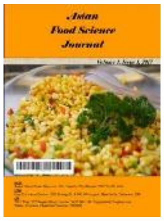

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Effect of Hybrid Photovoltaic Solar Drying Method on the Physicochemical Properties of Fresh and Dried Tomato Slices

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Authors' contributions

This work was carried out in collaboration between all authors. Author JBH designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors JBH and KBF managed the analyses of the study. Author KBF managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

A hybrid photovoltaic solar dryer under the climatic conditions was used to dry tomato slices at Yola in Nigeria. The effect of this drying method on the physicochemical properties of the dried tomatoes was examined and compared with fresh tomatoes by using standard methods. The percentage proximate compositions of the fresh tomatoes was significantly different ($p<0.05$) from the dried ones. The fresh tomatoes contained 1.05% crude protein, 0.35% crude fat, 1.02% crude ash, 0.63% crude fiber and 2.57% carbohydrate while the open sun dried tomatoes contained 9.21% crude protein, 1.43% crude fat, 29.86% crude ash, 2.01% crude fiber and 49.24% carbohydrate. Solar dried tomatoes contained 10.67% crude protein, 1.47% crude fat, 47.03% crude ash, 2.41% crude fiber and 28.87% carbohydrate. Hybrid photovoltaic dried tomatoes contained 11.29% crude protein, 1.87% crude fat, 45.88% crude ash, 2.47% crude fiber and 30.86% carbohydrate. The titratable acidity of the hybrid photovoltaic dried tomatoes was

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significantly higher ($p<0.05$) than that of solar and open sun dried tomatoes. However, the pH of the fresh tomatoes was significantly higher ($p<0.05$) than the dried ones. The taste index showed that the tomatoes dried by hybrid photovoltaic drying method was superior to the tomato dried through direct solar energy dryer and open sun drying other products. Conclusively, tomato by hybrid photovoltaic drying method was superior to other drying methods used and given product with higher quality.

Keywords: Tomato; hybrid photovoltaic; taste index; physicochemical properties; solar drying.

1. INTRODUCTION

Tomatoes (*Lycopersicon esculentum* L.var) are among one of the most important vegetable grown crops, mostly in the tropical countries. They are highly seasonal and available in large quantities at a particular season of the year. Tomato is reported by Lorenz and Maynard [1] as an important vegetable for human use because of its vitamins and minerals content that provide the basic body nutritional requirements. FAOSTAT [2] reported tomato as the second most important vegetable crop next to potato and according to Splittstoesser [3], it is ranked 14 among sixteen common vegetables (spinach, lima beans, peas, sweet potato, carrots, cabbage, lettuce, onion, etc) based on total nutritional concentration but ranked first based on the contribution of nutrients to the diet.

Nigeria was ranked by FAOSTAT [2] as the 16th largest tomato producing nation in the world and has the comparative advantage and potential to lead the world in tomato production and exports. The production of tomatoes in Nigeria in 2010 was about 1.8 million metric tonnes which accounted for about 68.4% of West Africa, 10.8% of Africa's total output and 1.28% of world's output [2]. Unfortunately, the country still experiences deficiency in critical inputs, lack of improved technology, low yield and productivity, high postharvest losses and lack of processing and marketing infrastructure [4]. The demand for tomato and its by-products far outweighs the supply. With a population of over 170 million people, an estimated national population growth rate was 5.7% per annum and an average economic growth rate 3.5% per annum in the past five years. Ugonna, Jolaoso and Onwualu [5] reported that Nigeria has a large market for processed tomato products. The tomato industry has the ability to increase the export earnings of African countries whilst improving the living standards of the individual producer. This is because tomatoes and tomato-based foods provide a wide variety of nutrients and many health-related benefits to the body. Also, Tomato production can serve as a source of income for most rural and peri-urban producers in most developing countries [6].

Despite all these benefits from the crop, many challenges are making its production unprofitable in most developing countries especially those in Africa. Postharvest losses and other challenges however, pose a great threat in the quest to attain all these benefits. This postharvest challenges, both on-farm and off-farm are gradually collapsing the tomato industry in most of the African countries [6]. At the peak season large quantity of tomato gets spoiled due to market glut. Thus, processing, preservation and storage of tomatoes during peak season can prevent the huge post-harvest losses in tomato and make them available in the off season at comparatively lesser cost [6]. Tomatoes, as other vegetables, can be dried using various methods. Drying is the cheapest mode of preservation of fruits and vegetables immediately after harvest since the existence of human. Hussein et. al. [6] reported that dehydrated tomato powder holds a promising and potential market for processing industries for preparation of products like sauce, ketchup, chutneys, soups and baby foods. In any tomato drying method used the quality of the final products is strongly dependent on the technique and the process variables used and the required time for drying the product depends on many parameters such as tomato variety, the soluble solids content (^{o} brix) of the fresh product, the air humidity, the size of the tomato segments, the air temperature and velocity and the efficiency of the drying system. The rate of drying affects the end quality of the dried product [7].

In a hybrid photovoltaic solar dryer, drying is continued during off sunshine hours by back-up heat energy or storage heat energy [8]. Therefore, drying is continued and the product is saved from possible deterioration by microbial infestation. Continuous drying also prevents microbial growth during drying [9]. Some hybrid dryers were developed to control the drying air conditions throughout the drying time independent of sun-shine especially at night or poor weather when it is not possible to use the solar energy, using alternative heating sources such as sawdust burner [10]; kerosene stove [11] or by using a biomass stove [12,13]; electric heater [14,15]. The interest in the production of dried tomatoes is increasing because of the possibility of using them in different purposes and drying efficiencies alone may not be adequate in qualifying this dryer for acceptance, except when the quality of the dried product is comparable to other alternatives in terms of nutritional value, physicochemical and organoleptic properties.

Thus, this study is aimed towards testing the hybrid photovoltaic solar drying method by carrying out quality assessment of hybrid dried tomato. Through its physicochemical properties compared to solar and open sun dried tomato.

2. MATERIALS AND METHODS

2.1 Sample Source and Preparation

The tomatoes used in this study were obtained from the Jimeta Modern Market Yola, Nigeria. Samples of tomatoes were selected from the lot based on; firmness, colour and size uniformity. They were sorted, cleaned thoroughly by washing under tap water, rinsed with distilled water and then wiped with an absorbent paper [16]. Twelve (12) kilograms of tomatoes were washed, sorted, blanched (in boiling water 100°C for 2 minutes) and divided into three equal portions of 4kg each. Then, each portion was sliced with hand Tomato Slicer to a thickness of 6 ± 0.5 mm and drying was performed in three types of drying methods i.e. open sun drying, solar drying and hybrid-photovoltaic solar drying methods. The moisture content of the fresh fruits was immediately determined according to the AOAC [17] method (number 934.01), and found to be 94.22±0.21 g water per 100 g sample.

2.2 Drying Procedures

2.2.1 Open sun drying method

The first portion of the sliced was spread in a single layer on a four different wire meshes (1kg on each wire mesh) and sun dried until constant moisture content was achieved. The drying time required to reach the equilibrium moisture content was $10^1/_2$ hours and the moisture content of the dried slices was 7.63±0.60 g water per 100 g slices dried. The average of atmospheric temperature was approximately 40 to 45°C daily.

2.2.2 For solar drying method

The second portion was dried in the constructed hybrid photovoltaic dryer (1kg on each tray) by using solar collector as the heating source alone [8]. This is the solar drying method; here the heating source is from solar collector alone. The heater was not working in this case but the solar energy from the panel was charging the battery. So if the weather changes with poor sun intensity especially when drying through the night, the stored energy in the battery will power the heater to generate heat to facilitate drying process. The sliced tomato were spread in a single layer on a four different wire meshes (1kg on each wire mesh) and then dried until constant moisture content was achieved. The drying time required to reach the equilibrium moisture content was $8^1/_2$ hours and the moisture content of the dried slices was 9.56±0.48 g water per 100 g slices dried. The average of atmospheric temperature was approximately 40 to 45°C daily.

2.2.3 Hybrid-photovoltaic solar dryer

The third portion was dried in the same constructed hybrid photovoltaic dryer (1kg on each tray) but by using both heating source together [8]. The dryer consists of a DC extractor fan, drying chamber (500 × 500 × 1100 mm^3), drying trays, collector (which is an absorber plate made of aluminum sheet painted black and a transparent glass of 5mm tick which permit in only sun radiation.), air channel (air vent which is provided on the lower front side of the collector for easy passage of air into the dryer), DC blower fan and 500 W power heater located at the bottom of the drying chamber, two solar panel rated 180W power each, solar battery rated 200Ah and a temperature sensor which was located at the center of the chamber to sense the chamber temperature [8]. The two heating sources were working i.e. the heater was working and the solar collector was also working. The solar energy from the panel was charging the battery, so as it charges the battery, the energy is been used. This method has the advantage of constant heat supply thus, if heat from solar collector drops/lowers down due to change in intensity of the sun, the solar regulator (fixed in the control box) will regulate the charge supply from the battery and the heater will supply a stable heat. The sliced tomato were spread in a single layer on a four different wire meshes (1kg on each wire mesh) and then dried until constant moisture content was achieved. The drying time required to reach the equilibrium moisture content was 6 hours and the moisture content of the dried slices was 9.83±0.10 g water per 100 g slices dried. The average of atmospheric temperature was approximately 40 to 45°C daily.

2.3 Determination of Physicochemical Properties of the Fresh and Dried Tomatoes

2.3.1 Determination of proximate composition of the fresh and dried tomatoes

The moisture content was determined according to the method of AOAC [17]. The Samples were dried at 105°C for 3 h using the preset oven (Fisher Scientific Isotemp Oven, model 655F, Chicago, USA). The method described by AOAC [18] was employed for ash content determination. The crucible containing the pre-weighed samples were placed in a heated furnace (Fisher Isotemp Muffle Furnace, model 186A, USA) at 600°C for 6 h after which they were cooled to room temperature in desiccators and weighed. The protein content (% nitrogen x 6.25) and fat content (1g was extracted for ether extract determination using diethyl ether (64°C as solvent) were determined according to the method of AOAC [18].

2.3.2 Determination of pH value

The pH which is a measure of the acidity or alkalinity of a substance was measured using digital pH meter (Model: EQ-610 Equip-Tronics), in accordance with AOAC [17] method. Fresh tomatoes were blended using a Kenwood blender (Philips HR 2001, China). The homogenate was then centrifuged at 1500 rpm for 10 minutes, and the supernatant was used. In the case of the dried sample 2 g tomato powder was blended with 80 ml of water, filtered with Whatman No. 1 filter paper, and 10 ml aliquot was used for the determination.

2.3.3 Determination of total solid

Total solid was calculated using the formula as described by AOAC [17]; %Total solid = 100 – % moisture content

2.3.4 Determination of total soluble solid (% Brix)

Total soluble solid (% Brix) was determined using a Abbe Refractometer as described by AOAC [17]. Fresh tomatoes were blended using a Kenwood blender (Philips HR 2001, China). The homogenate was then centrifuged at 1500 rpm for 10 minutes, and the supernatant was used. In the case of the dried sample 1 g tomato powder was blended with 40 ml of water, filtered with Whatman No. 1 filter paper, and 5 ml aliquot was used for the determination.

2.3.5 Determination of titratable acidity

The titratable acidity of the sample was determined as described by [19]. Fresh tomatoes were blended using a Kenwood blender (Philips HR 2001, China). The homogenate was then centrifuged at 1500 rpm for 10 minutes, and the supernatant was used. In the case of the dried sample 2 g tomato powder was blended with 80 ml of water, filtered with Whatman No. 1 filter paper, and 25 ml aliquot was used for the determination.

2.3.6 Determination of taste index

Taste index was calculated using the formula as described by [16];

Taste index = total soluble solid/titratable acidity

2.4 Statistical Analysis

All experiments were performed in triplicate, and the results were expressed as means ± standard error (SE). Analysis of variance (ANOVA) was carried out to determine any significant differences in measurements using the SPSS statistical software (SPSS 20.0 for Windows; SPSS Inc., Chicago, IL, USA) and considering the confidence level of 95%. The significance of the difference between the means was determined using the Duncan Multiple range test, and the differences were considered to be significant at $p < 0.05$.

3. RESULTS AND DISCUSSION

The physicochemical properties of tomato such as proximate compositions, pH, total solids (TS), total soluble solids (TSS), titratable acidity (TA) and taste index (TI) are among the important determinants of its consumer acceptability. Table 1 shows the results obtained for the physicochemical properties of fresh and dried tomatoes. Means with the same superscripts are not significantly different ($p>0.05$). Means were calculated from triplicate measurements. The moisture content of fresh tomato was 94.22 %, sun dried tomato was 9.83%, solar dried was 9.56% and hybrid dried was 7.63%. The results indicate that much moisture was removed in hybrid drying method compared to sun and solar drying method within a short period of time.

These results is in agreement with Toor and Savage [20] findings. They reported that to process tomatoes into an intermediate moisture food product, the final moisture content should be lower than 15% in order to maintain dried products in a stable and low water activity state. During drying, water at the surface of the substance evaporates and water in the inner part migrates to the surface to get evaporated. The ease of this migration depends on the porosity of the substance and the surface area available. Other factors that may enhance quick drying of food items are: high temperature, high wind speed and low relative humidity. These factors are what was observed for high drying rate and lower drying time in hybrid drying method.

Thus, drying tomato slice by hybrid method was observed to be more effective than solar in large production scale. The value of crude protein content in fresh tomatoes before drying was computed to be 1.05%. An increase in the crude protein content of the dried tomatoes was observed after the drying process, with the hybrid drying method having the highest value (11.29%) follow by solar drying method (10.69%) and sun drying method having the lowest value (9.21%). This may be due to high moisture remover caused by the drying method used. The behaviour exhibited here by protein, as confirmed by USDA [21], shows that the protein content of a vegetable after drying can be greater than that of the fresh sample which was attributed to the presence of microbes in the sample. The changes in protein content might also be related to non-enzymatic browning reactions which was found to be more in sun dried samples [22].

The fat content of the fresh tomatoes was 0.35%, this is significantly different to the dried samples. The fat content of the dried tomatoes ranges from 1.43% to 1.87%, with the hybrid drying method having the highest value and sun drying method having the least value. This increase was observed to be due to high drying rate in a short time and increase in the concentration of tomato. This high drying rate in a short time also prevent melting of the fat thereby increasing their value. The ash content of the fresh tomatoes was 1.02% and that of the dried tomatoes are 29.86% for sun dried, 47.03% for solar dried and 45.88% for hybrid dried. This result on ash content show that there was more ash in dried tomato than fresh tomato. This implies that there are more combustible materials in dried tomato compared to the fresh tomato sample subjected to dehydration. Harbers [23] reported that ash content gives an idea about the mineral composition of food. The difference in crude fibre content of the fresh (0.63%) and dried tomatoes (2.01% for sun dried, 2.41% for solar dried and 2.47% for hybrid dried) indicate more crude fibre in the dried samples; it also implies that there are more indigestible materials in dried tomato [24]. The carbohydrates content of the dried tomatoes ranges from 28.87% to 49.24%, these results so that most of the dry matter in tomatoes is carbohydrates. On a fresh weight basis, the carbohydrate content of fresh tomatoes was 2.57%. This result is in agreement with Gould [25] findings which reported that the carbohydrate content of fresh tomatoes varies between 2.2 and 3.6%.

The fresh tomatoes recorded pH of 4.32 and dried tomatoes were 4.36, 4.30 and 4.28 for sun, solar and hybrid drying method respectively. This result was comparable to 4.02 reported for fresh tomato by Muratore, Rizzo, Licciardello and Maccorone [26] and 4.24 reported for fresh tomato by Owusu et. al. [16]. The value of TA in fresh tomatoes was computed to be 0.24. The values obtained were 0.37, 0.39 and 0.40 for sun, solar and hybrid drying method respectively. TA and pH are interrelated in terms of acidity, but have different impacts on food quality Sadler and Murphy [27]. The total acid available to react with sodium hydroxide solution during titration is TA whiles the pH gives a measure of the strength of the acid in food [16, 28]. Sadler and Murphy [27] reported that the impact of an acid on food flavour is much more determined by TA than pH. The lower pH obtained for hybrid dried tomatoes to solar and sun dried tomatoes is an indication of its resistance to microbial attack. The TA values of the dried tomatoes slices were not significantly different to the fresh sample. But pH of all tomatoes dried were found to be statistically significant in terms of temperature. The TA increased with increasing drying temperature, however, the pH showed a decreasing trend. This observation has also been reported by [16]. The increase in TA with drying temperature may be due to the organic acids in tomato becoming more concentrated while the reduction in pH with drying temperature may be due to increased dissociation of the organic acids with temperature. Rice and Pederson [29] and Owusu et. al. [16] have reported greater inhibition of *Bacillus coagulans* at lower pH in tomatoes. Thus after drying, hybrid dried tomatoes may have a better microbiological stability than solar dried and sun dried tomatoes.

Table 1. Physicochemical properties of fresh and dried tomatoes

Samples	Moisture content (%)	Crude protein (%)	Crude fat (%)	Ash (%)	Crude fiber (%)	Carbohydrate (%)	TA (%)	pH	TSS (°Brix)	TI
Fresh	94.22 ± 0.01[a]	1.05 ± 0.01[c]	0.35 ± 0.02[c]	1.02 ± 0.02[d]	0.63 ± 0.01[c]	2.57 ± 0.38[d]	0.24 ± 0.01[c]	4.32 ± 0.01[b]	4.90 ± 0.06[a]	20.42 ± 0.38[a]
Sun Dried	9.83 ± 0.10[b]	9.21 ± 0.02[b]	1.43 ± 0.15[b]	29.86 ± 0.05[c]	2.01 ± 0.04[b]	49.24 ± 0.58[a]	0.37 ± 0.02[b]	4.36 ± 0.01[a]	3.27 ± 0.04[d]	8.84 ± 0.46[c]
Solar Dried	9.56 ± 0.48[b]	10.67 ± 0.38[a]	1.47 ± 0.03[b]	47.03 ± 0.08[a]	2.41 ± 0.02[a]	28.87 ± 0.75[c]	0.39 ± 0.01[ab]	4.30 ± 0.01[c]	4.27 ± 0.03[c]	10.86 ± 0.18[b]
Hybrid Dried	7.63 ± 0.60[c]	11.29 ± 0.63[a]	1.87 ± 0.09[a]	45.88 ± 0.03[b]	2.47 ± 0.02[a]	30.86 ± 0.09[b]	0.40 ± 0.01[a]	4.28 ± 0.01[d]	4.53 ± 0.03[b]	11.25 ± 0.32[b]

Key: TSS = Total soluble solid; TA = Titratable acidity; TI = Taste index; a-d: Means in the same column bearing different superscript are significantly different at p<0.05

The value of TS in fresh tomatoes was computed to be 6.11%. The values obtained were 90.17%, 90.44% and 94.37% for sun, solar and hybrid drying method respectively. This result shows the extent of moisture loss in each method used. Organization for Economic Cooperation and Development [OECD] [30] reported that the amount of total solids varies with genetic constitution (tomato variety) and environmental factors such as site of cultivation, soil condition, climate, not least precipitation during the period of fruit development and harvesting. Tomato usually consists of 5.5-6.2% total solids [30]. However, it have also been reported to be as high as 7.0-8.5% [25]. TSS of tomatoes are a measure of all the soluble solids that are dissolved in the fruits. This includes sugars, salts, acids, vitamins etc. In this study, TSS for fresh tomatoes was 4.90 (oBrix) and the dried samples were 3.27, 4.27 and 4.53 (oBrix) for sun, solar and hybrid drying method respectively, these results are in accordance with previous studies. According to Tudžarov [31], the quantity of TSS in the investigated cultivars ranged from 3.46 to 4.18 (oBrix), while Hossain, Alam, Hakim and Amanullah [32] reported values for total soluble solids from 4.79 to 6.02 (oBrix), depending on the cultivar. The decrease in TSS upon drying and with increasing drying temperature may be due to caramelization [16].

The relationship between TSS and TA is very important in determining tomato quality for further processing, because it provides information on the balance of sugars and acids in the fruit. The brix/acidity (TSS/TA) index or taste index (TI) of the tomatoes were significantly different. The TI of fresh tomatoes (20.42) was significantly higher than that of dried tomatoes. The respective TI indices for hybrid, This shows that the taste of hybrid dried tomatoes was more preferable than that of solar dried tomatoes, that of solar dried tomatoes was more preferable than that of sun dried tomatoes, and sun dried tomatoes more preferable than control. In essence, the taste of the tomatoes dried by hybrid dryer was superior to the other tomatoes products examined.

4. CONCLUSIONS

The study concluded that good quality shelf stable dried tomato slices could be produced using hybrid drying method for sustainable supply chain. The quality of the dried tomatoes produced by hybrid drying method was better in quality and other examined parameters than fresh tomatoes. The study has therefore provided useful information, in drying process design for tomatoes, which can assist in reducing post losses. It also proved that the efficiency of agricultural dryers could be increased through the use of a combination of solar and heating element coil powered by photovoltaic (PV) solar panel, compared to conventional dryers with only solar or only biomass heating sources.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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