., 2021), and anti-Alzheimer properties (Nguyen-Ngoc *et al*., 2022). Maoberry contains several polyphenols and bioactive compounds, thus has a preventative effect against metabolic syndromes, chronic diseases, and neurodegenerative diseases. Maoberry is also rich in phenolics, flavonoids, and anthocyanins, which are great sources of antioxidants (Suravanichnirachorn *et al*., 2018). Although these studies indicated that maoberry has many health benefits and is inexpensive, it is not popular with Thai consumers due to its sour, astringent, and bitter taste attributes, and is only available during a short season from July to August. Therefore, new product development is needed to add value to maoberry by making it easier to be consumed by all age groups of consumers.

Materials and methods

Preparation of raw materials

Maoberries were purchased in Udon Thani province, north-eastern Thailand from July to August 2023. Different colours of maoberries indicate their stage of maturity: half-ripe (red), almost ripe (black-red), and fully ripe (black). The maoberries were washed thoroughly in tap water, rinsed with distilled water, air-dried, then separated into the three colours based on maturity. Following seed removal, the pulp was placed in plastic bags, and stored at -18°C until further analyses. Inulin (degree of polymerisation > 14) was obtained from the Fuji Nihon Thai Inulin Company, Ltd. (Bangkok, Thailand).

Maoberry sorbet formulation and preparation

A total of nine sorbets were made with the three different colours of fruit maturity (red, black-red, and black colour) and three concentrations of inulin (0, 3.5, and 6.5%). To prepare 100 g of Thai-style chili salt, 91.43 g of sugar were mixed with 5.71 g of salt and 2.86 g of chopped chili (w/w). The ingredients for each sorbet recipe were divided into three parts: 150 g of maoberry pulp was weighed (9.3%, w/w). The chili salt (6.5%, w/w) syrup was prepared, then inulin was added. After the sample was blended for 3 min, it was aged at 3°C overnight. The sorbet was then frozen at -30°C for 25 min (Nemox Pro 2500 Auto Gelato Machine, Pontevico, Italy), and stored at -18°C. The physicochemical and physical properties of the sorbets were evaluated after 7 d of storage.

pH and total soluble solids content

After the sorbets were thawed at 20°C (room temperature), the pH value of each sample was determined using a digital pH meter (Seven2Go S7-Field kit, Mettler Toledo, Greifensee, Switzerland). The total soluble solids content was determined using a MA871 digital brix refractometer (Milwaukee Instruments, Inc., Rocky Mount, NC, USA).

Colour

The colour of sorbets was determined using a spectrophotometer (Color Quest XE, HunterLab, Reston, VA, USA) using a light source illuminant D65 and a 10 degree observer function.

Viscosity

The viscosity of sorbets was determined at 25°C using a Brookfield viscometer (Model DV-II, Brookfield Engineering Labs. Inc., Middleborough, MA, USA) equipped with no. 1 spindle running at 100 rpm.

Firmness

The firmness of sorbets was determined using a texture analyser (TA plus, Lloyd Instruments, Fareham, UK) equipped with a 1-kN load cell and a stainless-steel cylinder probe (0.5 cm diameter). The sorbets were stored for 1 w at -18°C before texture analysis. The conditions for analysis were as follows: test speed 2 mm/s and distance 10 mm. Each sorbet sample remained in the container, and was penetrated on the smooth surface. The peak force was considered as the firmness, and expressed in Newton (N).

Overrun, melting rate, and melting behaviour

The overrun of sorbets was determined as described by Petkova *et al*. (2022). In brief, the weights of the sorbet before freezing and after hardening were measured. The percentage of overrun was calculated using Eq. 1:

$$\text{Overrun (\%)} = [(\text{weight sorbet mix} - \text{weight of sorbet}) / \text{weight of sorbet}] \times 100 \quad \text{(Eq. 1)}$$

The melting rate was determined as described by Petkova *et al*. (2022). Each frozen product was removed from the container (diameter 6 cm, height 3 cm), and placed on a sieve (60 mesh) which was mounted on a funnel over a measuring cylinder at room temperature (20°C) and 55% RH. The weight of the melting sorbet was recorded every 5 min for 120 min. The melting rate was expressed in g/min.

The melting behaviour was observed through image analysis. Each sorbet was placed on a plate. An image was taken every 10 min using a camera phone (iPhone 13, Apple Inc., Cupertino, CA, USA) over a period of 65 min.

Determination of total phenolic and total flavonoid contents

Total phenolic content

The total phenolic content was determined as described by Patthamakanokporn *et al*. (2008) with slight modification. Gallic acid was used as the standard. The reaction was colorimetrically measured at 765 nm using a 96-well microplate reader (Biotek Synergy H1, Agilent, Santa Clara, CA, USA). The contents obtained were expressed as milligrams of gallic acid equivalent per 100 mL (mg GAE/100 mL).

Total flavonoid content

The total flavonoid content was determined as described by Zheng *et al*. (2018) with slight modifications. The reaction was determined colorimetrically at a wavelength of 510 nm using quercetin as the standard. The contents obtained were expressed as milligrams of quercetin equivalent per 100 mL (mg QE/100 mL).

Determination of antioxidant activity

2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging activity assay

The DPPH assay was performed as described by Fan *et al*. (2019) with slight modifications. The DPPH reagent was used as an indicator of the free radical scavenging activity with Trolox as the standard. The reaction was colorimetrically recorded at an absorbance of 517 nm using the 96-well microplate reader. The values obtained were expressed as milligrams of Trolox equivalent per 100 mL (mg TE/100 mL).

Ferric-reducing antioxidant power (FRAP) assay

The FRAP assay was performed as described by Patthamakanokporn *et al*. (2008) with slight modification. The FRAP reagent consisted of acetate buffer (pH 3.6), 2,4,6-tris-(2-pyridyl)-1,3,5-triazine (TPTZ) solution, and $FeCl_3 \cdot 6H_2O$ solution at a ratio of 10:1:1, respectively. The assay was conducted at 37°C using Trolox as the standard. The absorbance was measured at 593 nm. The values obtained were expressed as milligrams of Trolox equivalent per 100 mL (mg TE/100 mL).

Oxygen radical absorbance capacity (ORAC) assay

The ORAC assay was performed as described by Ou *et al*. (2002). 2,2′-azobis(2-amidinopropane)dihydrochloride (AAPH) was used as the free radical initiator. The reaction was conducted at 37°C for 90 min using Trolox as the standard. The fluorescence intensity was monitored at a wavelength of 490 nm (excitation) and 514 nm (emission). The results were calculated using an equation relating Trolox concentration to the net area under the fluorescein decay curve (AUC). The AUC was calculated using Eq. 2:

$$AUC = (0.5 + f_1/f_0 + f_2/f_0 + f_3/f_0 + \ldots + (0.5)f_i/f_0) \quad \text{(Eq. 2)}$$

where, f_0 = initial fluorescence reading, and f_i = fluorescence reading at i min. The values obtained were expressed as milligrams of Trolox equivalent per 100 mL (mg TE/100 mL).

2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) assay

The ABTS assay was performed as described by Fan *et al*. (2019) with slight modifications. The ABTS reagent was used as an indicator of free radical scavenging activity, with Trolox used as the standard. The reaction was calorimetrically determined at 734 nm using the 96-well microplate reader. The values obtained were expressed as milligrams of Trolox equivalent per 100 mL (mg TE/100 mL).

Statistical analysis

The experiment was set up as a 3 × 3 factorial in a completely randomised design. Data were analysed by analysis of variance (ANOVA) and Duncan's test to compare the mean values at a 5% level of significance using the Statistical Package for the Social Sciences (SPSS) (IBM, Armonk, NY, USA). The graphs were plotted and presented using Prism 9 (GraphPad, San Diego, CA, USA).

Results and discussion

Physical and physicochemical properties

Table 1 shows how using maoberry at different maturity stages with different amounts of inulin in the formulation of the sorbet affected the physical and physicochemical properties of the product. Red maoberry sorbet had the lowest pH value (2.99) and total soluble solids (23.90 °Brix). When using black maoberries, the pH value and total soluble solids of the sorbet were significantly higher than for red and black-red maoberries ($p < 0.05$). The different stages of maturity of the maoberry led to differences in the taste and texture profiles of the sorbets. The total soluble solids and pH value of the fruit influenced the sweetness as sugar is the most abundant soluble solid in many types of fruit. Therefore, the total soluble solids and pH value can provide an estimation of the sugar and acid contents in the fruit. Sorbet made with fully ripe maoberries (black colour) was the sweetest, while sorbet made with half-ripe maoberries (red colour) was the sourest. Maoberry sorbet prepared from fully ripened fruit had the highest viscosity (33.71 cP), overrun (29.07%), pH (3.85), and total soluble solids (24.85 °Brix), followed by the almost fully ripe maoberries (black-red) and the half-ripe maoberries (red). The development of the most mature stage of the fruit may lead to the enhancement and accumulation of soluble solids, especially sugar. Similar results of an increase in total soluble solids in the advanced maturity stages of olive sorbet were also observed by Sumrah *et al*. (2015). Therefore, the total soluble solids and viscosity increased, and the pH value decreased as the berries matured.

Table 1. Effect of maturity stages of maoberry and levels of inulin on physicochemical properties of sorbets.

Sample	Viscosity (cP)	Overrun (%)	Firmness (N)	pH	TSS (°Brix)
A: Maoberry colour					
Black	33.71^{a}	29.07^{a}	39.78^{c}	3.85^{a}	24.85^{a}
Black-Red	31.58^{b}	23.28^{c}	67.08^{b}	3.17^{b}	23.82^{b}
Red	28.98^{c}	24.68^{b}	81.63^{a}	2.99^{c}	23.90^{b}
SL	0.000	0.000	0.000	0.000	0.000
B: Inulin level					
0%	29.33^{c}	21.82^{c}	74.50^{a}	3.39^{a}	21.68^{c}
3.5%	31.68^{b}	28.39^{a}	58.85^{b}	3.31^{b}	24.55^{b}
6.5%	33.26^{a}	26.82^{b}	55.14^{c}	3.30^{b}	26.33^{a}
SL	0.000	0.000	0.000	0.041	0.000
Interaction A × B					
SL	0.053	0.000	0.000	0.628	0.000
Sample (colour/inulin (%))					
Black/0	31.70 ± 0.8^{c}	29.53 ± 2.7^{ab}	26.37 ± 1.8^{g}	3.88 ± 0.04^{a}	23.00 ± 0.0^{e}
Black/3.5	33.45 ± 0.3^{b}	30.54 ± 0.2^{a}	36.94 ± 0.9^{f}	3.83 ± 0.04^{a}	25.00 ± 0.1^{c}
Black/6.5	36.00 ± 0.9^{a}	27.15 ± 0.8^{c}	56.04 ± 1.6^{e}	3.84 ± 0.03^{a}	26.55 ± 0.1^{a}
Black-Red/0	29.60 ± 0.3^{e}	16.44 ± 1.9^{e}	79.74 ± 2.5^{b}	3.26 ± 0.01^{b}	20.80 ± 0.2^{g}
Black-Red/3.5	32.10 ± 0.4^{c}	26.91 ± 1.0^{c}	65.70 ± 3.4^{d}	3.12 ± 0.12^{c}	24.46 ± 0.2^{d}
Black-Red/6.5	33.05 ± 0.1^{b}	26.49 ± 0.8^{c}	55.81 ± 1.7^{e}	3.12 ± 0.09^{c}	26.20 ± 0.0^{b}
Red/0	26.70 ± 0.1^{f}	19.49 ± 0.3^{d}	117.38 ± 5.6^{a}	3.03 ± 0.08^{cd}	21.25 ± 0.5^{f}
Red/3.5	29.50 ± 0.1^{e}	27.72 ± 0.1^{bc}	73.94 ± 1.6^{c}	2.99 ± 0.07^{cd}	24.20 ± 0.0^{d}
Red/6.5	30.75 ± 0.1^{d}	26.84 ± 0.5^{c}	53.58 ± 2.0^{e}	2.95 ± 0.06^{d}	26.25 ± 0.2^{ab}

Data are mean ± standard deviation. Means followed by different lowercase superscripts in the same column are significantly different ($p < 0.05$). SL: significant level.

Adding inulin helped to increase the viscosity of the prepared sorbet mix because of its high water-binding capacity. The viscosity of sorbets mixed with inulin ranged from 31.68 to 33.26 cP, compared with that of a sorbet without inulin at 29.33 cP, because the total soluble solid contents increased when inulin was added to the sorbet. Maoberry sorbet with no inulin had the lowest total soluble solid content (21.68 °Brix), followed by the sorbets with 3.5 and 6.5% added inulin at 24.55 and 26.33 °Brix, respectively. This was possibly caused by the interaction between inulin and the liquid component of the sorbet forming a gel-like network (El-Nagar *et al*., 2002).

Adding inulin to the maoberry sorbet also significantly influenced the overrun values which ranged from 26.82 to 28.39% ($p < 0.05$), while the overrun for sorbet with no inulin was only 21.82%. Palka and Skotnicka (2022) reported an increase (5.57 - 12%) in the overrun of tropical fruit sorbets after adding inulin. Inulin has been reported to help retain free water in the structure of sorbet, resulting in smaller ice crystals, which led to a softer texture or decreased firmness of the sorbet (Akbari *et al*., 2016). The effect of adding inulin on the firmness of maoberry sorbet is shown in Table 1. Maoberry sorbet with 6.5% added inulin had the lowest firmness value of 55.14 N, followed by maoberry sorbet with 3.5% added inulin (58.85 N), and sorbet with no inulin (74.50 N), indicating that adding inulin to maoberry sorbet significantly decreased the firmness value ($p < 0.05$). This agreed with El-Nagar *et al*. (2002) and Meyer *et al*. (2011) who reported that inulin decreased the hardness and increased the chewiness of ice cream by increasing the flow consistency and pseudo-plasticity.

Table 2 shows the effect of different treatments on the colour parameters of maoberry sorbet. The colour in terms of lightness, redness, yellowness, chroma, and hue angle of sorbets prepared from maoberry at three maturity stages were significantly different. Sorbet prepared with red maoberries exhibited the highest lightness (59.29) and yellowness (5.86) values, and hue angle (22.84). In contrast, sorbet prepared with black maoberries

Table 2. Effect of maturity stages of maoberry and levels of inulin on colour parameters of sorbets.

Sample	Lightness	Redness	Yellowness	Chroma	Hue angle
A: Maoberry colour					
Black	50.97^{c}	14.86^{b}	2.37^{c}	15.05^{c}	9.11^{c}
Black-Red	52.37^{b}	21.07^{a}	3.95^{b}	21.45^{b}	10.61^{b}
Red	59.29^{a}	20.61^{a}	5.86^{a}	22.34^{a}	22.84^{a}
SL	0.000	0.000	0.000	0.000	0.000
B: Inulin level					
0%	51.38^{b}	19.57^{a}	5.15^{a}	20.30^{a}	13.76^{b}
3.5%	55.87^{a}	19.22^{a}	5.32^{a}	20.07^{a}	15.2^{a}
6.5%	55.36^{a}	17.76^{b}	4.42^{b}	18.47^{b}	13.59^{b}
SL	0.000	0.000	0.000	0.000	0.000
Interaction A × B					
SL	0.001	0.000	0.031	0.000	0.000
Sample (colour/inulin (%))					
Black/0	49.74 ± 0.2^{b}	13.90 ± 0.5^{f}	2.34 ± 0.1^{ef}	14.09 ± 0.5^{f}	9.57 ± 0.2^{e}
Black/3.5	52.72 ± 0.9^{c}	15.39 ± 0.6^{e}	2.76 ± 0.2^{de}	15.63 ± 0.6^{e}	10.2 ± 1.2^{e}
Black/6.5	50.46 ± 0.6^{d}	15.30 ± 0.4^{e}	2.04 ± 0.1^{f}	15.43 ± 0.4^{e}	7.57 ± 0.3^{g}
Black-Red/0	50.12 ± 0.1^{d}	20.11 ± 0.0^{c}	4.29 ± 0.0^{c}	20.56 ± 0.1^{cd}	12.04 ± 0.0^{c}
Black-Red/3.5	54.21 ± 1.5^{c}	23.04 ± 0.8^{b}	4.53 ± 0.2^{c}	23.48 ± 0.8^{b}	11.12 ± 0.2^{d}
Black-Red/6.5	52.77 ± 0.7^{c}	20.09 ± 0.8^{c}	3.06 ± 0.1^{d}	20.32 ± 0.8^{cd}	8.68 ± 0.1^{f}
Red/0	54.31 ± 1.7^{c}	24.72 ± 0.6^{a}	8.85 ± 0.1^{a}	26.26 ± 0.6^{a}	19.70 ± 0.1^{b}
Red/3.5	60.70 ± 1.4^{b}	19.23 ± 0.7^{c}	8.69 ± 0.6^{a}	21.1 ± 0.9^{c}	24.29 ± 0.6^{a}
Red/6.5	62.86 ± 2.1^{a}	17.90 ± 0.9^{d}	8.17 ± 0.4^{b}	19.68 ± 1.0^{d}	24.54 ± 0.1^{a}

Data are mean ± standard deviation. Means followed by different lowercase superscripts in the same column are significantly different ($p < 0.05$). SL: significant level.

exhibited the lowest lightness (50.97), redness (14.86), and yellowness (2.37) values, and hue angle (9.11). These results covered colour changes from light red to dark purple, colours observed in a typical maturation process. Previous studies have also reported that maoberry was green at the unripe stage, red at the half-ripe stage, and black at the fully ripe stage (Sartagoda *et al*., 2021; Crieta *et al*., 2021).

The lightness of the sorbet decreased from approximately 55 to 51 because of adding inulin. However, inulin added at 3.5% did not significantly influence the redness (19.22), yellowness (5.32), and chroma (20.07) of the sorbet compared with the control (redness, 19.57; yellowness, 5.15; and chroma, 20.30); while the redness (17.67), yellowness (4.42), and chroma values decreased significantly after adding inulin at 6.5% to the sorbet ($p < 0.05$). The effect of inulin addition in the present work agreed with the results of Tiwari *et al*. (2015) who also reported significant changes in the colour parameters of low-fat ice-cream, where the lightness, redness, and yellowness values of low-fat ice-cream were reduced by adding inulin.

Melting rate and behaviour

The melting rate is an important parameter in assessing the quality of sorbet. The effect of the maturity stage of maoberry and inulin level on the melting behaviour of the sorbet is shown in Figure 1. The shortest melting time (first drop at 20 min) was recorded for black-red and red maoberry sorbet with 6.5% added inulin, while the longest melting time (first drop at 30 min) was for black maoberry sorbet with no inulin. Figure 2 shows that black maoberry sorbet with 6.5% added inulin had the highest melting rate (5.07 g/min), followed by red maoberry sorbet with 6.5% added inulin (4.95 g/min), and black-red maoberry sorbet with 6.5% added inulin (4.71 g/min). The sorbets with added inulin exhibited numerous small air cells during melting because adding inulin to sorbet promoted the formation of small air cells which was consistent with the high percentage of overrun. In contrast, black maoberry sorbet with no inulin exhibited the lowest melting rate (4.05 g/min), followed by black-red sorbet with no inulin (4.11 g/min), and red sorbet with no inulin (4.37 g/min). These results clearly indicated that adding inulin led to a faster melting rate. These results agreed with those of a study by Góral *et al*. (2018) who reported that increasing the inulin content from 0 to 4% decreased the melting time. A previous study also reported that adding inulin (2 - 5%) to tropical fruit sorbets significantly decreased the melting resistance (Palka and Skotnicka, 2022). The level of total soluble solids is a key factor affecting the melting time of sorbet: the higher the total solids, the lower the freezing point, *i.e*. freezing point depression (Syed *et al*., 2018). Although adding inulin to maoberry sorbet increased the melting rate, the added inulin retained free water in the sorbet structure, thus resulting in smaller ice crystals, leading to a softer texture or decreased firmness of sorbet, which might increase consumer acceptability.

Total phenolic and total flavonoid contents

The effect on the total phenolic and total flavonoid contents of maoberry sorbet is shown in Figure 3. The greatest total phenolic content was observed in black maoberry sorbet with no inulin (38.15 mg GAE/100 mL), which was not significantly different from the other sorbets prepared from black maoberries. The total phenolic contents of black-red and red maoberry sorbets were significantly lower than those of black maoberry sorbet, because the phytochemicals such as anthocyanin and rutin, and polyphenols of maoberry had increased during ripening (Hardinasinta *et al*., 2021). The total phenolic content of sorbets made with black-red maoberries ranged from 18.33 to 22.57 mg GAE/100 mL, and with red maoberries from 18.02 to 29.36 mg GAE/100 mL.

A similar trend was also observed in the total flavonoid contents. The average total flavonoid contents of black maoberry sorbets were not significantly different (15.25 - 15.38 mg QE/100 mL). The total flavonoid contents of sorbet made from black maoberries was almost two to three times higher than those made from black-red maoberries (5.42 - 7.40 mg QE/100 mL). These results were expected as maoberries accumulate more anthocyanins as they mature. Sartagoda *et al*. (2021) reported that the total phenolic contents, total flavonoid contents, and total anthocyanin contents of maoberries increased as they matured.

Antioxidant analysis

FRAP, DPPH, ABTS, and ORAC assays have often been used to evaluate antioxidant capacity in

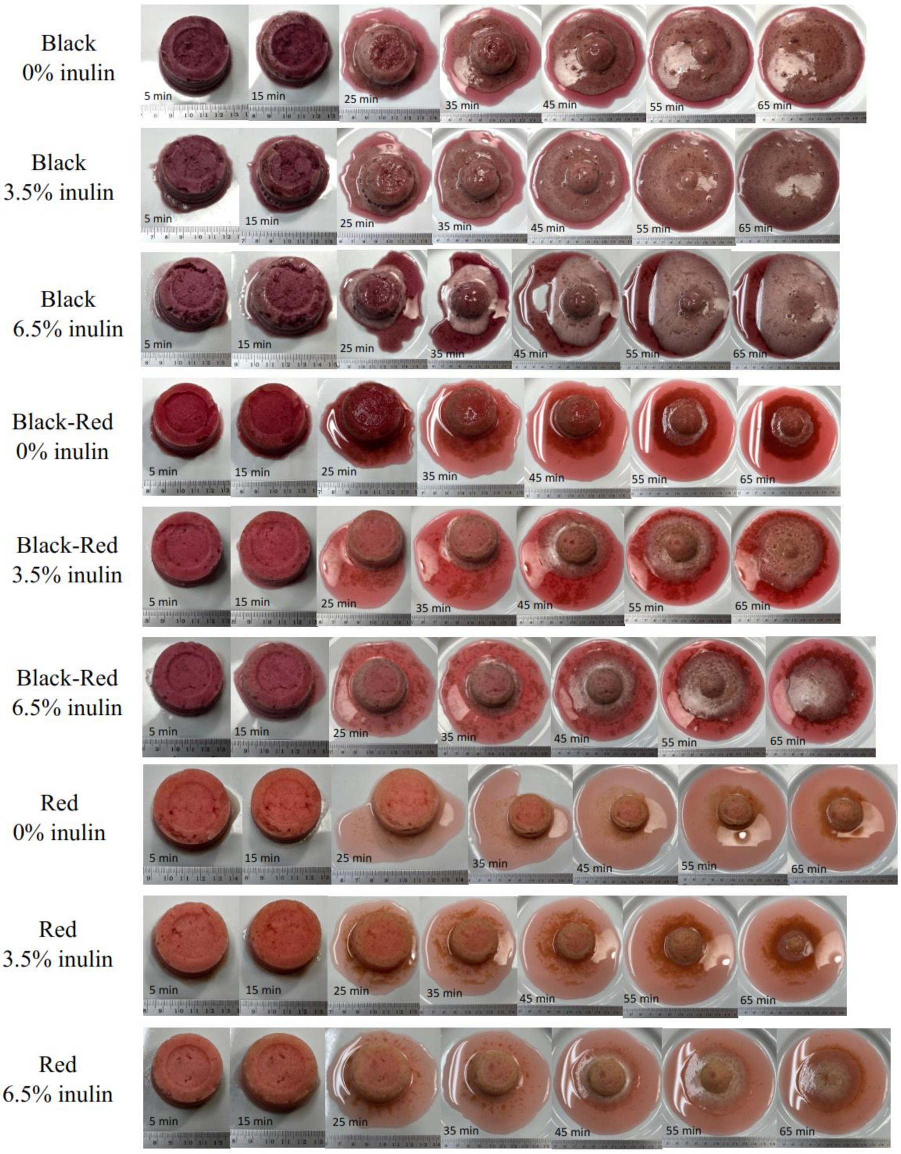

Figure 1. Melting behaviours of maoberry sorbets.

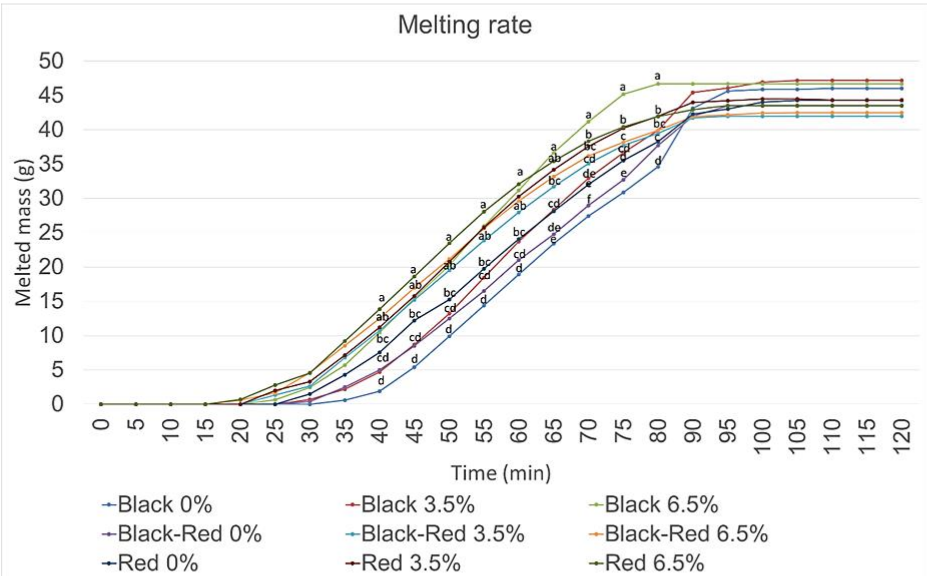

Figure 2. Melting rates of maoberry sorbets.

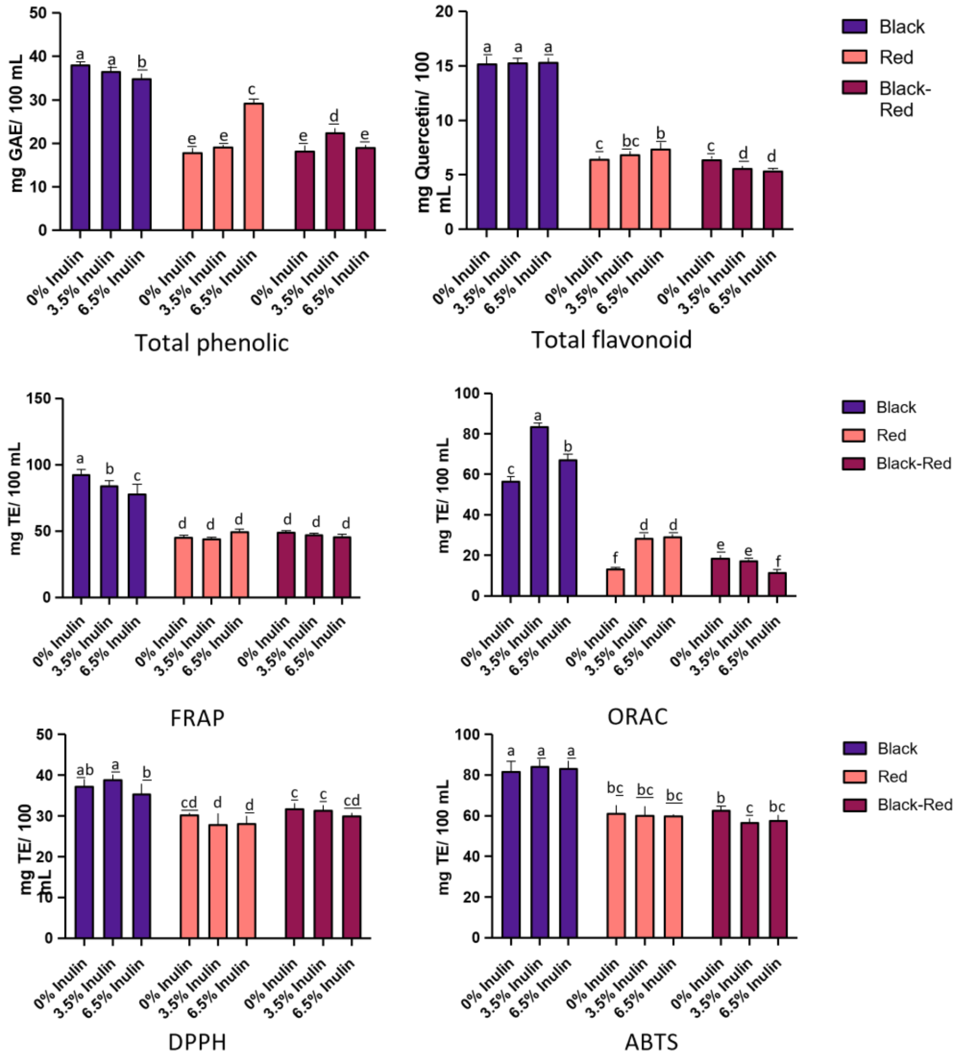

Figure 3. Total phenolic compounds, total flavonoid compounds, FRAP values, ORAC values, DPPH values, and ABTS values of maoberry sorbets.

foods. No single method is sufficient, so more than one type of antioxidant capacity measurement is required to take into account the various modes of action of antioxidants. The changes in the antioxidant activity of maoberry sorbets caused by different maturities and inulin levels were explored by measuring FRAP, DPPH, ABTS, and ORAC values, and are shown in Figure 3. Adding inulin did not affect the ABTS (67.81 - 68.89 mg TE/100 mL) and DPPH (31.29 - 33.23 mg TE/100 mL) values. The variation in antioxidant activities might have been caused by differences in the maturity of the fruit. At the early stage of maturity, maoberries are bright red, while at the later stage the colour changes to dark-purple or black. The greatest FRAP value was observed in black maoberry sorbet (85.29 mg TE/100 mL), followed by black-red (46.73 mg TE/100 mL) and red maoberry (45.40 mg TE/100 mL) sorbets. This result was confirmed by the ABTS values which were highest in black maoberry sorbet (83.43 mg TE/100 mL), but were significantly lower in black-red and red maoberry (46.73 and 45.40 mg TE/100 mL, respectively) sorbets ($p < 0.05$). The same trend shown with FRAP and ABTS also occurred for the DPPH value where those for black maoberry sorbet (37.26 mg TE/100 mL) were significantly higher than those for black-red (31.19 mg TE/100 mL) and red maoberry (28.93 mg TE/100 mL) sorbets. The ORAC values for black maoberry sorbets (56.75 - 83.67 mg TE/100 mL) were significantly higher than those for black-red (11.79 - 18.85 mg TE/100 mL) and red maoberry (13.59 - 29.45 mg TE/100 mL) sorbets ($p < 0.05$). These results were consistent with a previous study reporting that the antioxidant capacity assessed by FRAP, DPPH, and ABTS assays of papaya increased as the fruit ripened (Addai *et al*., 2013). Acosta-Montoya *et al*. (2010) reported that the ripening or increasing maturity of fruit influenced their physicochemical properties, nutritional composition, and contents of bioactive compounds. They also found that blackberry fruit became darker and less red, with increasing anthocyanin contents and ORAC values during ripening. The health benefits of maoberries have been widely studied because they contain bioactive, antioxidant, and anti-inflammatory compounds. Aksornchu *et al.* (2021) reported that maoberries also have antidiabetic and antiglycation effects which inhibit carbohydrate digestive enzyme activity, and reduce monosaccharide-induced protein glycation. Krongyut and Sutthanut (2019) reported that potential anti-obesity and anti-adipogenesis effects were significantly correlated with the antioxidant capacity.

Conclusion

The present work demonstrated that the maturity level of maoberry influenced its physicochemical properties, total phenolic and total flavonoid contents, and antioxidant activities. The total flavonoid and FRAP values of fully ripe black-purple maoberries were almost twice those of the half-ripe red maoberries. Maoberry has huge potential as a functional food since it is predominantly composed of phenolic and flavonoid compounds with antioxidant capacity. The present work also indicated that adding inulin to maoberry sorbet improved its viscosity and overrun, and decreased firmness, all of which could enhance consumer acceptability. Adding inulin at 3.5% could also provide a good source of dietary fibre, but addition at 6.5%, although also providing an excellent source of dietary fibre in the sorbet product, would impact the melting rate.

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