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Reducing Chilling Injury and Maintaining Quality During Cold Storage of Sweet Potato Roots by Hot Water, Salicylic Acid and Potassium Silicate Treatments

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Abstract: Sweet potatoes (*Ipomoea batatas* L. Lam) Beauregard cultivar which obtained from a Private Farm in Motobas District, Kafr El-Sheikh Governorate Egypt, during two successive seasons of 2018 and 2019 , Sweet potato roots were harvested at a fully mature stage and then transported to the Laboratory of Handling of Vegetable Crops Department, Horticulture Research Institute, Giza Governorate, Egypt and conducted cured operation at 30°C and 85-90% relative humidity for 7 days to skin maturity. The average weight of the roots was about 250-300 g to study the effect of dipping in hot water at 45°C for 10 min, hot water at 45°C for 20 min, hot water at 48°C for 5 min, hot water at 48°C for 10 min, salicylic acid at 200 ppm for 10 min and potassium silicate at 150 ppm beside untreated control on reducing chilling injury (CI) and maintaining the quality of sweet potato roots during cold storage for 40 days at 5°C plus two days at 15°C (shelf life). The obtained results revealed that sweet potato roots dipped in hot water at 45°C for 20 min and salicylic acid treatments did not any development any symptoms of CI during all storage periods at 5°C plus 2 days at 15°C. The roots dipped in potassium silicate, hot water at 45°C for 10 min, hot water at 48°C for 5 min and hot water at 48°C for 10 min treatments reduced the rate of CI development. Sweet potato roots dipped in hot water at 45°C for 20 min or salicylic acid treatments were the most effective treatments in reducing weight loss %, maintaining the total sugars content , total phenols content, give typical flavor and gave good appearance without decay and chilling injury symptoms till 40 days at 5°C plus two days at15°C.

Key words: Sweet Potato · Chilling Injury · Hot Water · Potassium Silicate · Salicylic Acid · Low Temperature · Quality · Cold Storage

INTRODUCTION

Sweet potatoes (*Ipomoea batatas* (L.) Lam) is an important crop in the world because sweet potatoes due to its contain a substantial amount of nutrients, they are a good food source in developing countries [1]. It's classified as the sixth most important food crop after rice, wheat, potatoes, maize and cassava [2]. Moreover, It's considered one of the major *Convolvulaceae* vegetable crops grown in Egypt for local consumption and export. The cultivated area of sweet potato in Egypt was 27705 fed. yielded 387481 ton with average14 tan/fed. in 2018 FAO[3].

Cold storage is one of the most effective postharvest technologies to control the quality of fruit and vegetables from the harvest until final preparation for human consumption in food chain to slow respiration and other metabolic processes in order to preserve postharvest life of horticultural products [4, 5].

Sweet potatoes belong to tropical origin its tuberous root is susceptible to chilling injury (CI) after a few days at 10°C or shorter periods at lower temperatures [6]. Cold storage can induce fast sweetening in sweet potato roots if exposure sweet potato to cold (5°C) for 20 days but this treatment also caused CI [7]. CI of sweet potato roots often occurs during on farm storage, long distance transport or in markets and is due to a lack of temperature controlled storage. CI symptoms such as surface pitting and dark watery patches and internal tissue browning. The development of these chilling disorders reduces consumer acceptance of the roots, thus limiting storage life and increasing loss [8]. Several methods have been

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applied to reduce chilling injury in order to extend fruits shelf life and impressive response has been reported among these techniques applied to many horticulture crops, including sweet potatoes, hot water, salicylic acid and potassium silicate.

Heat treatments (HT) have been used as nonchemical methods to modify the post-harvest quality and reduce pathogen levels and disease development of a wide variety of horticultural product [9-11]. Moreover, HT has garnered much more research attention for its potential in alleviating postharvest physiological disorders, reducing chilling injury (CI) and maintaining fruit quality [12]. HT was also effective in activating antioxidant enzymes including SOD, CAT and Ascorbate peroxidase POD [13, 14].

Salicylic acid (SA) as natural and safe phenolic molecule at non- toxic concentrations may be commercially used in alleviation chilling injury in fruit and vegetables [15]. SA has high commercial potential for use at low concentration in alleviating CI in fruits and vegetables. Moreover, postharvest application with SA was highly effective in reducing CI and decay during cold storage of cucumber, tomato and sweet pepper [16-18].

Silicate has been shown to induce resistance to both biotic and abiotic stress. There is ample experimental evidence suggesting that Si affects the activity of major antioxidant enzyme involved in plant stress defense systems [19, 20]. Moreover, recent postharvest studies on avocado have proved silicate to be a safe and effective antioxidant [21]. Also, Saad [16] found that dipped in potassium silicate reduced CI symptoms in cucumber fruits during storage at 5°C.

Therefore, the main objectives of the present study was to investigate the effect of dipping in hot water, potassium silicate and salicylic acid treatments as postharvest treatments to reducing CI and maintaining the quality of sweet potato roots during cold storage at 5°C and 90 % RH plus 2 days (shelf life conditions).

MATERIAL AND METHODS

The present study was conducted in the Laboratory of Vegetable Handling and Postharvest Research Department, Horticultural Research Institute, Agriculture Research Center, Giza, Egypt, to study the effect of some postharvest treatments such as hot water, salicylic acid and potassium silicate on reducing chilling injury during cold storage of sweet potato roots cv. (*Beauregard*). Tuber roots were harvested at fully mature stage on September 10th and 13 th in 2018 and 2019 seasons, respectively from Private Farm in Motobas Distract, Kafr El-Sheikh Governorate Egypt. Tuber roots of sweet potato were chosen for uniform in size and appearance, free of disease, without physical injury infection and mechanical damage. Average weight of roots was about 250-300g. Then, transferred to the Laboratory and conducted cured operation at 30°C and 85-90% relative humidity for 7 days to skin maturity , healing cuts and other injuries occurred during harvesting and handling [6]. After curing, roots were washed and surface-sterilized in 150 ppm sodium hypochlorite solution for 5 min. then, rinsed and dried, the sweet potato roots were divided into seven different treatments were applied as follow:

- Dipping in hot water at 45°C for 10 min.
- Dipping in hot water at 45°C for 20 min.
- Dipping in hot water at 48°C for 5 min.
- Dipping in hot water at 48°C for 10 min.
- Dipping in solution of salicylic acid (SA) at 200 ppm for 10 min.
- Dipping in solution of potassium silicate (PS) at 150 ppm for 10 min.
- Dipping in tap water for 10 min (Control).

The source of SA ($C_7H_6O_3$) and Potassium silicate (K_2SiO_3) were purchased from El-Gomhoria Co. Egypt. Potassium silicate contains (10% K2O+25% SiO2). All treatments were dried and placed inside carton boxes of 3 kg each box contained (10-12 Roots) represented as experimental unit (EU). Twelve EU were prepared for each treatment. Samples were randomly taken in three replicates and were arranged in complete randomized design. Measurement, were examined immediately after curing and at 10 days intervals (0, 10, 20.30 and 40days) of storage at 5°C and 90 % RH in addition to 2 days at 15°C as shelf life conditions for the following characteristics.

Physical Analysis:

- Fresh weight loss (%): It was calculated according to the equation: = [(initial weight of roots – weight of roots at sampling data) / (initial weight of roots)] x100. Weight loss was recorded after 10 days intervals during 40 days at 5°C followed by 2 days at shelf life conditions.
- General appearance (score): General appearance (GA) was determined according to the following score system of 9 = excellent, 7 = good, 5 = fair, 3= poor and 1= unsalable.

- Chilling injury score (CI): CI symptoms of sweet potato tuber roots were characterized by surface pitting, dark watery patches and internal tissue browning [6]. Chilling injury was evaluated visually roots for each treatment.: Chilling injury is severity score ranges from 1 to 5, Where 1= no pitting, 2 = 10% of the surface area pitted, 3= 11-25% of the surface area pitted, 4= 26-50% of the area pitted and 5= = 50% of the surface area pitted as describe by Wang and Qi [22].
- Decay: It was calculated for each treatment based on the over 10% of the surface shows visible rotting of each root. Roots showing extensive rotting (over 50% surfaces) were removed from the storage room [9]. Decay was determined as score 1=none, 2=slight, 3= moderate, 4= moderately severe and 5= severe.
- Flavor: it was evaluated for each treatment to determined eating quality by the tasters in freshly cooked of sweet potato, each sample was scored on a separate form according to the following score 1=none, 2=slight, 3=moderate, 4=moderate full and 5=full typical tasting as described by Laurie *et al*. [23].

Chemical Analysis:

- Total Phenols Contents: It was extracted using the methods of Kahkonen *et al.* [24].
- Total sugar content: It was determined by HPLC Hewlett Packard series 1050 instrument, as described in AOAC [25].

Statistical Analysis: The experiment was factorial with 2 factors in complete randomized design (CRD) with 3 replicates. Comparison between means was evaluated by Duncan's Multiple Range Test at 5% level of significance. The statistical analysis was performed according to Snedecor and Cochran [26].

RESULTS AND DISCUSSION

Fresh Weight Loss (%): Excessive water loss does not only affect the saleable weight, but also makes the roots look unattractive due to shrivel [27]. Weight loss is an important factor in extending the storage life of fresh sweet potato by shrinkage following evaporation of water through the skin and respiration [6]. Data presented in Table (1) revealed that weight loss (%) of sweet potato roots was increased with the prolongation of storage period in the two seasons. The loss in weight may be due to transpiration, respiration and other senescence related metabolic processes during storage [28]. Concerning the effect of postharvest treatments, data showed that there were significant differences between treatments in weight loss % during storage and shelf life. All postharvest treatments reduced weight loss % as compared with untreated (control) during storage and shelf life. Moreover, sweet potato roots dipped in (SA) solution was the most effective treatment in reducing the weight loss percentage followed by dipping in hot water at 45°C for 20 min then dipping in PS solution. On the other side, dipping in hot water at 45°C for 10 min, hot water at 48°C for 5 min and hot water at 48°C for10 min were less effective in this concern with no significant differences among these treatments during the two seasons.

These results were achieved in the two seasons and were in agreement with those reported by Siddiqui and Nidhi [29]; El-Sayed *et al.* [30] and Wenzhong and Tanaka [14] for hot water treatments. Saad [16]; Ahmad *et al.* [31] and Shafiee *et al.* [32] for salicylic acid. Mditshwa *et al.* [33] and Tesfay *et al*. [21] for Potassium silicate.

Reduce of weight loss for hot water treatment may be due to inactivate the protein and tissue of the surface flesh of sweet potato, thus retarding the evaporation of water through the skin and protecting the tissue from pathogens [34]. Salicylic acid suppressed respiration rate and fruit weight loss by stoma closing [35, 36].

As for the effect of PS on weight loss due to the modification of cell membranes after Si application [34]. Furthermore, deposition of silicon into the cell membrane has been largely associated with the prevention of moisture loss through transpiration and provision of mechanical strength and rigidity to plant cell and tissue [37, 38].

Regarding the interaction between postharvest treatments and storage period after 40 days at 5°C plus 2 days at 15°C (shelf life), results indicated that Sweet potato roots dipped in SA was the most effective treatment in reducing the weight loss (%), followed by dipping in hot water at 45°C for 20 and PS treatments with no significant between them in the two seasons. Whereas, untreated (control) recorded the highest percentage of weight loss during storage. These results were achieved in the two seasons.

Table 1: Effect of some postharvest treatments on weight loss (%) of sweet potato roots during cold storage at 5°C plus 2 days at shelf life in 2018 and 2019 seasons

Treatments (Dipping in)	Storage period (days) + 2 days shelf life 10+2	20+ 2	30+2	40+2	Mean
			2018 Season		
Hot water at 45°C for 10 min	1.38 hi	2.46 d	3.33 c	4.30 b	2.87 B
Hot water at 45°C for 20 min	0.39 kl	1.01 ij	1.66 f-h	2.26 de	1.33 D
Hot water at 48°C for 5 min	1.43 hi	2.48 d	3.47 c	4.37 b	2.94 B
Hot water at 48°C for 10 min	1.37 hi	2.51 d	3.53 c	4.39 b	2.95 B
SA solution at 200 ppm for 10 min	0.29 l	0.84 jk	1.30 h-j	1.92 f-g	1.09 E
PS solution at 150 ppm for 10 min	0.84 jk	1.44 g-i	2.07 d-f	2.54 d	1.72 C
Tap water for 10 min (Control)	3.52 c	4.34b	4.76 b	5.80 a	4.61 A
Mean	1.32 D	2.15 C	2.87 B	3.35 A	
			2019 Season		
Hot water at 45°C for 10 min	1.47 g-i	2.53 e	3.44 d	4.45 c	2.97 B
Hot water at 45°C for 20 min	0.41 kl	1.11 ij	1.68 gh	2.33 ef	1.38 D
Hot water at 48°C for 5 min	1.52 g-i	2.51 e	3.52 d	4.45 c	3.00 B
Hot water at 48°C for 10 min	1.39 h-j	2.55 e	3.62 d	4.48 c	3.01 B
SA solution at 200 ppm for 10 min	0.36 l	0.88 j-l	1.36 h-j	1.96 fg	1.14 E
PS solution at 150 ppm for 10 min	0.90 jk	1.51g-i	2.26 ef	2.69 e	1.84 C
Tap water for 10 min (Control)	3.62 d	4.49 c	5.13b	5.87 a	4.78 A
Mean	1.38 D	2.22 C	3.00 B	3.75 A	

Means in the same column having the same letter are not significantly different at 0.05 levels by Duncan's multiple rang test

Table 2: Effect of some postharvest treatments on general appearance (score) of sweet potato roots during cold storage at 5°C plus 2 days at shelf life in 2018 and 2019 seasons

Treatments (dipping in)	Storage period (days) + 2days shelf life 0	10+2	20+2	30+2	40+2	Mean
			2018 Season			
Hot water at 45°C for 10 min	9.00 a	8.33 ab	5.67 c-e	5.00 d-f	3.00 f-g	6.20 C
Hot water at 45°C for 20 min	9.00 a	9.00 a	9.00 a	8.33ab	7.00 a-d	8.47 A
Hot water at 48°C for 5 min	9.00 a	8.33 ab	6.33 b-e	5.67 c-e	2.33 gh	6.33 C
Hot water at 48°C for10 min	9.00 a	7.67 a-c	5.67 c-e	5.00 d-f	3.00 f-g	6.07 C
SA solution at 200 ppm for 10 min	9.00 a	9.00 a	8.33 ab	7.67 a-c	7.00 a-d	8.20 A
PS solution at 150 ppm for10 min	9.00 a	9.00 a	7.00 a-d	6.33 b-e	4.33 e-g	7.13 B
Tap water for 10 min (Control)	9.00 a	7.00 a-d	4.33 e-g	3.00 f-g	1.67 h	5.00D
Mean	9.00 A	8.33 B	6.62 C	5.86 D	4.05 E	
			2019 Season			
Hot water at 45°C for 10 min	9.00 a	7.67 a-c	6.33 a-e	5.67 b-f	3.00 eg	6.33 C
Hot water at 45°C for 20 min	9.00 a	9.00 a	9.00 a	8.33 ab	7.67 a-c	8.60 A
Hot water at 48°C for 5 min	9.00 a	7.67 a-c	5.67 b-f	6.33 a-e	3.00 fg	6.33 C
Hot water at 48°C for10 min	9.00 a	7.00 a-d	6.33 a-e	5.67 b-f	3.67e-g	6.33 C
SA solution at 200 ppm for 10 min	9.00 a	9.00 a	9.00 a	7.67 a-c	7.00 a-d	8.33 A
PS solution at 150 ppm for10 min	9.00 a	8.33 ab	7.67 a-c	7.00 a-d	4.33 eg	7.27 B
Tap water for 10 min (Control)	9.00 a	7.00 a-d	5.00 c-f	3.67 eg	1.67 g	5.27 D
Mean	9.00 A	7.95 B	7.00 C	6.33 C	4.33D	

Means in the same column having the same letter are not significantly different at 0.05 levels by Duncan's multiple rang test

General Appearance (Score): Data presented in Table (2) indicated that general appearance (GA) of sweet potato roots decreased with the prolongation of storage period plus shelf life. The GA dropped from excellent 9 to good or fair 7 to 5 after 30 days plus 2 days at 15°C (shelf life) of storage. Similar results were reported by El-Sayed *et al*. [30]. The quality of sweet potato roots decreased due to the respiration and transpiration contribute to loss in weight and alteration of internal and external appearance and shrinkage [39]. The decrease in quality was affected by spoilage of roots [13].

Concerning the effect of postharvest treatments, data revealed that sweet potato roots treated with all postharvest treatments had significantly the highest score of appearance as compared with untreated control. Moreover, sweet potato roots dipped in SA solution and hot water at 45°C for 20 min were the most effective treatments for maintaining GA in comparison with other treatments with no significant differences between them in the two seasons. Followed by dipping in PS treatment, while hot water at 45°C for 10 min, hot water at 48°C for 5 min and hot water at 48°C for10 min were less effective treatments in this concern with no significant differences among these treatments. On contrary, dipping in tap water (control) recorded the lowest GA during storage in this concern. These results were achieved in the two seasons and were in agreement with El-Sayed *et al*. [30] and Wenzhong and Tanaka [14] for hot water treatments. Saad, *et al.* [27]; Shafiee *et al.* [32] and Baninaiem *et al.* [40] for salicylic acid and Atress *et al.* [41] and Afifi [42] for potassium silicate.

Wenzhong *et al.* [34] found that hot water treatment supplied a lethal dose of heat to surface pathogens and black spot without damaging. Also, may be due to inactivate the protein and tissue of the surface flesh of sweet potato, thus retarding the evaporation of water through the skin and protecting the tissue from pathogens.

SA prevention of oxidative stresses, induction of crop tolerance to chilling injury, decrease in respiration rate, decrease in ripening and senescence rate, prevention of cell wall degrading enzymes and maintaining crop firmness [15].

Si application lies in suppression of respiration and ethylene production and enhances shelf life [43]. In addition, Tesfay *et al.* [21] reported that treating silicon lowered electrolyte leakage compared with control and improved quality parameters (mass loss and firmness), possibly due to Si deposition between cell wall and cell membrane, maintaining barrier against solute leakage.

In general, the interaction between postharvest treatments and storage periods was significant in the two seasons. Results indicated that sweet potato roots dipped in SA solution and hot water treatment at 45°C for 20 min showed the best appearance which gave good appearance at the end of storage period plus shelf life (40 days at 5°C + 2 days at 15°C), while dipping in PS solution rated good appearances after 30 days at 5°C + 2 days at 15° C in the second season only. On contrary, dipping in tap water (control) had the unsalable appearance at the end of storage period plus shelf life.

Chilling Injury (CI): The results in (Table 3) shown that, chilling injury increased gradually with the prolongation of storage period during the two seasons. These results are in agreement with those obtained by with Pan *et al.* [44] and Li, *et al*. [4]. Moreover, sweet potato roots in all treatments appeared without any symptoms of surface pitting after 10 days at 5°C plus 2 days at 15°C (shelf life). With trace CI symptoms initially occurred after 20 days at 5°C + 2 days at 15°C of cold storage, results indicated that slight of CI were found on the skin of sweet potato roots in un treatment control after 20 days at 5°C plus 2 days at 15°C and the symptoms of CI become more apparent in these roots after 30 days at 5°C plus 2 days at 15°C, reached the sever stage by 40 days at 5°C plus 2 days at 15°C. The differences in the severity of CI among different treatments became more appearance and increased rapidly with the prolongation of storage time. However, sweet potato roots dipped in SA solution and hot water at 45°C for 20 min did not develop any symptoms of CI during all storage period plus shelf life with no significant differences between them. The onset of CI symptoms in sweet potato roots was delayed by dipping in PS, hot water at 45°C for 10 min, hot water at 48°C for5 min and hot water at 48°C for10 min, However these treatments reduced the rate of CI development. These results were true in the two seasons and in agreement with Pan *et al.* [44] they found that heat treatments preserved physiological quality and alleviated CI of sweet potato roots stored at 5°C, maintained membrane integrity by inhibiting the increase of cell membrane permeability and reducing CI and membrane damage, maintaining, well-organized microstructure and enhancing antioxidant activity. Also, Klein and Lurie [45] found that heat treatment induce the production of heat chock proteins, which confer enhanced tolerance to chilling temperature.

SA applied exogenously it induced expression of reactive oxygen species avoidance genes and reactive oxygen species scavenging genes that increased the alternative oxidase capacity of the cells [15]. Moreover, induce synthesis and accumulation of heat shock proteins which confers protection against chilling injury [46].

Mditshwa *et al.* [33] showed that effective of silicon treatment on reduction chilling symptoms was due to higher total antioxidants and total phenolic content and flavonoid long-term storage therefore, maintain cell membrane integrity maintain cell membrane integrity. Hence, increased saturation of membrane lipids result in greater membrane rigidity whereas decreased membrane fluidity results in decreased permeability and subsequently low electrolyte leakage. In another study,

Table 3: Effect of some postharvest treatments on chilling injury (score) of sweet potato roots during cold storage at 5°C plus 2 days at shelf life in 2018 and 2019 seasons

Treatments (Dipping in)	Storage period (days) + 2days shelf life					
	0	10+2	20+2	30+2	40+2	Mean
			2018 Season			
Hot water at 45°C for 10 min	1.00 f	1.00 f	1.33 ef	2.00 c-f	2.33 c-e	1.53 B
Hot water at 45°C for 20 min	1.00 f	1.00 f	1.00 f	1.00 f	1.00 f	1.00 C
Hot water at 48°C for 5 min	1.00 f	1.00 f	1.33 ef	2.00 c-f	2.33 c-e	1.53 B
Hot water at 48°C for 10 min	1.00 f	1.00 f	1.00 f	1.67 d-f	3.00 b-c	1.53 B
SA solution at 200 ppm for 10 min	1.00 f	1.00 f	1.00 f	1.00 f	1.00 f	1.00 C
PS solution at 150 ppm for 10 min	1.00 f	1.00 f	1.00 f	1.00 f	1.67 d-f	1.13C
Tap water for 10 min (Control)	1.00 f	1.00 f	2.67 b-d	3.67 ab	4.33 a	2.53 A
Mean	1.00 D	1.00 D	1.33 C	1.76 B	2.23 A	
			2019 Season			
Hot water at 45°C for 10min	1.00 f	1.00 f	1.00 f	2.00 c-e	2.00 c-e	1.40 B
Hot water at 45°C for 20min	1.00 f	1.00 f	1.00 f	1.00 f	1.00 f	1.00 C
Hot water at 48°C for 5 min	1.00 f	1.00 f	1.00 f	1.67 d-f	2.33 b-d	1.40 B
Hot water at 48°C for 10 min	1.00 f	1.00 f	1.00 f	2.00 c-e	2.67 bc	1.53 B
SA solution at 200 ppm for 10 min	1.00 f	1.00 f	1.00 f	1.00 f	1.00 f	1.00 C
PS solution at 150 ppm for 10 min	1.00 f	1.00 f	1.00 f	1.00 f	1.33 ef	1.07 C
Tap water for 10 min (Control)	1.00 f	1.00 f	3.00 b	4.33 a	4.67 a	2.80 A
Mean	1.00 D	1.00 D	1.29 C	1.86 B	2.14 A	

Means in the same column having the same letter are not significantly different at 0.05 levels by Duncan's multiple rang test.

Table 4: Effect of some postharvest treatments on decay (score) of sweet potato roots during cold storage at 5°C plus 2 days at shelf life in 2018 and 2019 seasons

Treatments (Dipping in)	Storage period (days) + 2days shelf life					
	0	10+2	20+2	30+2	40+2	Mean
			2018 Season			
Hot water at 45°C for 10 min	1.00 c	1.00 c	1.33 c	1.67 c	2.67 b	1.53 B
Hot water at 45°C for 20 min	1.00 c	1.00 c	1.00 c	1.00 c	1.00 c	1.00 C
Hot water at 48°C for 5 min	1.00 c	1.00 c	1.33 c	1.67 c	3.00 b	1.60 B
Hot water at 48°C for 10 min	1.00 c	1.00 c	1.00 c	1.67 c	2.67 b	1.47 B
SA solution at 200 ppm for 10 min	1.00 c	1.00 c	1.00 c	1.00 c	1.00 c	1.00 C
PS solution at 150 ppm for 10 min	1.00 c	1.00 c	1.00 c	1.00 c	1.33 c	1.07 C
Tap water for 10 min (Control)	1.00 c	1.00 c	1.67 c	3.00 b	4.00 a	2.13 A
Mean	1.00 C	1.00 C	1.19 C	1.57 B	2.24 A	
			2019 Season			
Hot water at 45°C for 10min	1.00 e	1.00 e	1.00 e	2.00 cd	2.67 bc	1.53 B
Hot water at 45°C for 20min	1.00 e	1.00 e	1.00 e	1.00 e	1.00 e	1.00 C
Hot water at 48°C for 5 min	1.00 e	1.00 e	1.00 e	1.67 de	2.67 bc	1.47 B
Hot water at 48°C for 10 min	1.00 e	1.00 e	1.00 e	2.00 cd	3.00 b	1.60 B
SA solution at 200 ppm for 10 min	1.00 e	1.00 e	1.00 e	1.00 e	1.00 e	1.00 C
PS solution at 150 ppm for 10 min	1.00 e	1.00 e	1.00 e	1.00 e	1.33 de	1.07 C
Tap water for 10 min (Control)	1.00 e	1.00 e	2.00 cd	3.33 b	4.33 a	2.33 A
Mean	1.00 C	1.00 C	1.14 C	1.71 B	2.26 A	

Means in the same column having the same letter are not significantly different at 0.05 levels by Duncan's multiple rang test

Wang and Galleta [47] reported that the application of Si enhanced the ratio of unsaturated to saturated lipids, subsequently, inducing membrane stress resistance of strawberry fruit.

With regard to, the interaction between postharvest treatments and storage periods, data revealed that there were significant differences among the interaction treatments in the two seasons. Results indicated that sweet potato roots dipped in SA solution and hot water at 45°C for 20 min did not develop any symptoms of CI during all storage period at 5°C plus 2 days at 15°C (shelf life) with no significant among these treatments. While dipping in tap water (control) the onset of CI Symptoms after 20 days at 5°C plus 2 days at 15°C and quickly deteriorated during storage periods in the two seasons.

Decay (Score): Data in Table (4) show that, decay (score) of sweet potato roots was significantly increased with the prolongation of storage period in the two seasons. The decayed roots started to be shown after 30 days at 5°C plus 2 days at 5°C plus 2 days at 15°C shelf life conditions. The decay rate of sweet potato roots increased gradually during storage and gave the highest score at the end of storage. These results are in agreement with those obtained by El-Sayed *et al.* [30] and Wenzhong and Tanaka [10].There were significant differences among postharvest treatments on decay score during storage at 5°C plus 2 days at shelf life. All postharvest treatments were much better in reducing decay score and so longer storage period compared with untreated control. However, sweet potato roots dipped in hot water at 45°C for 20 min, SA solution and PS solution did not show any decay until the end of storage period plus shelf life in the two seasons with no significant differences among these treatments. Sweet potato roots treated with hot water at 45°C for 10 min, hot water at 48°C for5 min and hot water at 48°C for10 min reduced the incidence of decay score during storage periods with no significant differences among these treatments in the two seasons, on contrary dipping in tap water (control) gave the highest decay score. These results were true in the two seasons and are in agreement with Suhaizan *et al*. [48] and Brash *et al.* [49] for hot water treatments, Saad [16] for salicylic acid and Afifi [42] for potassium silicate.

As for the effect of hot water treatments, Wenzhong *et al.* [34] considered that hot water treatment supplied a lethal dose of heat to surface pathogens and black spot without damaging the nutritional and processing qualities of sweet potato. Dipping the fruits in hot water resulted in some decrease in decay and fungal development may be related to washing off the natural pathogenic spore population from the surface of fruit [50].

SA treatment reduces postharvest diseases in fruits since it induces disease resistance of fruits to pathogens by enhancing activities of Polyphenol oxidase (PPO), Phenylalanine Ammonia Lyase (PAL) and increasing levels of H_2O_2 or O_2. Generation rate, as well as regulating the expression of relative genes and proteins [51]. In the other study Yao and Tian [52] reported that the reduce in decayed fruits treated with SA may be due to an increase in activity of guaiacol peroxidase (POX) enzyme and decrease activities in PPO enzyme of Valencia oranges during cold storage.

Tarabih *et al.* [53] indicated that potassium silicate increase the concentration of antifungal compounds and the enzyme PAL to be able to increase the concentration of phenolic compounds present at later ripening stages in order to decrease decay incidence in apple fruit.

Regarding the interaction between postharvest treatments and storage periods plus shelf life, data show that there were significant differences among the interaction treatments in two seasons. Results indicated that sweet potato roots dipped in SA solution and hot water at 45°C for 20 min did not appear any symptoms of decay during all storage period plus shelf life. While, untreated control appeared damaged after 20 days at 5°C plus 2 days at shelf life and rapid deterioration occurred during storage periods in the two seasons.

Flavor (Score): Data in the Table (5) showed that there were significant differences in flavor (score) of sweet potato roots during storage at 5°C plus 2 days at15°C (shelf life). All treatments did not show any changes in flavor score till 10 days at 5° C plus 2 days at 15°C. Flavor score was then decreased as the storage period was prolonged in the two seasons. These results are agreement with Picha [39]. The reducing in sweetness may be a result of increased metabolic conversion of the sugars to sustain respiration and other activities within the roots [54].

Concerning the effect of postharvest treatments, data revealed that there were significant differences between postharvest treatments in flavor score of sweet potato roots during storage cold storage at 5°C plus 2 days at 15°C (shelf life). All postharvest treatments gave higher score in flavor as compared with untreated control in tow the seasons. However, sweet potato roots dipped in hot water at 45°C for 20 min, salicylic acid solution and potassium silicate solution were the most effective treatments in maintaining the flavor score in tuber roots of sweet potato with no significant differences among them during storage plus shelf life. On the other side, sweet potato dipped in hot water at 45°C for 10 min, hot water at 48°C for 5 min. and hot water at 48°C for10 min had less effects on keeping Flavor score with non-significant differences among these treatments in the two seasons.

Regarding the interaction between postharvest treatments and storage periods, data showed that sweet potato roots dipped in hot water at 45°C for 20 min, salicylic acid solution and potassium silicate solution treatments give typical flavor of sweet potato roots at the end of storage plus shelf life, with no significant differences among them in the two seasons.

Table 5: Effect of some postharvest treatments on flavor (score) of sweet potato roots during cold storage at 5°C plus 2 days at shelf life in 2018 and 2019 seasons

	Storage period (days) + 2days shelf life)					
Treatments (dipping in)	0	10+2	20+2	30+2	40+2	Mean
			2018 season			
Hot water at 45°C for 10 min	5.00 a	5.00 a	4.33 a-c	3.67 c-e	3.00 ef	4.20 B
Hot water at 45°C for 20 min	5.00 a	5.00 a	5.00 a	4.67 ab	4.33 a-c	4.80 A
Hot water at 48°C for 5 min	5.00 a	5.00 a	4.33 a-c	3.33 d-f	3.00 ef	4.13 B
Hot water at 48°C for 10 min	5.00 a	5.00 a	5.00 a	4.00 b-d	3.00 ef	4.40 B
SA solution at 200 ppm for 10 min	5.00 a	5.00 a	5.00 a	5.00 a	4.33 a-c	4.87 A
PS solution at 150 ppm for 10 min	5.00 a	5.00 a	5.00 a	4.67 ab	4.00 b-d	4.73 A
Tap water for 10 min (Control)	5.00 a	5.00 a	4.00 b-d	2.67 fg	2.00 g	3.80 C
Mean	5.00 A	5.00 A	4.67 B	4.00C	3.33 D	
			2019 season			
Hot water at 45°C for 10 min	5.00 a	5.00 a	4.00 b-d	3.67 c-e	3.00 e	4.13 B
Hot water at 45°C for 20 min	5.00 a	5.00 a	5.00 a	4.67 ab	4.00 b-d	4.73 A
Hot water at 48°C for 5 min	5.00 a	5.00 a	4.33 a-c	3.33 de	3.00 e	4.13 B
Hot water at 48°C for 10 min	5.00 a	5.00 a	5.00 a	4.00 b-d	3.00 e	4.40 B
SA solution at 200 ppm for 10 min	5.00 a	5.00 a	5.00 a	4.67 ab	4.33 a-c	4.80 A
PS solution at 150 ppm for 10 min	5.00 a	5.00 a	5.00 a	4.67 ab	4.00 b-d	4.73 A
Tap water for 10 min (Control)	5.00 a	5.00 a	3.67 c-e	3.00 e	2.00 f	3.73 C
Mean	5.00 A	5.00 A	4.57 B	4.00 C	3.33 D	

Means in the same column having the same letter are not significantly different at 0.05 levels by Duncan's multiple rang test

Table 6: Effect of some postharvest treatments on total phenols (mg/100g FW) of sweet potato roots during cold storage at 5°C plus 2 days at shelf life in 2018 and 2019 seasons

	Storage period (days) + 2days shelf life					
Treatments (Dipping in)	0	10+2	20+2	30+2	40+2	Mean
			2018 Season			
Hot water at 45°C for 10min	55.67 g	69.33 e	75.67 de	89.77 c	99.83 b	78.05 B
Hot water at 45°C for 20min	55.67 g	73.27 de	79.60 d	93.47 bc	107.90 a	81.98 A
Hot water at 48°C for 5 min	55.67 g	68.67 ef	75.80 de	89.92 c	100.07 b	78.02 B
Hot water at 48°C for 10 min	55.67 g	69.10 e	76.07 de	90.10 c	100.00 b	78.19 B
SA solution at 200 ppm for 10 min	55.67 g	72.98 de	78.70 d	93.17 bc	107.80 a	81.66 A
PS solution at 150 ppm for 10 min	55.67 g	72.70 de	78.70 d	93.00 bc	107.77 a	81.57 A
Tap water for 10 min (Control)	55.67 g	61.67 fg	70.57 e	79.53 d	91.00 c	71.69 C
Mean	55.67 E	69.67 D	76.44 C	89.85 B	102.05A	
			2019 Season			
Hot water at 45°C for 10min	57.33 m	69.67jk	76.00 gh	90.10 d	101.33 b	78.89 B
Hot water at 45°C for 20 min	57.33 m	73.60 hi	79.93 e	93.80 c	105.97a	82.13 A
Hot water at 48°C for 5 min	57.33 m	69.00 k	76.13 f-h	90.25 cd	101.57 b	78.86 B
Hot water at 48°C for 10 min	57.33 m	69.43 jk	76.40 e-h	90.43 cd	101.27b	78.97 B
SA solution at 200 ppm for 10 min	57.33 m	73.32 hi	79.63 ef	93.60 cd	105.70 a	81.92 A
PS solution at 150 ppm for 10 min	57.33 m	73.03 h-j	79.03 e-g	93.30 cd	105.57 a	81.65 A
Tap water for 10 min (Control)	57.33 m	62.00 l	71.33 i-k	80.00 e	91.53 cd	72.44 C
Mean	57.33 E	70.01 D	76.92 C	90.21 B	10185 A	

Means in the same column having the same letter are not significantly different at 0.05 levels by Duncan's multiple rang test

Total Phenolic Content: Phenolic compounds are secondary metabolites in plants that are involved in a number of metabolic pathways. These metabolites and their derivatives play an important role in cell wall integrity and defense against pathogen attack [55]. Results in Table (6) indicate that total phenolic content of sweet potato roots significantly increased with prolongation of storage period at 5°C plus 2 days at 15 °C shelf life in the two seasons. These results are agreement with those obtained by Padda and Picha [8] and Wang et *al.* [56] on sweet potato roots. Antioxidants, which can delay or inhibit the oxidation of lipids or other molecules by inhibiting the initiation or propagation of oxidizing chain reactions, have been found to play an important role in the plant's resistance to chilling stress [57].

Concerning the effect of postharvest treatments data revealed that sweet potato roots dipped in hot water at 45°C for 20 min, SA solution and PS solution were the most effective treatments in increasing total phenolic compounds in sweet potato roots during cold storage with non-significant differences among these treatments. On the other side, those treatments with hot water at 45°C for 10 min, hot water at 48°C for5 min. and hot water at 48°C for10 min had less effects on keeping phenolic component with non-significant differences among these treatments in the two seasons. These results are agreement with Kim, *et al*. [58] for hot water treatment, Ahmad *et al.* [31] for salicylic acid and Mditshwa *et al.* [33] for potassium silicate.

Bassala and El-Hamahmy [59] found that hot water dip treatment enhanced the level of free phenols in Valencia oranges during storage which was associated with reduced chilling injury symptoms. Also, dipping in hot water at 41°C for 20 min was more effective than at 50°C for 5 min in this respect. The highest free phenols content in HWD treated fruit was associated with the lowest CI symptoms this may help explain why and how HWD treatments reduced CI incidence. Padda and Picha [8] indicated that the increase in total phenolic concentration was attributed to a parallel increase in phenylalanine ammonia-lyase activity (PAL), an important enzyme in the phenylpropanoid pathway involved in phenolic synthesis.

(SA) stimulates the activity of phenylalanine ammonia lyase (PAL), an important enzyme in the biosynthesis of phenols in fruit and vegetables, during the storage period. Therefore, SA could prevent postharvest oxidative stress and alleviate the injury caused by low temperature through the alteration of antioxidant enzymes and phenylpropanoid enzymes [15].

Michalak [60] reported that the application of silicon to citrus fruit, particularly postharvest, is expected to increase the phenolic content resulting in cold stress resistance and subsequently low chilling injury. As well as improvement in postharvest quality due to increased total antioxidant capacity.

The interaction between postharvest treatments and storage periods plus shelf life after 40 days of storage at 5°C plus 2 days at 15°C, data revealed that sweet potato roots dipped in hot water at 45°C for 20 min, SA solution and PS solution were the most effective treatments in increasing total phenolic compounds during cold storage with non-significant differences among these treatments, followed by dipping in hot water at 45°C for 10 min, hot water at 48°C for5 min and hot water at 48°C for10 min as compared with untreated control in the two seasons.

Total Sugar Content: Regarding to storage periods, results presented in Table (7) show that total sugars were increased after 10 days of storage at 5°C plus 2 days at 15°C shelf life, then decreased with prolongation of storage period in the two seasons. These results are in agreement El- Sayed *el al*. [30].

Concerning the effect of some postharvest treatments, data also indicated that all treated roots had significantly high value of total sugar content as compared with untreated roots (control) during storage at 5°C plus 2 days at 15°C shelf life. Sweet potato roots dipped in hot water at 45°C for 20 min, SA solution and PS solution was retained more total sugars contents with no significant differences among these treatments in the two seasons in the two seasons, followed by dipping in hot water at 45°C for 10 min, hot water at 48°C for5 min and hot water at 48°C for10 min. with no significant differences among these treatments in the two seasons. The lowest value of total sugars content was obtained from untreated roots (control). These results were achieved in both seasons and were in agreement with Wenzhong and Tanaka [10] and Wenzhong *et al.* [34] for hot water treatments, Kumar and Kaur [61] for salicylic acid and Tarabih *et al.* [53] for potassium silicate.

Zhang *et al*. [62] reported that the better internal quality of sweet potato was obtained from the combination of heat treatment and storage, due to á-amylase in sweet potato roots play a key role in starch degradation during storage. Moreover, the increment in total sugar content might due to the moisture loss through transpiration and the conversion of starch to sugars [39].

Wills *et al.* [63] indicated that SA increase in sugars content may be due to the hydrolysis of starch into sugars, whereas decline in sugars may be attributed to the fact that after the completion of hydrolysis of starch, no further increase in sugar content occur and subsequently a decline in sugars is predictable as they along with other organic acids are primary substrates for respiration.

Purvis and Shewfelt [64] indicated that potassium silicate increase sugar accumulation in the cell osmotic potential as well as the cell water potential, ultimately resulting in a reduction occurrence of chilling injury, this results were matching with decreased of chilling injury with increasing of total soluble sugars percentage and TSS/acid ratio.

Table 7: Effect of some postharvest treatments on total sugar content (g/100g FW) of sweet potato roots during cold storage at 5°C plus 2 days at shelf life in 2018 and 2019 seasons

Treatments (Dipping in)	Storage period (days) + 2days shelf life 0	10+2	20+2	30+2	40+2	Mean
	2018 Season					
Hot water at 45°C for 10 min	6.73 ab	6.79a	6.87 a	6.60 a-c	5.37 e	6.47 B
Hot water at 45°C for 20 min	6.73 ab	6.73 ab	6.80 a	6.77 a	6.47 bc	6.70 A
Hot water at 48°C for 5 min	6.73 ab	6.83 a	6.83 a	6.63 ab	5.40 e	6.48 B
Hot water at 48°C for 10 min	6.73 ab	6.81 a	6.86 a	6.64 ab	5.41 e	6.49 B
SA solution at 200 ppm for 10 min	6.73 ab	6.76 ab	6.82 a	6.74 a-c	6.42 c	6.69 A
PS solution at 150 ppm for 10 min	6.73 ab	6.80 a	6.86 a	6.73 ab	6.37 c	6.70 A
Tap water for 10 min (Control)	6.73 ab	6.85 a	5.97 d	5.20 e	4.20 f	5.79 C
Mean	6.73 AB	6.80 A	6.71 B	6.59 C	5.66D	
			2019 Season			
Hot water at 45°C for 10 min	7.33 a	6.83 bc	6.90 b	6.66 b-e	5.37 h	6.62 B
Hot water at 45°C for 20 min	7.33 a	6.77 bc	6.83 bc	6.81 bc	6.50 c-f	6.85 A
Hot water at 48°C for 5 min	7.33 a	6.83 bc	6.86 bc	6.69 b-e	5.48 gh	6.64 B
Hot water at 48°C for 10 min	7.33 a	6.84bc	6.89 b	6.72 b-d	5.48 gh	6.65 B
SA solution at 200 ppm for 10 min	7.33 a	6.79 bc	6.86 bc	6.80 bc	6.38 d-f	6.83 A
PS solution at 150 ppm for 10 min	7.33 a	6.80 bc	6.89 b	6.79 bc	6.31 ef	6.82 A
Tap water for 10 min (Control)	7.33 a	6.89 b	6.17 f	5.77 g	4.13 i	6.06 C
Mean	7.33 A	6.82 B	6.77 B	6.60 C	5.67 D	

Means in the same column having the same letter are not significantly different at 0.05 levels by Duncan's multiple rang test

For the interaction between postharvest treatments and storage periods, data revealed that sweet potato roots dipped in hot water at 45°C for 20 min, SA solution and potassium silicate solution gave highest total sugars content after 40 days at 5°C plus 2 days at 15°C shelf life with no significant differences among these treatments in the two seasons. Whereas, untreated control gave the lowest total sugar content in the two seasons.

CONCLUSION

From the previous results, it could be conclude that sweet potato roots dipped in hot water at 45°C for 20 min or salicylic acid treatments were the most effective treatments in reducing weight loss % maintaining the total sugars and phenols content, give typical flavor and gave good appearance without decay and chilling injury symptoms till 40 days at 5°C plus two days at15°C.

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