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Effect of Hot Water Exposure Duration, Storage and Hot Water Temperature on Chilling Injury, Incidence and Quality of Keitt Mango (*Mangifera indica* L.)

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Authors' contributions

This work was carried in collaboration among all authors. Author SBP initiated, conducted the field experiment, collected, analyzed data and wrote the manuscript. Authors VE and ST edited the draft manuscript. All authors read the manuscript.

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ABSTRACT

Low temperature storage is the most effective method of extending postharvest life and maintain fruit quality because it delays physiological processes such as ethylene production and senescence. Unfortunately, fruit such as mangoes are sensitive to low temperature storage and may be detrimental due to chilling injury, which reduces fruit quality. Effects of storage temperature, hot water at various temperatures and durations on alleviation of mango chilling injury and quality were evaluated on Keitt mango for the growing season in Botswana. The treatments were fruits dipped in distilled water at room temperature (25±2ºC- control), dipped in hot water at 50 and 55ºC for duration of 3, 5 and 10 minutes and storage temperatures at 4, 7, 10, 13 and 25±2ºC, plus 95% RH. The results showed that as storage temperature at below 13ºC, chilling injury incidence and severity significantly ($P \leq 0.0001$) increased. Atwater temperature from 25ºC to 50 and 55ºC and duration in which mango fruit was held in hot water, increased from 3 to 5 and 10 minutes, chilling injury incidence and severity significantly ($P \leq 0.0001$) decreased.

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Keywords: Chilling injury; severity; fruit quality; storage temperature; hot water.

1. INTRODUCTION

Mango (*Mangifera indica*) belongs to the family Anacardiaceae also known as the cashew family with about 75 genera and 700 species, mostly tropical with subtropical and temperate species [1]. Mango is an excellent source of vitamin A and C and a good source of fibre [1]. The caloric value of mango is mostly derived from sugars. It is as high as that of grapes and even higher than that of apple, pear and peaches. Proteins in mango fruit are generally higher than that of other fruits, except avocado [2]. The importance given to a specific quality attribute varies in accordance with the commodity concerned and with the individual (producer, consumer and handler) or market concerned with quality assessment. Quality, i.e. the degree of excellence or superiority, is a combination of attributes, properties or characteristics that give each commodity value in terms of its intended use [3].

Starch degradation is biochemical process linked to fruit ripening and contributes to fruit TSS content [4]. TSS content indicates the level of acids and sugars in the fruit; the biochemical pathways that produce these compounds are stimulated by climacteric ethylene in climacteric fruit, but their initiation precedes this event in fruit development [5]. An understanding of the effect of heat treatment on mango fruit quality (sweetness, colour, pH, titratable acidity) is important as temperature informs the physiological processes such as ripening and senesence.

Harvested mangoes ripen and deteriorate quickly at ambient temperature [6], hence the short shelf-life of mango. Low temperature Storage at approx. 12-13ºC is considered to be the most effective method of extending postharvest life without compromising the quality of the fruit because low temperature delays respiration, ethylene production, physiological ripening, senescence, undesirable metabolic changes and decay [7,8,9]. However, most fruit including mango that originated from the tropical and subtropical regions are chilling sensitive when exposed to temperatures that are above the freezing point [10]. Keeping mango under critical minimum temperature causes the physiological disorder known as chilling injury. The sensitivity of mangoes to temperature below the critical threshold is dependent on the cultivar, water exposure duration, temperature exposure, degree of fruit maturity and environmental conditions during and after storage [11]. The symptoms of chilling injury that have been observed in mango fruit include greyish, scald-like discoloration on the epidermis, pitting, uneven ripening, poor flavour and colour (anthocyanins and carotenoids) (Hatton, et al. 1965) [12-15]. Several techniques have shown potential to alleviate the onset of chilling injury symptoms in perishable commodities in order to prolong their shelf-life and maintain quality. Chilling injury in tropical and subtropical fruits can be alleviated successfully by temperature preconditioning, intermittent warming, and heat treatment (Wang, 1993). The effect of heat treatment on fruit heat tolerance depends on species, stage of maturity, hot water temperature and water exposure duration [16]. Hot water treatment of a number of horticultural crops has been demonstrated to be effective in product shelf-life improvement [17] reduction of chilling injury, control of microbial and, insect infestations and quarantine treatment [18]. Non-chemical quarantine treatments in mango industry are increasingly becoming important because of the increasing demand for chemical residues free fresh produce and environmental friendly procedures. Recently, international interest in heat treatment technology for quality maintenance and disease control has been reported in literature [19]. It is therefore, important to alleviate chilling injury in tropical crops, hence the significance of this study.

1.1 Objective

This study evaluated the effects of storage temperature and hot water at various temperature and duration times on alleviation of mango chilling injury and fruit quality.

2. MATERIALS AND METHODS

2.1 Experimental Site

A laboratory experiment was conducted from February to May 2015 at Botswana University of Agricultural and Natural Resources, Sebele (latitude 24º34'S and longitude 25º57'E) elevated at 994 m above sea level.

2.2 Fruit Material

Mangoes (cultivar Keitt) which were used in this study, were bought at physiological maturity with flesh yellow in color, while the skin was green and hard. On arrival at the University laboratory, the fruits were selected for uniformity, color size and defect-free. Blemished fruits were discarded. The fruits were cleaned with distilled water and allowed to dry in air at ambient temperature, weighed and labeled.

2.3 Experimental Design

A 5 × 3 × 3 factorial experiment in a completely randomized design was used with three main treatments (storage temperature, hot water and hot water exposure duration). Storage temperature treatment had five levels (4, 7, 10, 13 and 25ºC), hot water treatment had three levels (25, 50 and 55ºC), whereas hot water exposure duration treatment had three levels (3, 5 and 10 minutes). Each treatment was replicated three times. One hundred and thirty-five (135) fruits were used in each storage temperature.

2.4 Treatments Description

Storage temperature treatment- Mango fruits were packed in perforated paper board cartons and were subjected to temperatures of 4, 7, 10, 13 and 25°C. Five different fridges (Samsung compressor, RSA1WTMG1/XFA) were used for these treatments.

Hot water treatment- In this treatment mango fruits were dipped in distilled water at room temperature (25ºC), second level at 50ºC and level three at 55ºC. Water was heated in a 20 L insulated and thermostatically controlled water bath to raise the temperature as per the treatment requirement.

Hot water duration treatment- Fruits subjected to hot water were immersed in hot water for 3, 5 and 10 min.

2.5 Data Collection

Dependent variables assessed were chilling injury and injury severity, total soluble solids (TSS), titratable acidity (TA), pH, skin and pulp or flesh color.

2.5.1 Chilling injury incidence

Chilling injury was visually evaluated on the number of fruits that developed chilling injury symptoms out of the total fruit used per treatment, irrespective of the degree of injury expressed as a percentage. Chilling injury incidence was calculated using the following equation;

Chilling injury incidence = (number of fruit with injury/Total number of fruit assessed) × 100 (1)

2.5.2 Chilling injury severity index

The severity of chilling injury was evaluated on a predetermined scale from 0 to 4, where 0 = no injury, 1 ≤ 25% surface browning, 2 ≤ 50% surfaces browning, 3 ≤ 75% surfaces browning and 4 ≥ 76% surface browning [6] Chilling injury severity index was calculated using the following equation;

Chilling injury severity index = ∑(chilling score × number of fruit at this level)/Total number of fruit assessed (2)

2.5.3 Total soluble solids

TSS were determined using a hand refractometer (Atago Model N1, American Optical, Buffalo, New York).

2.5.4 Juice pH

The pH value of juice was measured through a digital pH meter (Consort C831, Belgium) by immersing the pH probe into the extracted fruit juice [20].

2.5.5 Titratable acidity

Titratable acidity was determined by titration of 5 mL juice with 0.1 M NaOH until 8.1 [20]. The results were expressed as total TA equivalents.

g total titratable acidity/100 mL juice = (mL base × 1 ×100 × 2 × normality of base)/mL sample (3)

2.5.6 Skin and pulp/flesh color

Skin and flesh color were measured using a Minolta Chroma meter (Minolta CR 200, Japan). The measurements were reported in terms of CIE (Commission International de l' Eclaireage) L*a*b* color space.

2.6 Data Analysis

The data collected was subjected to analysis of variance (ANOVA) using the Statistical Analysis System (SAS). Treatment means were separated using the Least Significant Difference (LSD) at $p \le 0.05$.

3. RESULTS AND DISCUSSION

3.1 Chilling Injury Incidence and Severity

The findings of this study showed that the three treatments (storage temperature, hot water and hot water exposure duration) significantly ($p<0.01$) affected the mango chilling incidence development (Table 1) and severity (Table 2). Generally, as storage temperature decreased below 13ºC, the mango chilling injury incidence and severity significantly ($p<0.01$) increased. The following chilling injury symptoms were observed on mango fruits stored at 4, 7 and 10ºC, i.e. shriveling, dark scald discoloration, browning, uneven ripening, pitting or sunken lesions and poor color development. However, the incidence and severity varied with the storage temperatures. Similar results have been reported by Tasneem [21], Emongor [15] and Emongor & Tautsagae [22]. Tansneem [21] reported that mango fruit stored at temperatures below 10ºC (1 or 4ºC), significantly ($p<0.05$) developed surface pitting, scalding, poor aroma, uneven ripening, skin discoloration and poor color development. Fruits stored at 1°C and 4ºC had the highest incidence and severity of chilling injury.

Among different heat treatments, the use of hot water as a disinfestation has been widely adopted because of its efficacy and low cost [23]. In this study as the water temperature increased from 25ºC to 50 to 55ºC and duration in which mango fruit was held in hot water from 3 to 5 to 10 minutes, chilling injury incidence (Table 1) and severity (Table 2) significantly ($p<0.01$) decreased. Zhang, et al. [24] reported that treating mango fruit with hot water at 55ºC for 10 minutes and stored at 5ºC for three weeks, reduced chilling injury development. Similarly, Yimyong, et al. [25] found slight chilling injury symptoms manifested by visible shriveling but was reduced by pre-storage hot water treatment at 50ºC for 10 minutes during ripening at ambient temperature after the transfer from cold storage at 8 or 12ºC in 'Okrong' mangoes. The minor chilling injury symptoms in the study of Yimyong, et al. [25] might be the result of storage temperatures of 8 or 12ºC. Furthermore, Gonzalez, et al. [26] reported that peppers treated with hot water at 53ºC for 4 minutes, had a reduced incidence of chilling injury after 14 and 28 days of storage at 8ºC. After cold storage and ripening, heated fruit had a lower incidence of disease and developed less chilling injury than non-heated fruits [14]. Karuppiah, et al. (2004) reported that grapefruits dipped at 53, 56 and 59ºC water, reduced chilling injury by 3, 6 or 10%, respectively.

Table 1. Effect of hot water exposure duration, storage and hot water temperature on mango chilling injury incidence

Treatments	Chilling injury incidence %					
Storage temperature °C	**Week 1**	**Week 2**	**Week 3**	**Week 4**	**Week 5**	**Week 6**
4	15.86^{a}	46.85^{a}	71.78^{a}	87.76^{a}	95.11^{a}	100^{a}
7	11.0^{b}	39.44^{a}	61.89^{b}	78^{b}	93.89^{a}	100^{a}
10	0.0^{c}	0.0^{b}	18.33^{c}	51.89^{c}	71.89^{b}	93.89^{b}
13	0.0^{c}	0.0^{b}	0.0^{d}	0.0^{d}	0.0^{c}	0.0^{c}
25	0.0^{c}	0.0^{b}	0.0^{d}	0.0^{d}	0.0^{c}	0.0^{c}
Significance	**	**	**	**	**	**
Hot water °C						
25	11.73^{a}	23.8^{a}	38.53^{a}	49.73^{a}	55.6^{a}	60^{a}
50	2.93^{b}	16.98^{b}	29.67^{b}	44.53^{b}	53.4^{b}	59.27^{b}
55	1.47^{c}	11^{c}	23^{c}	36.33^{c}	47.53^{c}	57.09^{c}
Significance	**	**	**	**	**	**
Hot water exposure duration						
3 minutes	7.33^{a}	19.24^{a}	32.67^{a}	46.0^{a}	53.40^{a}	59.27^{a}
5 minutes	5.13^{b}	18.53^{a}	31.20^{b}	44.53^{a}	53.40^{a}	59.27^{a}
10 minutes	3.67^{c}	14.00^{b}	27.33^{c}	40.07^{b}	49.73^{b}	57.80^{b}
Significance	**	**	**	**	**	**

*** Significant at $p<0.01$. Means separated using Least Significant Difference (LSD) Test at $p\leq0.05$, means within columns followed by the same letters are not significantly different. Week 1-6 are dates from 2nd February 2015 to 9th March 2015, respectively*

Table 2. Effects of hot water exposure duration, storage and hot water temperature on mango chilling injury severity

Treatments	Chilling injury severity								
	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9
Storage temp. °C									
4	0.38^{a}	1.23^{a}	2.07^{a}	2.72^{a}	3.23^{a}	3.71^{a}	3.83^{a}	4^{a}	4^{a}
7	0.21^{b}	0.56^{b}	1.14^{b}	1.5^{b}	2.07^{b}	3.2^{b}	3.52^{b}	3.98^{a}	4^{a}
10	0^{c}	0^{c}	0.24^{c}	1.22^{c}	1.91^{c}	2.5^{c}	3.06^{c}	3.58^{b}	3.8^{b}
13	0^{c}	0^{c}	0^{d}	0^{d}	0^{d}	0^{d}	0^{d}	0^{c}	0^{cc}
25	0^{c}	0^{c}	0^{d}	0^{d}	0^{d}	0^{d}	0	0^{c}	0^{c}
Significance	**	**	**	**	**	**	**	**	**
Hot water °C									
25	0.31^{a}	0.59^{a}	0.97^{a}	1.39^{a}	1.68^{a}	2.03^{a}	2.23^{a}	2.4^{a}	2.4^{a}
50	0.29^{b}	0.29^{b}	0.65^{b}	1.05^{b}	1.48^{b}	1.99^{a}	2.18^{a}	2.36^{b}	2.39^{a}
55	0.01^{b}	0.19^{c}	0.45^{c}	0.82^{c}	1.17^{c}	1.63^{b}	1.84^{b}	2.17^{c}	2.3^{b}
Significance	**	**	**	**	**	**	**	**	**
Hot water exposure duration									
3 minutes	0.13^{a}	0.4^{a}	0.74^{a}	1.15^{a}	1.47^{a}	1.95^{a}	2.16^{a}	2.33^{a}	2.37^{a}
5 minutes	0.12^{ab}	0.35^{b}	0.69^{b}	1.11^{a}	1.9^{a}	1.9^{a}	2.07^{b}	2.33^{a}	2.37^{a}
10 minutes	0.11^{bb}	0.32^{c}	0.64^{c}	1.01^{b}	1.79^{b}	1.79^{b}	2.02^{b}	2.27^{b}	2.35^{b}
Significance	**	**	**	**	**	**	**	**	**

*** Significant at p<0.01. Means separated using Least Significant Difference (LSD) Test at p≤0.05, means within columns followed by the same letters are not significantly different. Where week 1-9 are dates from 2nd February 2015 to 30th March 2015*

3.2 Fruit Quality Attributes

There were significant (p<0.01) effects of the storage temperature and water temperature on mango TSS (Table 3). As the storage temperature and water temperature increased, the TSS increased significantly. Fruit dipped in water at 25ºC and stored at 4ºC had the lowest TSS, while those dipped at 55ºC and stored at 13ºC had significantly (p<0.01) highest TSSs. Fruits dipped in water at 25ºC for a duration of three minutes had the lowest TSS content. Same scenario was revealed for juice pH, pulp/flesh? color and skin color, whereas the opposite was revealed for TA as affected by the three main treatments (Table 3). Emongor [15] reported that as storage temperature increased from 5 to 12ºC, mango fruit TSS contentof four varieties (Tommy Atkins, Haden, Kent and Keitt), significantly (p<0. 05) increased. Yousef, et al. [27] reported that the TSS content of mango fruit significantly (p<0.05) increased from 7.3 to 15.6% as storage temperature increased from 8 to 13ºC.

Increased temperature during storage or hot water, enhanced starch and polysaccharides hydrolysis into sugars and decreased TA in mango, hence improved fruit quality [28,29,22]. In agreement with the present study, Kumah, et al. [30] reported a general trend in increasing pH of Keitt mango fruits. Fruit treated with hot water at 50ºC for 10 minutes and 48ºC for 10 minutes increased in pH. Thompson [31] also reported that the pH of fruit flesh increased with the onset of maturation until ripening. In support of the present findings, Tridjaja and Mahendrat [32] concluded that Huramanis mangoes were best consumed when pH is higher than 3.7.

Titratable acidity decreased with increase in storage and water temperatures. This was attributed to fruit ripening. In support of the present study, Jacobi, et al. [16] further reported that conditioning Kensington mangoes at 40ºC prior to hot water treatment of 45ºC for 30 minutes or 47ºC for 15 minutes, accelerated fruit ripening, lowered TA than untreated fruits. Srinivasa, et al. (2001) reported that TA of Alphonso mango packed in carton or control sample, showed a decreasing trend from 2.17 to 0.08% on the 12th day when stored at ambient temperature (27±1ºC).

Temperature plays an important role in color development of ripening fruit [33,34]. An increase in storage temperatures between 14 and 30ºC hastens the rate of ripening and the fruit softens at a faster rate [35]. Temperatures below 14ºC can cause uneven ripening and poor fruit color development due to chilling injury [36,15]. In support of the present study, [37]

Table 3. Effect of hot water exposure duration, storage and hot water temperature on mango quality

Storage temperature °C	Quality attributes				
	TSS (%)	**pH**	**TA (g/100 mL)**	**Pulp/flesh? color (Chroma)**	**Skin color (Chroma)**
4	11.23^c	3.52^e	10.72^a	38.07^d	19.65^e
7	11.46^c	3.71^d	9.19^b	48.31^c	23.93^d
10	12.15^a	3.90^c	6.97^c	51.06^b	30.66^c
13	12.89^a	4.33^b	5.09^d	56.82^a	35.57^b
25	13.00^a	4.43^a	2.90^e	57.41^a	43.29^a
Significance	**	**	**	**	**
Hot water °C					
25	10.77^c	3.72^c	8.39^a	47.49^b	26.84^c
50	12.57^b	4.01^b	7.05^b	51.07^a	30.38^b
55	13.09^a	4.20^a	5.48^c	52.45^a	34.63^a
Significance	**	**	**	**	**
Hot water exposure duration					
3 minutes	11.76^b	3.86^c	7.49^a	49.94^a	29.75^c
5 minutes	12.11^b	3.94^b	7.08^a	50.77^a	30.51^b
10 minutes	12.56^a	4.13^a	6.34^b	52.21^a	31.59^a
Significance	**	**	**	ns	**

*** Significant at p<0.01. Means separated using Least Significant Difference (LSD) Test at p≤0.05, means within columns followed by the same letters are not significantly different. TSS is total soluble solids and TA is titratable acidity*

Nyanjage, et al. [38] reported that mango fruit dipped in hot water at 36.5ºC for 60 minutes, 46.5ºC for 43 minutes and 46.5ºC for 90 minutes and stored at 12±1ºC, fruit reflectance decreased but chroma and hue angle increased over storage time and increase in storage temperature.

4. CONCLUSION

Based on the findings it is concluded that storage temperature treatment between 7-10ºC, hot water treatment between 50-55ºC and exposure to hot water for 10 minutes were effective in lowering chilling injury, severity and maintaining the quality of Keitt mangoes. Therefore, it is recommended that in order to reduce Keitt mango chilling injury incidence and severity and maintain fruit quality, the fruit should be treated with hot water at 55ºC for 10 minutes and stored at 7ºC.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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