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Evaluation of the Efficiency of Locally Fabricated Evaporative Cooling Structures on Nutritional Parameters of Sweet Orange

Samson Marvellous Oladeji[1]*, Adeniyi Olufemi Adesina[1] and Oyebola Odunayo Olabinjo[2]

1 Department of Chemistry, The Federal University of Technology Akure, Nigeria
2 Department of Agricultural and Environmental Engineering, The Federal University of Technology Akure, Nigeria

***Corresponding author:**
Samson Marvellous Oladeji

marvellousoladeji@gmail.com

Department of Chemistry, The Federal University of Technology Akure, Nigeria.

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Abstract

The perishability nature of sweet oranges demands them to be stored at a lower temperature to minimize the chemical, biochemical and physiological changes. The high cost and energy involved in the use of conventional refrigerators is a daunting problem in several developing countries. An evaporative cooling structure is a prominent storage system for reducing the temperature and increasing the relative humidity in an enclosure with no or little energy input. In this research work, the efficiency of three differently padded evaporative cooling structures (Jute pad"B", Luffa Cylindrical pad"C", and local sponge pad"D") was evaluated by monitoring the change in proximate composition, Vitamin C, and total sugar using standard analytical procedures at three days intervals for eight days with refrigerator and open-air as controls. The results showed a 16.06% loss of Vitamin C in C, 25.93% in D, 28.04% in B, while 44.38% and 10.06% in open air and refrigerator, respectively.

Total sugar increased in all the cooling structures with maximum value in B (9.07%) followed by C (8.64%) and D (8.18%), but open-air and refrigerator recorded 10.54% and 6.55%, respectively. Furthermore, in proximate analysis, the moisture content was 76.258%, which decreased slightly in all the storage systems except in the refrigerator, where it slightly increased (76.260%). Also, ash content, crude protein, and fats showed no significant difference ($p<0.05$), but carbohydrate and crude fiber significantly increased and decreased, respectively. The efficiencies of the cooling structures for the preservation of Vitamin C and total sugar are ranked as C>D>B and D>C>B, respectively.

Keywords: Evaporative cooling structures; Nutritional parameters; Proximate values; *Citrus sinensis*; Storage time.

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Introduction

The sweet orange tree (*Citrus sinensis*) is one of the most widely cultivated fruit plants in the world [1-3]. Sweet orange belongs to the family of Rutaceae together with lemons, mandarins, grapefruits, limes and sour oranges [4, 5]. Orange trees are extensively grown in tropical and subtropical areas [6]. The orange fruit is made up of inner component called endocarp which contains vesicles with juice; and an external layer formed by albedo (mesocarp) and flavedo (epicarp or exocarp) [7]. The seeds are often embedded at the fruit's centre, in close contact with the juice sacs. Citrus fruits are extremely valuable economically, ranking first in fruit output [7]. It can be consumed raw or processed into orange juice [8]. *Citrus sinensis* is recognized to be high in Vitamin C, an active water-soluble vitamin that is needed for good health [9]. *Citrus sinensis* contains bioactive components such as carotenoids and a wide range of phenolic compounds that have anti-inflammatory and anti-cancer properties [10].

Despite their widespread production and use as a low-cost source of vitamins, only roughly 5% to 20% of oranges are traded globally due to their perishability [11]. Because of inadequate storage facilities, the high post-harvest loss rate has risen dramatically over the years [12]. The typical post-harvest loss reported in developed and developing nations is 5% to 25% and 20% to 50%, respectively [13]. The post-harvest of sweet orange in Nigeria was estimated to be in billion per tonnes [6]. However, the Nigeria's high temperature climatic condition increases the transpiration and respiration rate, resulting in unsatisfactory shelf-life, flavor, and other consequences [14]. At high relative humidity, on the other hand, the fruit will retain its nutritional quality, appearance, and flavor with minimal softening and wilting [15]. As a result, it is necessary to prevent this loss by developing a system that operates at high humidity and low temperature, hence, limit the transpiration rate and microbial development [16].

Refrigerator storage is the most sophisticated and advanced method of keeping sweet oranges [17]. In these conventional refrigerators, CFCs, sulphur dioxide, and ammonia are used as refrigerants, and these compounds are harmful and can deplete the ozone layer [18]. Many small-scale farmers in developing nations cannot afford a refrigerator due to the high cost of installation, energy usage, and maintenance [19]. Likewise, over the time, there has been a growing need for environmentally friendly alternatives around the world. As a result, there is a need for a low-cost, environmentally friendly, and effective method of lowering the temperature by humidifying the air [20, 16].

Evaporative cooling storage structure is an adiabatically operated double wall structure [21]. These walls are lined with pads-a porous water absorbing materials - that are maintained frequently moist with water, eliminating the need for refrigerants [16]. The structure is built to provide for the necessary cooling temperatures of 0°C to 21°C needed to slow down the deterioration process. The principle on which the evaporative cooling storage works is based on evaporation, such that the evaporation of water from a surface raises the humidity of the air closer to the water's surface [22].

Evaporative cooling structures are simple to build with locally available materials, easy to run, efficient, environmentally benign, and economical for most peasant farmers in developing countries such as Nigeria [23, 24]. Hence, this study is mapped out to examine the efficiency of evaporating cooling systems designed using local materials by examining how storage of sweet orange in three differently padded cooling structures affects the shelf life, proximate composition, total sugar and Vitamin C contents of the fruit, in comparison with the storage in the conventional refrigerator and ambient temperature (open-air).

Materials and Methods

Reagents

Petroleum ether, Sulphuric acid (H_2SO_4), Sodium Hydroxide (NaOH), Hydrochloric Acid (HCl), Ethanol (C_2H_5OH), Boric Acid (H_3BO_3), Copper Sulphate Catalyst, methyl red indicator, distilled water, Sodium Carbonate, reagent grade phenol, Garlic acid standard, Standard Glucose, Colin ciocalteau's reagent, Trichloro Acetic Acid (TCA) and Dinitro Phenyl Hydrazine (DNPH). All the reagents used are bought from Pascal Scientific Nigeria limited, Akure Ondo State.

Evaporative cooling systems

The three evaporative cooling systems used in this study were designed by the Department of Agricultural Engineering Federal University of Technology, Akure. The cooling systems are made with different padding materials (Luffa cylindrical pad, Local sponge, and Jute pad).

Sample collection and preparation

Citrus sinesis (sweet orange) were purchased from Sasa market Akure, Ondo State Nigeria. The fruits were washed thoroughly with distilled water and stored in each of the evaporative structures while some are stored in the refrigerator and open air as the controls. For each analysis carried out in this study samples were collected from each of the cooling structures and controls. The juices were extracted manually using hand press fruit juice squeezer (shangpeixuan). The juices (samples) were filtered to remove pulp and seed, stored in already labeled polyethylene plastic containers.

Proximate analysis

The AOAC (1990) method was adopted for the Proximate Analysis of the orange juice.

Determination of vitamin C (ascorbic acid):

Anal PD and Shuchi D [25] procedure of vitamin C determination was adopted using metaphosphoric acetic acid and Dinitrophenylhydrazine (DNPH).

Determination of total sugars

The total sugar content in the sample after 2, 5 and 8 days of storage respectively in the cooling structures and control was determined using Phenol-Suplhuric Acid Method by adopting Neeru A, et al. [26].

Results and Discussion

Proximate analysis

Fresh citrus juices are highly nutritious, invigorating and non-alcoholic beverages, which are liked throughout the world. Chuku EC and Chuku OS, et al. [18] reported the fresh juice from citrus contains high amount of moisture crude fiber and carbohydrate but low protein, ash and fats.

The ash content is the inorganic residue that remains after the removal of organic component and water [27]. It is not susceptible to environmental conditions and little physiological activity [28]. **Table 1** shows that there is no significant difference ($p<0.05$) in the ash content of the sweet orange stored in all the storage systems for the period of 8 days, this is in agreement with Ibrahim [29]. The ash content of 1.015 g/100 g reported for the fresh sweet orange in this study is in consonance with the findings of Onibon VO, et al. [30] who reported 920 mg/100 g but higher than 45 mg/100 g reported by Baturh Y and Olutola O [31] for similar study.

The moisture content in storage fruits (citrus sinesis) is an important indication of their susceptibility to microbial attack and subsequently perishability during storage [32]. Hence, an optimized storage conditions is needed to prevent the

Table 1 Proximate composition of the fresh sweet orange before and after 8 days of storage.

S/N	Ash Content	Moisture Content	Crude Fiber	Crude Fat	Crude Protein	Carbohydrate
A	1.015 ± 0.002b	76.258 ± 0.050e	15.773 ± 0.016e	1.080 ± 0.014a	1.022 ± 0.014c	4.852 ± 0.078a
B	1.012 ± 0.003a	76.228 ± 0.006a	15.735 ± 0.009b	1.078 ± 0.002a	1.008 ± 0.002a	4.939 ± 0.011e
C	1.014 ± 0.004ab	76.253 ± 0.016d	15.760 ± 0.008c	1.078 ± 0.002a	1.015 ± 0.012b	4.880 ± 0.054c
D	1.014 ± 0.002ab	76.250 ± 0.005b	15.764 ± 0.008d	1.080 ± 0.003a	1.016 ± 0.005b	4.876 ± 0.00b
E	1.013 ± 0.016ab	76.251 ± 0.006c	15.762 ± 0.026bc	1.079 ± 0.002a	1.015 ± 0.013b	4.880 ± 0.004c
F	1.015 ± 0.004b	76.260 ± 0.003f	15.720 ± 0.003a	1.080 ± 0.003a	1.021 ± 0.019c	4.904 ± 0.015d

Result were expressed as Mean ± SD for three independent sample (n=3). Means within the same column followed by the same small letter are not significantly different at ($p< 0.05$) according to Duncan's multiple test ran; 1=Fresh orange; A=Control 'Open Air; B=Jute Pad; C=Luffa Cylindrical Pad; D=Local Sponge Pad; E=Refrigerator.

microbial attack. The moisture content of the fresh sweet orange was 76.258% which implies that the activity of the spoilage microorganisms will be relatively high due to the presence of soluble enzymes and co-enzymes needed for its metabolic activities [33]. However, this was higher than all the cooling structure (Jute Pad, Luffa Cylindrical and Local Sponge Pad) except in the Refrigerator (76.260%) after 8 days which may be attributed to it high relative humidity as a result of it lower temperature. In same vein, from this study the ambient condition (Open air) will have the least relative humidity and high temperature this accounted for its low moisture content. This is in agreement with Muhammad S, et al. [28] who reported that perishable fruits are best stored at low temperature. Values obtain in this study was not in consonance with Chuku EC and Akani NP [34] and Balogun AA, et al. [3] which reported 84.6% and 84.69% respectively for sweet orange. This variation could be attributed to the variety's differences (genera and species) among other factors [31].

An average of 30–38 g and 21–25 g per day dietary fiber is required for men and women [35]. In this study, the crude fiber obtained in all the cooling structures averaged at 15.598 g/100 g and there is a significant difference ($P<0.05$) in all the cooling structure. The crude fibres obtained in all the storage systems were lower than the value obtained for the freshly squeezed sweet orange (15.773 g/100 g). This maybe as a result of the hydrolysis of complex molecules after the 8days at different storage conditions. The result obtained in this study is higher than the 12.79 g/100 g reported by Olabinjo OO, et al. [36] which may be due to differences in varieties but lower than 12.79 g/100 g reported by Olabinjo OO, et al. [36] for the crude fiber composition of sweet orange peel.

The available crude protein ranges from 1.008 mg/10 g in the open-air to 1.022 mg/10 g in the fresh orange. There is no significant difference at $p<0.05$ between the crude proteins of the sweet orange in all the three cooling structures. This is in the same vein with the report of Ibrahim [29]. However, this is relatively higher than 38 mg/10 g and 350 mg/10 g reported by Baturh Y and Olutola O [31] for valencia orange juice and Ibadan sweet orange respectively. In addition, this was higher than the 940 mg/100g reported by United States Department of Agriculture (USDA) Nutrient Database (2014) [37].

Sweet oranges generally have very low fats content. The crude fat content of freshly squeezed sweet orange was observed to be 1.080 g/100 g, which is higher than 845 mg/100 g that was reported by USDA Nutrient Database (2014) [37]. The difference could also be due to varieties differences [31]. **Table 1** showed that there is no significant difference ($p<0.05$) in the crude fats of sweet oranges stored in all the storage systems, which is in agreement to what Chuku EC and Akani NP [34] reported.

Table 1 shows that there is a significant difference in the carbohydrate content of the fresh orange, in the controls and the evaporative cooling structure this is in consonance with the report of Ibrahim (2013). The Open-air sweet orange has the highest carbohydrate composition (5.296/100 g) while the refrigerated sweet orange has the lowest value (4.876 g/100 g).

Vitamin C

Ascorbic acid (Vitamin C) content in oranges has been reported by Holocombe GD [38] is never constant. It varies with factors such as climatic/environmental conditions, maturity stage, handling and storage, ripening stage, species, and variety of the citrus fruit as well as temperature [39]. The result obtained in **Table 2** depicts the effects of storage on the Absorbic Acid content in oranges. In this study, the ascorbic acid content of sweet orange decreased gradually in all the storage systems from day 2 to day 8; this is similar to what was reported by Mavis OA, et al. [8]. This decrease trend varies and depends on the cooling structure being used [40]. The open air sweet orange has the highest percentage loss (44.38%) of ascorbic acid due to the rapid degradation and conversion to dehydroascorbic acid at high temperature thereby enhancing the rate of transpiration and respiration [41, 3]. This is lower than 54.2% reported by Faseema J, et al. [42] on sweet orange kept in an open-air basket. This difference may be due to different storage time and storage space that may cause high transpiration and respiration rates. Refrigerated sweet orange has the lowest percentage loss (10.06%) which may be attributed to low rate of transpiration and respiration in the *citrus sinesis* stored under this condition. This is in the same vein with what Ibrahim [29]. However, within the evaporative cooling structures, Jute Pad, B, has the highest percentage loss (28.04%) followed by Local Sponge Pad, D, (25.93%) while Luffa Cylindrical Pad has the lowest percentage loss (16.06%).

Therefore, Luffa Cylindrical Pad showed the maximum efficiency in preservation of the Vitamin C in sweet orange second to refrigerator. Furthermore, compared to the open-air sweet orange, evaporative cooling structures have minimal loss of Vitamin C over the storage period; this is in agreement with work

Table 2 Vit C (mg/100 g) of the *Citrus Sinensis* stored in different cooling structure.

C/S	Days 2	Day 5	Day 8	Percentage Loss
A	23.081 ± 0.003c	16.329 ± 0.002d	12.837 ± 0.001c	44.38
B	27.967 ± 0.005e	25.125 ± 0.001b	20.126 ± 0.009b	28.04
C	17.175 ± 0.003a	15.421 ± 0.005e	14.417 ± 0.003a	16.06
D	22.319 ± 0.002b	19.727 ± 0.003c	16.531 ± 0.006d	25.93
E	25.017 ± 0.001d	24.056 ± 0.001a	22.501 ± 0.004e	10.06

Table 3 Total Sugar (mg/100 g) of the *Citrus Sinensis* stored in different cooling structures.

C/S	Days 2	Day 5	Day 8	Percentage Increase
A	5.018 ± 0.001b	5.210 ± 0.005b	5.547 ± 0.005ab	10.54
B	5.069 ± 0.004c	5.203 ± 0.002a	5.401 ± 0.003bc	9.07
C	5.502 ± 0.007e	5.805 ± 0.003ab	6.001 ± 0.004ab	8.64
D	5.321 ± 0.006d	5.511 ± 0.001b	5.756 ± 0.008c	8.18
E	4.919 ± 0.002a	5.206 ± 0.004ab	5.344 ± 0.002a	6.55

of Kabasakalis V, et al. [43]. The reason for the minimal loss in evaporative cooling structures may be due to the ability of the structures to reduce the production rate of ethylene which causes softening and ripening, and subsequent deterioration in fruits [40]. Also, this can be attributed to other biochemical reactions resulting from senescence [44]. Therefore, the degree of decline of the Vitamin C content is proportional to the temperature of the cooling structure, for a short storage period [3].

Total sugars

The rate of conversion of total sugars to reducing sugars is determined by the conditions of storage such a temperature, time and physiological state of fruits [45]. The sugars in this fruit maybe completely oxidized to carbon dioxide and water and as well with the production of Adenosine Triphosphate during the post-harvest storage [39]. **Table 3** shows an increase in the value for the total sugar stored in cooling structure B, C, D and E. The increase was matched to the one reported by Erick KR, et al. [46]. From **Table 3**, the overall total sugar content increased by 10.54% from day 2 to day 8 in the open air which was the highest comparing to other storage systems while the least increase (6.55%) was observed in the refrigerator. These results shows that total sugar in sweet orange could increase during the storage; the total sugar increase at the high temperature may be rapid compared to the one at low temperature [28].

Furthermore, among the evaporative cooling structures, Local Sponge Pad showed the minimum percentage increase (8.18%) followed by Luffa Cylindrical Pad (18.64%) while maximum percentage increase was observed in Jute Pad (9.07%). This variation may be due to the differences in the padded materials used in the evaporative structures [40] while the overall gradual increase of total sugar in the evaporative cooling structures could be due to increase in the rate of ovule respiration at high humidity and low temperature observed in the cooling structures [47].

Conclusion

The nutritional analysis showed a gradual decrease in the vitamin C content of sweet oranges stored in the evaporative cooling structures, open air, and refrigerator during the storage period with the minimal loss in refrigerator (10.06% loss). Among the evaporative cooling structures, Luffa Cylindrical (16.06% loss) showed the maximum efficiency in the preservation of Vitamin C content over the 8 days storage time. Furthermore, analysis showed a steady increase in the total sugar content of the sweet orange in open air and all the storage systems where Jute Padded cooling structure showed the maximum increase (after the open air) with 9.06% increase within the storage time. The proximate analysis showed no significant difference in ash content, crude protein, and fats content but a gradual increase in the moisture content and crude fibre and a decrease in carbohydrate in all the evaporative cooling structures.

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