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ARTICLE

Oxidative Stability of Vacuum-Packed Chicken Wings Marinated with Fruit Juices during Frozen Storage

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Abstract Antioxidants present in fruits and vegetables have a potential to reduce disease risk, and increase the shelf life of food products by reducing lipid oxidation. The effect of marination with antioxidants-rich fruit juices on quality characteristics of vacuum-packed chicken wings were examined during frozen storage. Chicken wings were mixed separately with marinades containing pineapple juice, June plum juice, and mango juice and kept for 12 h and 24 h. Three best marination conditions were selected based on a sensory evaluation. Antioxidant activity and total phenolic content of fruit juices, and marinade uptake, and marinade loss of marinated chicken wings were determined. In addition, vacuum packed marinated chicken wings were tested for pH, water holding capacity (WHC), 2-thiobarbituric acid reactive substances (TBARS) value and antioxidant activity over a 4-wk frozen storage. The best sensory properties were reported from chicken wings marinated with pineapple juice for 24 h, mango juice for 24 h, and June plum juice for 12 h ($p<0.05$) compared to other marinade-time combinations. Mango juice showed the highest antioxidant activity (92.2%) and total phenolic content (38.45 μg/mL; $p<0.05$) compared to other fruit juices. The pH and WHC of vacuum-packed chicken wings were slightly decreased over the frozen storage ($p<0.05$). Moreover, chicken wings marinated with mango juice had the lowest TBARS values and the highest 2,2-diphenyl-1-picryl-hydrazyl-hydrate free radical scavenging activity. In conclusion, mango juice was selected among tested as the most effective marinade for enhancing the oxidative stability of lipid while maintaining the other meat quality traits of vacuum-packed chicken wings.

Keywords antioxidants, lipid oxidation, marinade, chicken wings, fruit juices

Introduction

Consumers are now more concerned on their daily eating habits and health benefits of foods they consume. Therefore, consumption of health promoting foods has become a trend worldwide particularly when they are economically affordable (Gök and Bor, 2016). Chicken wings are excellent sources of both macro- and micro-nutrients; chicken wings with skin contain 17.6% protein, 14.9% fat, and 0.7% ash (Koh and Yu, 2015). However, owing to its appearance and bony structure consumers are less likely to consume chicken wings making those low valued cuts.

Marination can be considered as one of the most suitable and popular methods to increase the consumption of chicken wings as it can enhance the aroma, flavor, juiciness, and tenderness of meat (Alvarado and McKee, 2007; Barbanti and Pasquini, 2005), and enhance the appearance, quality, yield, and shelf life of meat (Khan et al., 2016). In general, different marinade solutions are prepared using different levels of salt, spices, organic acids, antioxidants, tenderizers, flavor enhancers, and herbs for soaking meat (Gök and Bor, 2016). However, overall quality of marinated products is influenced by method of marination, type of marinade, and marination conditions (Alvarado and McKee, 2007; Fenton et al., 1993).

Antioxidants are substances which can prevent or delay oxidation of a substrate at low concentrations (Santos-Sánchez et al., 2019). According to Shahidi (2015), many of the plant based natural antioxidants with high demand belong to the phenolic and polyphenolic class of compounds, carotenoids, and antioxidant vitamins. Antioxidants that naturally occur in fruits and vegetables can reduce the risk of the development of chronic human diseases such as cardiovascular diseases, diabetes, and cancers and protect consumers' health (Jideani et al., 2021; Kikusato, 2021; Pokorny et al., 2001; Virgili et al., 2001; Weisburger, 1999). In addition, natural antioxidants from fruits, vegetables, herbs and spices, either in the form of extracts or as direct incorporation, have been used to increase the shelf life of meat and meat products by decreasing the lipid oxidation (Kadıoğlu et al., 2019; Karre et al., 2013; Shan et al., 2009).

A large variety of tropical fruits such as mango, pineapple, passion fruit, june plum, guava, wood apple, banana, and papaya are abundantly available in Asian countries at affordable rates (Weerahewa et al., 2013). In addition, June plum, a highly nutritious and antioxidant rich fruit variety, is considered as a commonly found, but underutilized fruit variety (Ratnayake et al., 2020). Therefore, there is an ample potential to use juices of these fruits in marinades to improve the quality characteristics of meat.

Number of researchers have investigated the effect of different marinades on the physicochemical and organoleptic attributes of different meat types such as chicken (Alvarado and McKee, 2007), pork (Cho et al., 2021; Sheard and Tali, 2004), beef (Hinkle, 2010), and horse meat (Vlahova-Vangelova et al., 2014). However, the studies conducted to optimize the type of marinades in particular fruit juices, and the holding time for marinated chicken wings are scant, especially after frozen storage with vacuum packaging to prolong the shelf-life. Therefore, the present study was mainly designed to determine the effective utilization of natural antioxidants-rich fruit juices as marinades for chicken wings without negatively affecting the physicochemical and sensory attributes of vacuum packed chicken wings under frozen storage.

Materials and Methods

Sample preparation

The fresh skin-on chicken wings (Cobb 500) were obtained from a local market in Badulla, Sri Lanka. The chicken wings were immediately transported to the laboratory in a polystyrene box containing ice, washed with tap water, drained and stored at –18℃ until further use.

Marination

Moderately ripened mangoes (*Mangifera indica*; Willard variety), pineapples (*Ananas comosus*; Mauritius variety), and June plums (*Spondias dulcis*; Tall variety) were obtained from local farmers in Sri Lanka for the preparation of marinades. On the day of the analysis, each type of fruit was manually peeled, washed with tap water, cut into pieces, chopped and strained to obtain fruit juices. Marinades were then prepared separately by mixing 60% of fruit juice, 37% of water and 3% of salt and filled into food grade plastic bottles. Chicken wings were tumbled separately in the marinades at 1:1 ratio for 30 min, subdivided into marination holding times (12 and 24 h) and finally kept at 4℃. Raw chicken wings were used as the control. After each marination period, chicken wings from different marinades were vacuum-packed separately and stored under frozen storage (–18℃). Three best marinade-time combinations were selected based on the results of a sensory evaluation and wings marinated with such combinations were used for weekly determination of pH, water holding capacity (WHC), 2-thiobarbituric acid reactive substances (TBARS) and 2,2-diphenyl-1-picryl-hydrazyl-hydrate (DPPH) values (Choe et al., 2020; Lee et al., 2021). Before analyses, the frozen marinated chicken wings were thawed overnight at 4℃.

Antioxidant activity of fruit juices

Fruit juices were analyzed for antioxidant activity using DPPH free radical scavenging assay according to the method described by Choe et al. (2020) with slight modifications. Methanolic DPPH stock solution (0.1 mM) was prepared by dissolving 10 mg of DPPH powder in 125 mL of methanol. After that, 5 mL of fruit juice was mixed with 80% methanol and kept in a shaker for 30 min at room temperature. The mixture was then centrifuged (ST 40R, Thermo Fisher Scientific, Osterode, Germany) at 1,409×g for 10 min at 4℃ and 200 μL of the supernatant was mixed with 1 mL of DPPH solution. The mixture was shaken well and kept to stand in a dark place for 30 min at room temperature. The absorbance of mixtures was read at 517 nm using a spectrophotometer (UV-2005, J.P. Selecta, Barcelona, Spain). The readings were compared with the control prepared with 200 μL of 80% methanol and 1 mL of DPPH. The scavenging activity was calculated using the following equation.

$$\text{Scavenging activity (\%)} = [1 - (\text{Absorbance of sample}/\text{Absorbance of control})] \times 100$$

Total phenolic content of fruit juices

Fruit juices were analyzed for total phenolic content using Folin-Ciocalteu method as described by Singleton et al. (1999) with slight modifications. First, 5 mL of each fruit juice was mixed with 80% methanol and kept in a shaker for 30 min at room temperature. The mixture was then centrifuged (ST 40R, Thermo Fisher Scientific) at 1,409×g for 10 min at 4℃. Supernatant (1 mL) and standard solution of gallic acid (10, 20, 40, 60, 80, and 100 μg/mL) were mixed separately with 1 mL of Folin- Ciocalteu reagent. After 5 min, the mixture was added with 10 mL of 7% Na_2CO_3 and incubated for 90 min at room temperature. The absorbance was measured at 750 nm using a spectrophotometer (UV-2005, J.P. Selecta). Total phenolic content of each fruit juice was reported as μg gallic acid equivalent (GAE)/mL.

Sensory evaluation

The design of the sensory evaluation for marinated chicken wings was reviewed and approved by the Research Ethics

Review Committee of Uva Wellassa University (No. UWU/REC/2021/002). Marinated chicken wings thawed overnight at 4°C were first cooked at 150°C for 30 min in an electrical oven. Cooked wing samples were then prepared to uniform size (1.5 cm×2 cm), wrapped in aluminum foil to preserve the aroma and prevent moisture loss, and kept in a drying oven (DHG-9145A, Zenith Lab, Changzhou, China) at 60°C until sensory evaluation. Thirty untrained panelists participated in the sensory evaluation in individual booths. The sensory properties such as color, odor, flavor, taste, juiciness, tenderness and overall acceptability were evaluated using a 7-point hedonic scale. Drinking water at room temperature was provided to the panelists to cleanse their mouth prior to and between sample evaluations. Three best marinade-time combinations were selected based on the results of this sensory evaluation for further analysis.

Marinade uptake and marinade loss

Uptake of marinade by chicken wings was determined as described by Fenton et al. (1993) and Klinhom et al. (2015) with slight modifications. The weights of the chicken wings before marination, immediately after tumbling and after each marination holding time were recorded. Excess marinades were removed from the chicken wing surfaces before weighing. The uptake of marinades was calculated using the following equation.

$$\text{Uptake of marinade (\%)} = \left[\frac{\begin{pmatrix}\text{Weight of chicken wings immediately after tumbling} \\ -\text{Initial weight of chicken wings}\end{pmatrix} \times 100}{\text{Initial weight of chicken wings}}\right]$$

Marinade loss of chicken wings was calculated according to the protocol of Fenton et al. (1993) using the following equation.

$$\text{Marinade loss (\%)} = \left[\frac{\begin{pmatrix}\text{Weight of chicken wings immediately after tumbling} \\ -\text{Weight of marinated chicken wings after holding time}\end{pmatrix} \times 100}{\text{Weight of chicken wings immediately after tumbling}}\right]$$

Water holding capacity (WHC)

WHC of chicken wing was determined based on the technique of Hamm (1961), as described by Wilhelm et al. (2010). Marinated chicken wing samples (2 g) were carefully placed between two pieces of filter papers (No. 4; Whatman International, Maidstone, UK) on acrylic plates and left under a 10-kg weight for 5 min separately. After recording the final weight of each sample, WHC was calculated using the following equation.

$$\text{WHC (\%)} = 100 - \left[\frac{(\text{Initial weight of chicken wings} - \text{Final weight of chicken wings}) \times 100}{\text{Initial weight of chicken wings}}\right]$$

pH value

Chicken wing samples (1 g) from each marinade were homogenized separately with 9 mL of distilled water for 60 s by using a homogenizer (T 10 basic Ultra-Turrax, Ika Laboratory Equipment, Korea) and filtered through a filter paper (No. 4, Whatman International). The pH value of each filtrate was determined with a pH meter (pH 700, Eutech Instruments Pte, Singapore) after calibration using buffers (pH 4.01, 7.00, and 10.01) at room temperature.

2-Thiobarbituric acid reactive substances (TBARS) value

TBARS values of marinated chicken wings were analyzed using the method described by Lee et al. (2021) with some modifications. Chicken wing samples (5 g) were homogenized in 15 mL of deionized water using homogenizer (D-500, Velp Scientifica, Usmate, Italy) at 14,000 rpm for 30 s. Butylated hydroxytoluene (BHT; 50-μL) (7.2% w/v in ethanol) and thiobarbituric acid/trichloroacetic acid solution (20 mM TBA and 15% [w/v] TCA; 2 mL) were added to the homogenate (1 mL) and vortexed for 30 s. The mixture was then incubated in a water bath (YCW-010E, Gemmy Industrial, Taipei, Taiwan) at 90℃ for 30 min, and subsequently cooled for 10 min in an ice-water bath. After centrifuging the samples at 1,409×g for 15 min (5℃) using a ST 40R centrifuge (Thermo Fisher Scientific), the absorbance of was measured at 532 nm with a UV-2005 spectrophotometer (J.P. Selecta) against a blank prepared with 1 mL deionized water and 2 mL TBA/TCA solution. The malondialdehyde (MDA) concentration of each sample was determined against an external standard curve constructed using tetraethoxypropane. The results were expressed as mg MDA per kg of marinated chicken wings.

DPPH free radical scavenging activity

DPPH free radical scavenging activity of the marinated chicken wings was measured using methods described by Choe et al. (2020) with slight modifications. Chicken wing samples (1 g) were mixed with 80% methanol and homogenized Mixtures were then kept in a shaker for 30 min at room temperature and centrifuged (ST 40R, Thermo Fisher Scientific) at 1,409×g for 10 min at 4℃. The same analytic procedure was followed as described in antioxidant activity of fruit juice section.

Statistical analysis

The complete experiment was repeated three times in a completely randomized design and duplicate samples were drawn for each parameter. The data were subjected to one-way analysis of variance (ANOVA) and Tukey's comparison of the means test ($p \leq 0.05$) using Minitab 17 software. Data obtained from sensory analysis was analyzed using the Friedman test.

Results and Discussion

Antioxidant activity and total phenolic content of fruit juices

The antioxidant activity and total phenolic content of fruit juices used in marinades are shown in Fig. 1. The highest antioxidant activity in terms of DPPH free radical scavenging activity was shown by mango and pineapple juices ($p<0.05$) while the total phenolic content of mango juice was significantly higher than that of other fruit juices tested in the present study. Antioxidant activity of mango varieties has previously been proven by various researchers. According to Umamahesh et al. (2016), mango contains high amount of antioxidants compared to other fruits. Both mango peel and kernel have been shown to be rich sources of antioxidant constituents such as gallates, flavonols, carotenoids, ascorbic acids, and xanthone glucosides (Ajila et al., 2007) which are considered as natural radical terminators. Furthermore, Arogba and Omede (2012) found that mango possesses high radical scavenging activity due to the presence of high levels of flavonoids and phenolic acids. Different cultivars of pineapple have exhibited different levels of antioxidant activity owing to the presence of carotenoids, vitamin C and phenolic compounds (Ferreira et al., 2016).

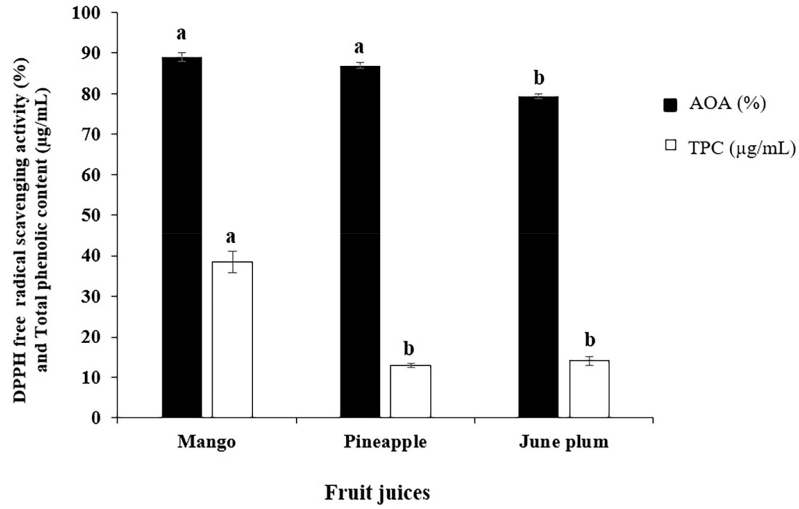

Fig. 1. Antioxidant activity (AOA) and total phenolic content (TPC) of fruit juices used in marinades. [a,b] Values with different letters differ significantly ($p<0.05$).

Sensory evaluation

Sensory analysis results of marinated chicken wings are presented in Table 1. Marination affected the flavor, taste and overall acceptability of the samples as judged by the sensory panel ($p<0.05$). Accordingly, chicken wings marinated for 24 h in pineapple juice received the highest scores for overall acceptability, taste and flavor attributes followed by those marinated for 12 h in June plum, and 24 h in mango juice compared to control samples ($p<0.05$). Considering these results, aforementioned three marinade-time combinations were selected for further analysis.

Marinade uptake and marinade loss

Uptake of marinade and marinade loss in chicken wings assessed under selected marinade-time combinations are shown in Fig. 2. Accordingly chicken wings marinated for 24 h in mango juice had the highest uptake of marinade compared to other marinade-time combinations ($p<0.05$). In addition, the highest marinade loss was reported in chicken wings marinated for 12

Table 1. Sensory attributes of chicken wings marinated with different fruit juices for different time periods

Marinade-time combination	Color	Odor	Flavor	Taste	Juiciness	Tenderness	Overall acceptability
Control	5.09	5.23	4.54^{A}	4.40^{A}	4.83	5.06	4.46^{A}
Mango/12 h	5.29	5.51	5.09^{AB}	4.77^{AB}	5.11	5.20	5.00^{AB}
Mango/24 h	5.06	5.23	5.00^{AB}	5.29^{AB}	5.14	5.43	5.43^{B}
Pineapple/12 h	5.26	5.09	5.29^{AB}	5.17^{AB}	5.26	5.31	5.29^{AB}
Pineapple/24 h	5.26	5.80	5.63^{B}	5.60^{B}	5.17	5.34	5.74^{B}
June plum/12 h	5.20	5.71	5.54^{B}	5.54^{B}	5.23	5.31	5.49^{B}
June plum/24 h	5.31	5.43	4.80^{AB}	4.71^{AB}	5.14	5.43	5.06^{AB}
SEM[1)]	0.093	0.088	0.087	0.093	0.089	0.075	0.085

Control, unmarinated chicken wings.
[1)] Pooled standard error of means.
[A,B] Values in the same column with different superscripts differ significantly ($p<0.05$).

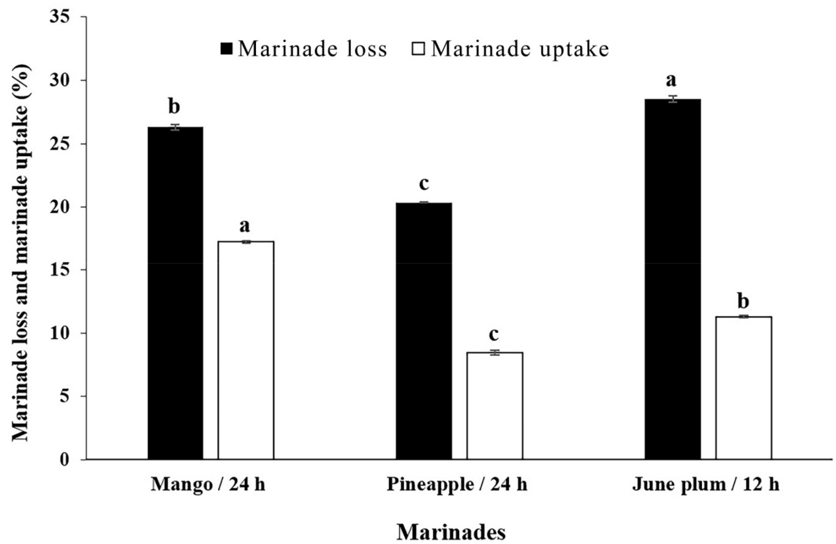

Fig. 2. Marinade loss and marinade uptake of chicken wings after marinating with different fruit juices. a–c Different letters between treatments are statistically different (p<0.05).

h in June plum juice. The observed results might be attributed to the fact that high fiber content of mango could support to increase WHC of marinated meat (Roidoung et al., 2020).

Meat quality attributes of chicken wings over the storage period

The changes in pH values of vacuum-packed marinated chicken wings over frozen storage are depicted in Table 2. Chicken wings marinated with June plum for 12 h showed the lowest pH values throughout the storage period (p<0.05) while the highest pH values were observed in control chicken wings. Decreases in pH values of all marinated chicken wings were reported over the storage period and it could be attributed to the acidity of fruit juices (Emanuel et al., 2012).

Table 3 shows the changes in WHC of vacuum-packed marinated chicken wings over frozen storage. WHC of the marinated chicken wings from all treatments was significantly decreased over the storage period. Barbut (1993) reported that

Table 2. pH values of chicken wings marinated with different fruit juices during storage period

Period	Treatments				SEM[1)]
	Control	Mango/ 24 h	Pineapple/ 24 h	June Plum/ 12 h	
Day 1	6.98^{Ec}	6.27^{Cb}	6.15^{Eb}	5.75^{Ea}	0.136
Day 7	6.52^{Dd}	6.18^{Cc}	5.83^{Db}	5.46^{Da}	0.119
Day 14	6.34^{Cd}	6.00^{Bc}	5.67^{Cb}	5.20^{Ca}	0.127
Day 21	6.13^{Bd}	5.82^{Bc}	5.40^{Bb}	5.00^{Ba}	0.129
Day 28	5.92^{Ad}	5.59^{Ac}	5.10^{Ab}	4.85^{Aa}	0.126
SEM[2)]	0.097	0.067	0.098	0.086	

Control, unmarinated chicken wings.
[1)] Pooled standard error of means (n=24).
[2)] Pooled standard error of means (n=30).
A–E Values in the same column with different superscripts differ significantly (p<0.05).
a–d Values in the same row with different superscripts differ significantly (p<0.05).

Table 3. Water holding capacity values of the vacuum-packed chicken wings marinated with different fruit juices during storage period

Period	Treatments				SEM[1)]
	Control	Mango/ 24 h	Pineapple/ 24 h	June Plum/ 12 h	
Day 1	90.83^{Eab}	89.67^{Ea}	92.33^{Eb}	92.17^{Eb}	0.367
Day 7	88.33^{Db}	86.83^{Da}	89.83^{Dc}	89.33^{Dc}	0.358
Day 14	85.00^{Cb}	83.67^{Ca}	87.00^{Cc}	84.83^{Cb}	0.375
Day 21	79.67^{Bb}	78.17^{Ba}	83.00^{Bc}	80.00^{Bb}	0.538
Day 28	73.33^{Aa}	74.33^{Aa}	79.33^{Ac}	77.50^{Ab}	0.739
SEM[2)]	1.681	1.501	1.251	1.477	

Control, unmarinated chicken wings.
[1)] Pooled standard error of means (n=24).
[2)] Pooled standard error of means (n=30).
$^{A–E}$ Values in the same column with different superscripts differ significantly ($p<0.05$).
$^{a–c}$ Values in the same row with different superscripts differ significantly ($p<0.05$).

lower muscle pH was associated with lower WHC. Hence, the decreased WHC over frozen storage can be attributed to the lower muscle pH reported during the storage which results in denaturation of myofibrilar and sarcoplasmic proteins (Olivo et al., 2001). The lowest WHC throughout the storage was observed in chicken wings marinated with mango juice for 24 h ($p<0.05$) whereas the highest WHC throughout the storage was reported in the chicken wings marinated with pineapple juice for 24 h ($p<0.05$). In previous studies, a reduction in WHC has been reported in enzymatically tenderized meat such as bromelain treated meat due to the changes occur in myofibrillar protein structure (Istrati et al., 2012). However, Manohar et al. (2016) observed a gradual increase in WHC of the meat as the bromelain concentration increased.

Lipid oxidation is considered as the primary process responsible for quality deterioration during storage mainly due to its negative impact on flavor, color, texture, and nutritional value (Kim et al., 2013). To investigate the effect of marinades containing different fruit juices on the lipid oxidation of chicken wings, TBARS values of vacuum-packed marinated chicken wings were measured over a 4-wk frozen storage (Table 4). Over the storage period, the lowest TBARS values were reported in chicken wings marinated with mango juice for 24 h followed by those marinated with pineapple juice for 24 h and June

Table 4. TBARS values of the vacuum-packed chicken wings marinated with different fruit juices during storage period

Period	Treatments				SEM[1)]
	Control	Mango/ 24 h	Pineapple/ 24 h	June Plum/ 12 h	
Day 1	0.25^{Ad}	0.11^{Aa}	0.18^{Ab}	0.21^{Ac}	0.015
Day 7	0.25^{Abd}	0.12^{Aba}	0.19^{ABb}	0.21^{Ac}	0.015
Day 14	0.26^{BCd}	0.12^{Aba}	0.19^{Bb}	0.22^{Bc}	0.015
Day 21	0.26^{CDd}	0.13^{Ba}	0.20^{Cb}	0.22^{Bc}	0.015
Day 28	0.27^{Ed}	0.14^{Ca}	0.20^{Db}	0.23^{Cc}	0.014
SEM[2)]	0.002	0.003	0.002	0.001	

Control, unmarinated chicken wings.
[1)] Pooled standard error of means (n=24).
[2)] Pooled standard error of means (n=30).
$^{A–E}$ Values in the same column with different superscripts differ significantly ($p<0.05$).
$^{a–d}$ Values in the same row with different superscripts differ significantly ($p<0.05$).
TBARS, 2-thiobarbituric acid reactive substances.

plum juice for 12 h, respectively ($p<0.05$). This finding is supported by the highest antioxidant activity and total phenolic contents detected in mango juice during this study (Fig. 1). TBARS values of the marinated chicken wings were significantly increased over the storage period irrespective of the marinade used, however within the acceptable limits. Domínguez et al. (2019) stated that lipid oxidation in meat and meat products are influenced by storage time; with increasing time the possibility of radicals to cause damage to lipids increases. In addition, the release of iron from heme-proteins gets accelerated with long storage periods and it catalyzes multiple reactions in the initiation and propagation phases of lipid oxidation.

DPPH free radical scavenging activity of marinated chicken wings over the frozen storage period is shown in Table 5. Vacuum packed chicken wings marinated with mango juice for 24 h had a significantly higher DPPH free radical scavenging activity throughout the storage period compared to those marinated with other two marinades and control. DPPH free radical scavenging activity of marinated chicken wings was significantly decreased with the storage, irrespective of the fruit juice used in marinades. Interestingly, DPPH free radical scavenging activity of all the marinated chicken wings was more than 2 folds higher than that of the control. Both mango and pineapple are considered as rich sources of dietary antioxidants such as amino acids, carotenoids, and phenolic compounds (Arampath and Dekker, 2021) while June plums are good sources of ascorbic acids, and phenolic compounds (Jayarathna et al., 2020). The findings of the present study on DPPH free radical scavenging activity of marinated chicken wings can also be confirmed by the highest antioxidant activity and total phenolic contents detected in mango juice during this study (Fig. 1).

Conclusion

Due to higher natural antioxidant activity and total phenolic content reported in mango juice, it can be effectively used in marination of chicken wings by improving the lipid oxidative stability. Although pineapple and June plum juices also showed some improvements in meat quality attributes of marinated chicken wings throughout the storage period, mango juice would be a better choice as a marinades when considering its antioxidant activity. As per the results of the current study, marinades enriched with mango juice can be successfully used to increase the yield and sensory attributes of chicken wings without compromising other meat quality attributes over frozen storage.

Table 5. DPPH values of vacuum-packed chicken wings marinated with different fruit juices during storage period

Period	Treatments				SEM[1)]
	Control	Mango/ 24 h	Pineapple/ 24 h	June Plum/12 h	
Day 1	25.50^{Ea}	68.70^{Ed}	63.13^{Ec}	56.83^{Eb}	5.045
Day 7	24.37^{Da}	67.50^{Dd}	61.07^{Dc}	55.30^{Db}	4.993
Day 14	22.17^{Ca}	65.77^{Cd}	59.43^{Cc}	53.13^{Cb}	5.050
Day 21	20.93^{Ba}	63.57^{Bd}	57.67^{Bc}	50.73^{Bb}	4.945
Day 28	18.57^{Aa}	60.73^{Ad}	55.53^{Ac}	47.27^{Ab}	4.911
SEM[2)]	0.660	0.763	0.712	0.908	

Control, unmarinated chicken wings.
[1)] Pooled standard error of means (n=24).
[2)] Pooled standard error of means (n=30).
$^{A–E}$ Values in the same column with different superscripts differ significantly ($p<0.05$).
$^{a–d}$ Values in the same row with different superscripts differ significantly ($p<0.05$).
DPPH, 2,2-diphenyl-1-picryl-hydrazyl-hydrate.

Conflicts of Interest

The authors declare no potential conflicts of interest.

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Author Contributions

Conceptualization: Rupasinghe RA, Jayasena DD, Jo C. Data curation: Rupasinghe RA, Jayasena DD, Jo C. Formal analysis: Rupasinghe RA, Jayasena DD. Methodology: Rupasinghe RA, Alakolanga AW, Jayasena DD. Validation: Alahakoon AU, Jayasena DD, Jo C. Investigation: Rupasinghe RA. Writing - original draft: Rupasinghe RA, Alahakoon AU, Jayasena DD. Writing - review & editing: Rupasinghe RA, Alahakoon AU, Alakolanga AW, Jayasena DD, Jo C.

Ethics Approval

The design of the sensory evaluation conducted in this study was reviewed and approved by the Research Ethics Review Committee of Uva Wellassa University (No. UWU/REC/2021/002).

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