QUALITY EVALUATION OF FOUR BANANA CULTIVARS DRIED IN A GREENHOUSE DRYER OPERATED UNDER DIFFERENT ENERGY MODES

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Abstract

Products undergo several processes that result into modification of its physical, chemical and nutritional properties during drying. These modifications are mainly dependent on the drying method applied. It is vital to evaluate the effects of any drying method on product quality before adopting it for commercial application. The purpose of this study was to evaluate the effects of different drying methods on quality attributes of banana slices of four cultivars. Three drying methods (solar, biomass and solar-biomass) were used to dry fresh banana slices in a greenhouse dryer with open sun as the control. Color, firmness and vitamin C content of fresh and dried slices were measured. Regardless of the drying method, results obtained showed that the dried products were darker, firmer and had lower vitamin C content compared to that of corresponding fresh products. Resulting total color difference ranged from 7.04±0.29 to 24.27±2.52, 4.86±0.93 to 16.53±12.81, 6.02±0.02 to 21.71±2.28 and 22.06±2.44 to 39.14±7.63 for solar, biomass, solar-biomass and open sun drying, respectively. The percentage increase in firmness of banana slices after drying ranged between 151.28±56.04% to 317.50±8.92%, 98.08±14.96% to 153.19±60.54%, 91.30±61.49% to 233.33±26.07% and 125.64±36.26% to 262.50±12.62% for solar, biomass, solar-biomass and open sun drying, respectively. The reduction in vitamin C content ranged from 72.44±3.96% to 85.87±2.64%, 69.23±14.14% to 86.90±2.84%, 63.85±3.19% to 87.19±13.97%, and 62.32±4.82% to 77.14±6.38% for solar, biomass, solar-biomass, and open sun drying respectively. Among the varieties considered, Apple banana had the best color retention, highest values of firmness and highest vitamin C content before and after drying. Further, drying of banana slices in the greenhouse dryer resulted in better conservation of quality as compared to open sun drying. Generally, drying of products in the hybrid greenhouse dryer has advantages of continuous drying despite changes in weather and time as well as protecting the product from contamination.

Key Words: Banana, color, firmness, vitamin C, variety, drying methods

Introduction

Banana is considered to be a leading fruit in the world and ranked top five in terms of economic value in the world trade (Aurore *et al.,* 2009). The main use of banana depends on the amount of starch and sugar levels in the fruit and may vary from region to region. Among the common edible subgroups of banana are dessert (AAA- genome), East African highland bananas (AAA-EA genome) and cooking varieties (ABB-genome). Dessert are consumed when ripe while cooking variety are consumed while cooked at various stages of maturity (Delphine *et al*., 2019). On the other hand, East African bananas can be consumed when ripe or cooked depending on community preference. Bananas from these edible sub-groups can be processed to other form such as flour, juice, puree and dried or fried crisp snack. The high moisture content of bananas limits their shelf-life and makes them more susceptible to storage and transport conditions. To increase on shelf life, they need to be preserved by either freezing, canning or drying. Drying is one of the most preferred method as it is easy and the dried product has reduced packing cost, requires less storage space and can be transported at relatively low cost. Additionally, their low water content deters the development of some microorganisms responsible for deterioration of fresh food (Santos and Silva, 2008). Additionally, drying makes the commodity available year round and at places where the commodity does not grow. This increases the demand and thus better income is generated as a result.

Sun drying is the most common drying method practiced in developing countries. It offers a cheap drying method but often is faced with several limitations due to intermittent weather conditions resulting in longer drying periods, re-wetting of the products as well as exposing the products to attack by insects, pests and dust (Amer *et al.,* 2009). Solar drying is an alternative drying method that reduces some of the challenges faced with sun drying. However, solar drying method just like sun drying is severely affected by intermittent weather conditions and is also not feasible for night time drying. In a hybrid solar drying system there is continuous drying due to supplemental heat supplied to the system from alternative energy sources and stored energy. Although hybrid solar dryers have been studied enormously, limited studies have been reported on the effects of different drying methods on the quality of green bananas. Several studies on quality of dried ripe bananas have been reported (Amer *et al.,* 2009, Intawee and Janjai, 2011, Hedge *et al.,* 2015) with fewer studies regarding the quality of dried green banana slices (Barroca and Guiné, 2013). Amankwah *et al*. (2019) studied the effects of different drying methods (solar adsorption drying, solar drying and open sun drying) on vitamin C, color and composition of yams. They observed that composition was not affected by drying method but did affect vitamin C content and color.

Conversely, there are a number of studies on the quality of blended green banana flour (Ndayambaje *et al*., 2019, Islam *et al*., 2012). Often for dried fruits and vegetables vitamin C, color and texture are considered as quality indicators of the final dried product (Santos and Silva, 2008, Barroca and Guiné, 2013, Kadam *et al.,* 2015). Changes in these physical characteristics during drying depends on the mode of drying applied (Piotr and Grzegorz, 2003). From literature survey, there are studies on use of solar greenhouse dryer with biomass back up (Arun *et al.,* 2014). However, there is limited knowledge on effects of different drying methods using a single solar greenhouse set up with biomass back up especially on local banana varieties available in Kenya. It is important to evaluate the effects of any drying method on product quality before adopting it for commercial application. The purpose of this study was to evaluate the effects of different drying methods on quality attributes of banana slices of four cultivars. This work contributes useful information regarding greenhouse drying of sliced bananas using different drying methods (solar, biomass and solar-biomass) especially for domestic and small-scale industrial use.

Materials and Methods

Study Site

The solar-biomass hybrid greenhouse dryer was developed at the Department of Agricultural and Biosystems Engineering, Jomo Kenyatta University of Agriculture and Technology (JKUAT). The study site is approximately 10 km West of Thika town and 36 km North East of Nairobi, Kenya. The institution is located on latitude 1.0891^{o} South, longitude 37.0105^{o} East and 1460 m above sea level.

Experimental Set Up

The hybrid greenhouse dryer consisting of solar dryer, biomass stove, double duct heat exchanger and drying trays was designed and developed (Figure 1). The greenhouse dryer measured 8 m long, 4 m wide and 3.6 m high. The structure was glazed with ultra violet (UV) stabilized polythene film of 0.2 mm thickness. The dryer was of standard peak even span positioned in an east-west orientation in order to maximize available solar energy throughout the year (Dragicevic, 2011). The drying trays had a total effective area of 24 m^2 with a banana loading capacity of 240 kg. Each drying tray measured 7 m by 1 m with a spacing between the two levels being 0.3 m. The biomass stove had dimensions of 0.48 m length, 0.4 m width and 0.4 m height, respectively, and was fabricated using a 1.29 mm plain aluminum sheet and lagged with fiber glass of 25.4 mm thickness. The study used briquettes made from charcoal dust as source of fuel. The biomass stove was coupled to a double duct heat exchanger such that the inner duct conveyed the flue gases and outer ducts had the drying air. The double duct heat exchanger run across the center of greenhouse dryer with the flue gases exhausted via a chimney provided at the end of west side. The drying air was redirected to the drying trays through ducts that had outlet holes designed to discharge the drying air direct to the product. In order to maintain a steady flow of air in the duct, a blower (FDA250R2/ST, China) of 2378 to 2551 m^3/hour was mounted on the biomass heater. Humid air from the dryer was exhausted to the outside using a fan (FDA250SL, China) of 1868 to 2803 m^3/hour mounted on the west roof of the dryer. The exhaust fan was controlled using a speed regulator (Orient fans, India) in order to achieve the desired air flow rate. The fans were powered using a solar power system consisting of a 125 Wp, 24 V PV module (TPS-105S-125W, China) recharging a 100 AH, 24 V solar battery. A 20 A PWM solar charge controller was used to protect the battery. In addition, a 350 W direct current to alternating current converter (HT-M-350-12, Taiwan) was used for current conversion. The floor of the dryer was made of black-painted concrete to help increase the effectiveness of heat absorption and radiation inside the greenhouse dryer.

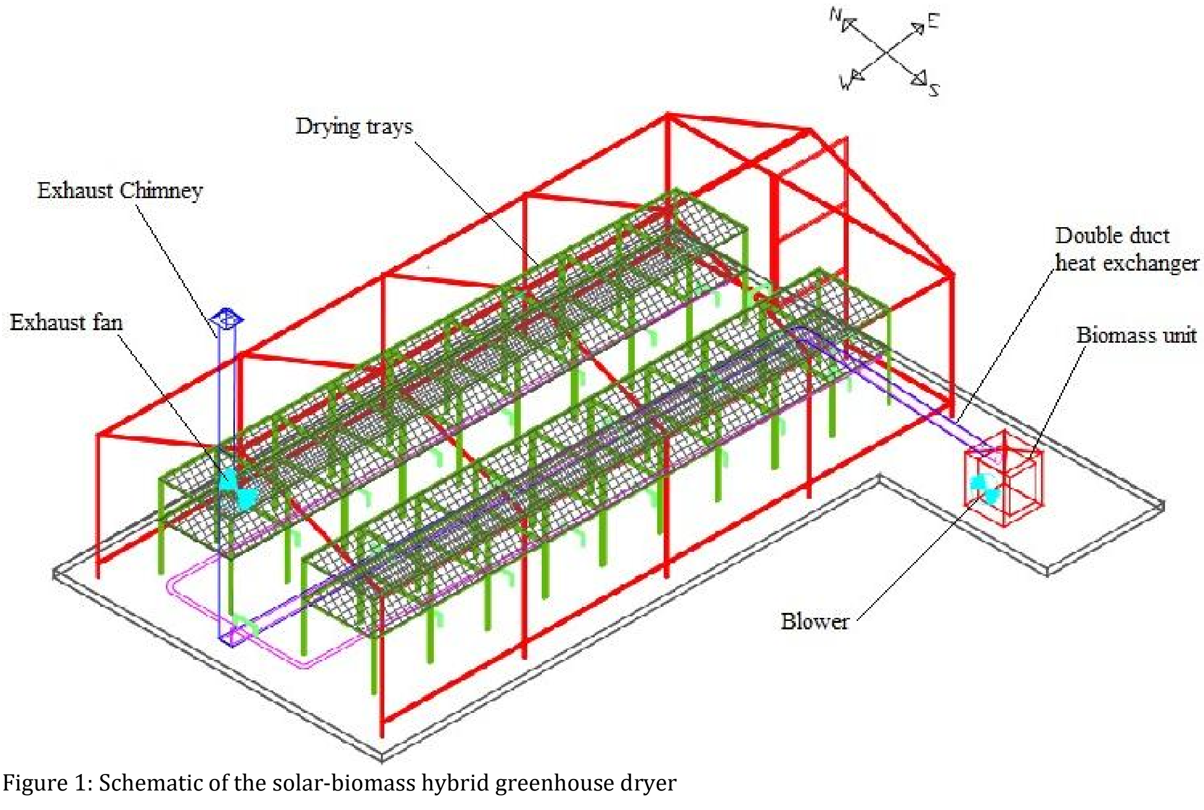

Figure 1: Schematic of the solar-biomass hybrid greenhouse dryer

Sample Procurement and Preparation

Mature green bananas at stage 1 of ripening (all green) of four varieties namely Apple Banana (*Musa sapientum*) (Sweet banana), Gros Michel AAA (*Musa acuminata) (AAA Group)* (Kampala), Kiganda AAA (*Musa acuminata (AAA-EA)*) and Muraru AAA (*Musa AA* "*Muraru*") were used in this study. Theses bananas were selected based on their uses and availability. They were obtained from identified banana farmers in Kiambu and Murang'a counties, Kenya and were harvested and transported to the experimental site with great care to minimize any mechanical injuries. Identification of farmers from these counties ensured that the bananas were sourced from matching locations sharing similar agro-climatic zone (UM2) and cultural practices, thus it was assumed that the bananas were subjected to similar cultivation practices (Kabubo and Mulwa, 2019). On reception, the bananas were inspected for any physical damage and only the healthy bananas were selected, and washed in clean water to remove any dirt on them. For the pulp drying (peeled), bananas samples were hand peeled using a clean stainless steel kitchen knife. The peeled bananas were then sliced into required thicknesses of 2, 3 or 4 mm as recommended by Wakjira *et al.* (2011). For unpeeled treatments, the bananas were also sliced as per the above procedure. During slicing, the samples were dipped in pre-treated water which constituted of 0.5% (w/v) sodium meta-bisulphite and 0.5% (w/v) salt. This treatment was necessary for both peeled and unpeeled banana samples in order to reduce enzymatic browning and microbial growth (Islam *et al.,* 2012). The samples were removed from the treating water using a colander freely draining as much water as possible. Excess moisture on the surface of the banana slices was drained using paper towels. The prepared samples were then weighed in lots of 500 g using a high precision balance (HZT-A 200, China) with a precision of ±0.01 g. These samples were immediately loaded on the drying trays in a thin layer while avoiding overlapping of slices. Each drying tray was divided into 24 equal parts and each part randomly held one treatment. The parts were labelled with the respective treatment before placing the samples on them.

Experimental Procedure

The experiment in the greenhouse dryer was spread from November 2018 to February 2019. The considered period was ideal in order to perform the experiments when the weather conditions were most suitable for each mode. Solar drying and open sun drying (control) were performed on 31st January 2019 from 8.00 am to 6.00 pm. Biomass mode only was performed during the night of 6th February 2019 from 8.00 pm to 6.00 am when there was no solar radiation. The experiment for combined solar-biomass mode was performed on a relatively overcast day that experienced intermittent rain (20th November 2018) from 8.00 am to 6.00 pm. A 10-hour period was considered for purposes of analysis as carrying on with biomass mode on two consecutive nights was not feasible. The limit was preserving the large quantities of samples involved. Weight reduction was monitored using a using a high precision balance (HZT-A 200, China) with a precision of ±0.01 g. Hourly temperature and relative humidity inside and outside the dryer were measured using DHT22 sensors while solar radiation was measured using a LDR sensor, for temperature humidity and radiation readings respectively. The DHT22 sensors are laboratory calibrated with a measurement range of 0-100% (±5percentage) for humidity and -40-125 ^{o}C (±0.2) for temperature (Tastan and Gökozan, 2019). The LDR sensors was calibrated using an LI-200R pyrometer. The reading from the sensors was logged to an arduino Mega (ATmega 2560) microcontroller which was equipped with 8 GB storage disk.

Measurements of color, firmness and vitamin C were determined on fresh and dried banana slices. A colorimeter (BCM-200, BIOBASE, Shandong, China (Mainland) with a measuring aperture of diameter 8 mm and

D65 light source was used for color measurements. The colorimeter was set in CIE L*a*b* color space display mode to determine the values of L^*, a^*, and b^*. The parameters L^*, a^* and b^* represented the degree of lightness to darkness, degree of redness to greenness and degree of yellowness to blueness, respectively. The colorimeter was calibrated using a white base provided with the instrument before the actual measurements were taken. During measurement, care was taken so as not to leak the light thrown from the colorimeter. For consistency in color monitoring, same samples were monitored throughout the drying process.

Firmness of fresh and dried banana slices was determined using a penetrometer (Compact-100, Sun Scientific Co. LTD, Japan) with operation mode of maximum force of 10 kg at a distance of 1.5 mm and a constant head speed of 5 mm/s (Maina *et al.,* 2019). The probe was allowed to penetrate the sample to a depth of 5 mm and the corresponding force required to penetrate this depth determined. The firmness value was expressed as Newton (N). Vitamin C content of fresh and dried banana slices was determined by indophenol titration procedure defined by AOAC (2010). The titration was performed in triplicate and the average value of titre recorded.

The instantaneous moisture content M, on wet basis (% wb), was evaluated using equation (1). In the equations, W_w is the amount of moisture removed (g), and W_p is the quantity of product (bananas) to be dried (g).

$$M = \frac{W_w}{W_p} \times 100 \quad (1)$$

The values of L^*, a^*, and b^* for the banana slices during drying were presented in tabular form. The total color difference of the dried banana slices (ΔE^*) was determined by comparing the color of dried banana slices to the fresh slices as presented in equation (2). In the equation, L_0^*, a_0^*, and b_0^* are the values of fresh slices (Amankwah *et al.,* 2019).

$$\Delta E^* = \sqrt{(L_0^* - L^*)^2 + (a_0^* - a^*)^2 + (b_0^* - b^*)^2} \quad (2)$$

Average and standard deviation for the firmness values for the banana slices during drying were also presented in tabular form. An increase in firmness of banana slices as a result of drying was computed using equation (3). In the equation, ΔF is the increase in firmness, F_f is the firmness of fresh banana slice and F_d is the firmness of dried banana slice.

$$\Delta F\ (\%) = \frac{F_d - F_f}{F_f} \times 100 \quad (3)$$

Amount of Vitamin C content (mg/100g) was determined using equation (4) as described by the vitamin C testing procedure (AOAC, 2010). In the equation, T is titre of dye (mg/ml), $blank$ is volume for sample blank titration (ml), c is standardized value, v is volume made (ml), l is volume of sample aliquot titrated (ml) and s is sample weight (g).

$$Vitamin\ C = \left(T \times \left(\frac{blank \times c \times v}{l \times s}\right)\right) \times 100 \quad (4)$$

The percentage retention of vitamin C during drying of banana slices was computed by equation (5). In the equation, C_f is the vitamin C content of fresh banana slice (mg/100g) and C_d is the vitamin C content of dried banana slice (mg/100g) (Sanusi *et al.,* 2018).

$$Retention\ of\ vitamin\ C\ (\%) = \frac{C_d}{C_f} \times 100 \quad (5)$$

Statistical Analysis

The data obtained from study was statistically subjected to one-way analysis of variance (ANOVA). Significant means were separated the Least Significant Difference (LSD) test s at $\alpha = 0.05$. These analyses were carried out using MS Excel 2016™.

Results and Discussion

Dryer Performance

During the drying period of solar mode, the average hourly solar radiation was found to be 494.01±337.35 W/m^2 with a peak radiation of 896.29 W/m^2 recorded at 3.00 pm. The corresponding average hourly inside and outside temperature was found to be 45.23±9.58°C and 32.89±5.27°C, respectively. Solar-biomass mode period had an average hourly solar radiation of 192.43±168.80 W/m^2 with corresponding average hourly inside and outside temperature 34.97±6.59°C and 21.76±1.99°C, respectively. The biomass mode period recorded average hourly inside and outside temperature of 26.22±4.09°C and 17.26±2.67°C, respectively. These conditions resulted in moisture reduction from 74.1±4.9, 78.3±3.9 and 73.0±5.3% to 33.52±10.15, 62.4±6.2 and 40.27±9.12% for solar, biomass and solar-biomass mode, respectively. Observations of similar magnitudes were made by other scholars. Intawee and Janjai (2011) reported greenhouse drying temperature of 35°C to 64°C on a clear sunny day with peak solar radiation of 1200 W/m^2 at noon. Equally, Genobiagon Jr. and Alagao (2019) reported moisture reduction from 78.6% to 33.3% and 38.0% for a clear sky and cloudy day, respectively, during banana slices drying in a cabinet dryer.

Table 1: Color parameters for both fresh and dried banana slices for solar mode

Banana variety	*L**	*a**	*b**
	Peeled fresh sample		
Apple banana	87.22±0.03 ^{a}	4.72±0.08 ^{c}	20.95±4.07 ^{c}
Gros Michel AAA	87.13±0.16 ^{a}	8.34±0.27 ^{a}	31.28±0.4 ^{a}
Kiganda AAA	86.16±2.98 ^{a}	7.11±0.18 ^{b}	29.68±1.41 ^{ab}
Muraru AAA	87.94±1.15 ^{a}	3.27±1.12 ^{d}	25.52±1.98 ^{b}
LSD	-	1.00	4.43
	Unpeeled fresh sample		
Apple banana	82.72±8.46 ^{a}	0.40±2.98 ^{a}	19.30±4.86 ^{b}
Gros Michel AAA	74.12±4.71 ^{a}	0.86±8.05 ^{a}	27.80±2.35 ^{a}
Kiganda AAA	75.89±10.06 ^{a}	2.35±8.42 ^{a}	29.88±4.47 ^{a}
Muraru AAA	75.89±18.34 ^{a}	-0.61±3.80 ^{a}	25.65±2.26 ^{a}
LSD	-	-	8.65
	Peeled dry sample		
Apple banana	86.19±0.29 ^{a}	10.61±1.27 ^{b}	17.60±2.21 ^{a}
Gros Michel AAA	84.00±0.30 ^{b}	15.00±0.04 ^{a}	13.77±0.33 ^{b}
Kiganda AAA	80.74±0.00 ^{c}	14.63±1.28 ^{a}	15.71±0.76 ^{ab}
Muraru AAA	80.97±2.13 ^{c}	13.74±1.25 ^{a}	14.72±0.57 ^{b}
LSD	1.93	2.07	2.59
	Unpeeled dry sample		
Apple banana	77.64±12.61 ^{a}	10.17±5.71 ^{a}	17.12±7.54 ^{a}
Gros Michel AAA	68.49±1.57 ^{a}	11.98±4.94 ^{a}	17.22±4.92 ^{a}
Kiganda AAA	65.64±1.73 ^{a}	15.25±2.57 ^{a}	16.81±1.80 ^{a}
Muraru AAA	70.18±15.18 ^{a}	9.02±3.03 ^{a}	20.16±7.54 ^{a}
LSD	-	-	-

Mean values with different superscripts in the same column for each treatment (peeled or un-peeled) are significantly different ($p < 0.05$; one-way ANOVA, LSD post hoc test).

Color changes in banana slices during drying

The results for color measurements for both fresh and dried banana slices dried under solar, biomass, solar-biomass and open sun are presented in Tables 1 to 4, respectively. The results obtained shows that the values of L^* and b^* for the dried slices were lower than those for fresh ones for all the drying methods considered. On the other hand, the values of a^* for dried slices were higher than those for fresh slices for all banana varieties and for each drying method used. Further, it was observed that the peeled samples were lighter that corresponding unpeeled samples as they had higher values of L^* and b^* and lower values of a^*. Additionally, the final product had a darker color compared to corresponding fresh product. The change in color was attributed to enzymatic browning as a result of differences in phenolic compounds (Amankwah *et al*., 2019), which are associated with oxidative browning of the banana slices. Barroca and Guiné (2013) made similar observations while drying two banana varieties namely *Musa nana and Musa cavendishii* in a convective dryer. The peel pigment present in the unpeeled samples resulted into more darkened samples as compared to peeled samples.

Table 2: Color parameters for both fresh and dried banana slices for biomass mode

Banana variety	L^*	a^*	b^*
	Peeled fresh sample		
Apple banana	86.53±1.41 [b]	8.05±1.42 [a]	24.06±0.00 [a]
Gros Michel AAA	89.67±0.00 [a]	7.49±1.63 [a]	21.45±1.30 [b]
Kiganda AAA	89.47±1.20 [a]	7.16±0.76 [a]	25.42±1.27 [a]
Muraru AAA	90.12±1.61 [a]	6.53±1.51 [a]	21.84±0.42 [b]
LSD	2.61	-	1.74
	Unpeeled fresh sample		
Apple banana	70.87±24.32 [a]	0.34±6.50 [a]	28.68±11.94 [a]
Gros Michel AAA	73.69±17.47 [a]	0.47±6.87 [a]	25.56±8.30 [a]
Kiganda AAA	75.59±22.49 [a]	0.56±4.14 [a]	22.60±0.75 [a]
Muraru AAA	70.31±22.14 [a]	0.48±8.23 [a]	29.70±6.22 [a]
LSD	-	-	-
	Peeled dry sample		
Apple banana	82.12±1.10 [a]	8.64±0.45 [a]	16.05±2.83 [b]
Gros Michel AAA	86.54±2.55 [a]	9.22±0.62 [a]	19.61±1.55 [ab]
Kiganda AAA	84.82±3.13 [a]	8.23±1.41 [a]	23.93±1.42 [a]
Muraru AAA	86.59±1.56 [a]	8.46±0.00 [a]	20.38±2.93 [a]
LSD	-	-	4.88
	Unpeeled dry sample		
Apple banana	65.64±22.85 [a]	0.88±8.21 [a]	26.13±10.49 [a]
Gros Michel AAA	62.15±35.36 [a]	2.09±3.90 [a]	18.11±8.34 [a]
Kiganda AAA	64.03±35.50 [a]	2.71±4.36 [a]	17.49±1.27 [a]
Muraru AAA	62.65±25.67 [a]	2.23±7.81 [a]	21.36±5.06 [a]
LSD	-	-	-

Mean values with different superscripts in the same column for each treatment (peeled or un-peeled) are significantly different ($p < 0.05$; one-way ANOVA, LSD post hoc test).

Table 3: Color parameters for both fresh and dried banana slices for solar-biomass mode

Banana variety	*L**	*a**	*b**
	Peeled fresh sample		
Apple banana	82.30±1.41 [a]	-0.88±1.56 [b]	19.69±1.70 [c]
Gros Michel AAA	78.40±0.95 [b]	1.10±0.58 [a]	30.50±1.42 [a]
Kiganda AAA	83.80±0.00 [a]	-4.40±0.76 [c]	26.90±2.36 [b]
Muraru AAA	83.50±1.50 [a]	-2.20±0.31 [b]	22.40±0.00 [c]
LSD	2.05	1.65	2.82
	Unpeeled fresh sample		
Apple banana	76.70±4.10 [ab]	1.05±1.34 [a]	24.80±0.28 [a]
Gros Michel AAA	74.75±0.35 [b]	0.80±0.99 [a]	28.90±1.98 [a]
Kiganda AAA	80.00±1.41 [a]	-2.65±0.21 [b]	26.10±7.64 [a]
Muraru AAA	80.95±1.77 [a]	-1.70±0.28 [b]	24.65±0.49 [a]
LSD	5.52	1.56	-
	Peeled dry sample		
Apple banana	75.60±1.41 [b]	0.30±0.10 [ab]	17.10±0.14 [b]
Gros Michel AAA	66.20±0.00 [c]	2.20±1.44 [a]	16.80±0.32 [b]
Kiganda AAA	64.20±0.14 [d]	0.10±1.54 [ab]	21.00±1.12 [a]
Muraru AAA	83.10±1.13 [a]	-1.10±0.00 [b]	16.50±0.06 [b]
LSD	1.50	2.48	1.00
	Unpeeled dry sample		
Apple banana	77.40±0.07 [a]	1.05±0.64 [a]	17.75±1.48 [a]
Gros Michel AAA	66.55±1.34 [b]	1.05±0.35 [a]	16.65±0.07 [a]
Kiganda AAA	61.05±0.49 [c]	1.80±0.85 [a]	18.10±0.14 [a]
Muraru AAA	76.15±2.62 [a]	0.95±1.20 [a]	16.45±0.49 [a]
LSD	2.49	-	-

Mean values with different superscripts in the same column for each treatment (peeled or un-peeled) are significantly different ($p < 0.05$; one-way ANOVA, LSD post hoc test).

The total color difference was found to be in the range of 7.04±0.29 to 24.27±2.52, 4.86±0.93 to 16.53±12.81, 6.02±0.02 to 21.71±2.28 and 22.06±2.44 to 39.14±7.63, for solar, biomass, solar-biomass and open sun dried banana slices, respectively (Table 5). The results of a one-way ANOVA confirmed that there was significant difference between the color change of all peeled banana slices dried using solar, biomass, solar-biomass and open sun drying ($p<0.05$). However, there was no significant difference between the color change of unpeeled Gros Michel AAA and Kiganda AAA slices dried using solar, biomass, solar-biomass and open sun drying ($p<0.05$). Open sun drying resulted in the highest color change as compared to other three drying methods. Amankwah *et al.* (2019) made similar observation while comparing color change of yam dried under open sun, solar cabinet dryer and solar adsorption dryer and attributed the color change to enzymatic browning as earlier cited.

Firmness

The firmness of the banana slices before and after drying using different drying methods are presented in Figure 2. The percentage increase in firmness was found to be in the range of 151.28±56.04% to 317.50±8.92%, 98.08±14.96% to 153.19±60.54%, 91.30±61.49% to 233.33±26.07% and 125.64±36.26% to 262.50±12.62% for solar, biomass, solar-biomass and open sun dried banana slices, respectively (Table 6). Results obtained shows that the firmness of the banana slices increased after drying for all the treatments. The increase in firmness was attributed to increased dry matter in the sample due to moisture removal which caused collapse of structure. Drying of agricultural products have exhibited similar behavior. Rodriguez *et al*. (2019) observed that dried raspberries had higher firmness as compared to fresh raspberries.

Table 4: Color parameters for both fresh and dried banana slices for open sun

Banana variety	L^*	a^*	b^*
Peeled fresh sample			
Apple banana	87.22±0.03 [a]	4.57±0.30 [c]	25.75±3.79 [a]
Gros Michel AAA	78.63±0.54 [b]	8.24±0.13 [a]	30.56±1.41 [a]
Kiganda AAA	86.16±4.40 [a]	6.76±0.68 [b]	29.63±1.34 [a]
Muraru AAA	88.16±1.03 [a]	3.28±1.11 [d]	25.42±1.98 [a]
LSD	4.30	1.15	-
Unpeeled fresh sample			
Apple banana	83.21±7.73 [a]	0.35±3.05 [a]	23.10±10.80 [a]
Gros Michel AAA	76.95±0.71 [a]	0.60±7.64 [a]	28.15±1.85 [a]
Kiganda AAA	66.39±23.49 [a]	2.25±8.56 [a]	30.03±4.68 [a]
Muraru AAA	75.80±18.35 [a]	-0.48±4.60 [a]	25.65±1.97 [a]
LSD	-	-	-
Peeled dry sample			
Apple banana	68.20±2.08 [a]	35.88±7.44 [a]	12.05±1.17 [b]
Gros Michel AAA	70.15±0.11 [a]	15.58±0.40 [b]	11.60±1.44 [b]
Kiganda AAA	71.67±6.04 [a]	16.62±1.46 [b]	13.25±1.68 [b]
Muraru AAA	71.93±0.90 [a]	18.55±1.78 [b]	17.90±1.53 [a]
LSD	-	6.94	2.73
Unpeeled dry sample			
Apple banana	65.45±6.83 [a]	25.63±11.16 [a]	12.87±1.54 [a]
Gros Michel AAA	64.19±0.31 [a]	15.18±10.70 [a]	13.46±2.43 [a]
Kiganda AAA	60.54±1.61 [a]	18.40±1.58 [a]	15.40±0.96 [a]
Muraru AAA	64.68±6.13 [a]	18.48±0.57 [a]	15.36±3.01 [a]
LSD	-	-	-

Mean values with different superscripts in the same column for each treatment (peeled or un-peeled) are significantly different ($p < 0.05$; one-way ANOVA, LSD post hoc test).

Vitamin C Content

The amount of Vitamin C before and after drying the banana slices under different drying methods are presented in Figure 3 whereas values of the percentage retention of vitamin C for dried banana slices are presented in Table 7. The amount of vitamin C content at initial varied from variety to variety with average of 53.25, 38.92, 38.39 and 38.27 mg/100g for Apple banana, Kiganda AAA, Gros Michel AAA, and Muraru AAA, respectively. These amounts reduced to 43.18, 33.11, 34.27, and 35.50 mg/100g after drying, respectively. The percentage retention was found to be in the range of 72.44±3.96% to 85.87±2.64%, 69.23±14.14% to 86.90±2.84%, 63.85±3.19% to 87.19±13.97%, and 62.32±4.82% to 77.14±6.38% for solar, biomass, solar-biomass, and open sun drying respectively. Further, it was noted that the amount of vitamin C for fresh and dried sample varied for the different banana cultivars. Peeled samples had higher vitamin C content as compared to unpeeled samples. Vitamin C is usually destroyed by various factors such as exposure of product to oxygen, light, temperature and relative humidity (Şahin *et al*., 2010). Ndayambaje *et al.* (2019) reported percentage retention of vitamin C of 74.54% for unripe sun-dried plantain (*Musa paradisiaca*). In addition, the reduction in vitamin C has been observed by Amankwah *et al*. (2019) and Şahin *et al.* (2010). Hapsari and Lestari (2016) reported different vitamin C content for four

Indonesian banana cultivars with an average of 22.84 mg/100 g edible portion. The amount of vitamin C present is as a result of interaction between genetic and growing environment. However, though unpeeled samples had lower vitamin C, they contain higher amounts of non-digestible fraction due to amount of fiber in the peel which improves digestion (Bezerra *et al.,* 2013).

Table 5: Total color difference (ΔE^*) of banana slices dried under different drying methods

Banana variety	Total color difference (ΔE^*) for each drying method				
	Solar mode	Biomass mode	Solar-biomass mode	Open sun	LSD
			Peeled		
Apple banana	7.04±0.29 [b]	9.26±2.36 [b]	7.48±0.37 [b]	39.14±7.63 [a]	6.80
Gros Michel AAA	19.00±0.10 [b]	4.86±0.93 [c]	18.39±1.98 [b]	22.06±2.44 [a]	2.76
Kiganda AAA	16.91±0.91 [c]	5.03±1.89 [d]	21.16±0.61 [b]	25.13±3.21 [a]	3.25
Muraru AAA	16.65±2.00 [b]	4.88±1.56 [c]	6.02±0.02 [c]	23.58±4.32 [a]	4.28
			Unpeeled		
Apple banana	11.84±8.45 [b]	6.12±0.80 [b]	7.63±1.51 [b]	33.43±13.10 [a]	15.84
Gros Michel AAA	19.49±2.56 [a]	16.53±12.81 [a]	14.83±1.05 [a]	27.28±7.01 [a]	-
Kiganda AAA	24.27±2.52 [a]	13.67±11.16 [a]	21.71±2.28 [a]	28.54±1.64 [a]	-
Muraru AAA	14.03±1.33 [b]	11.53±3.25 [bc]	9.87±1.48 [c]	26.15±0.31 [a]	3.25

Mean values within rows with different superscripts are significantly different ($p < 0.05$; one-way ANOVA, LSD post hoc test).

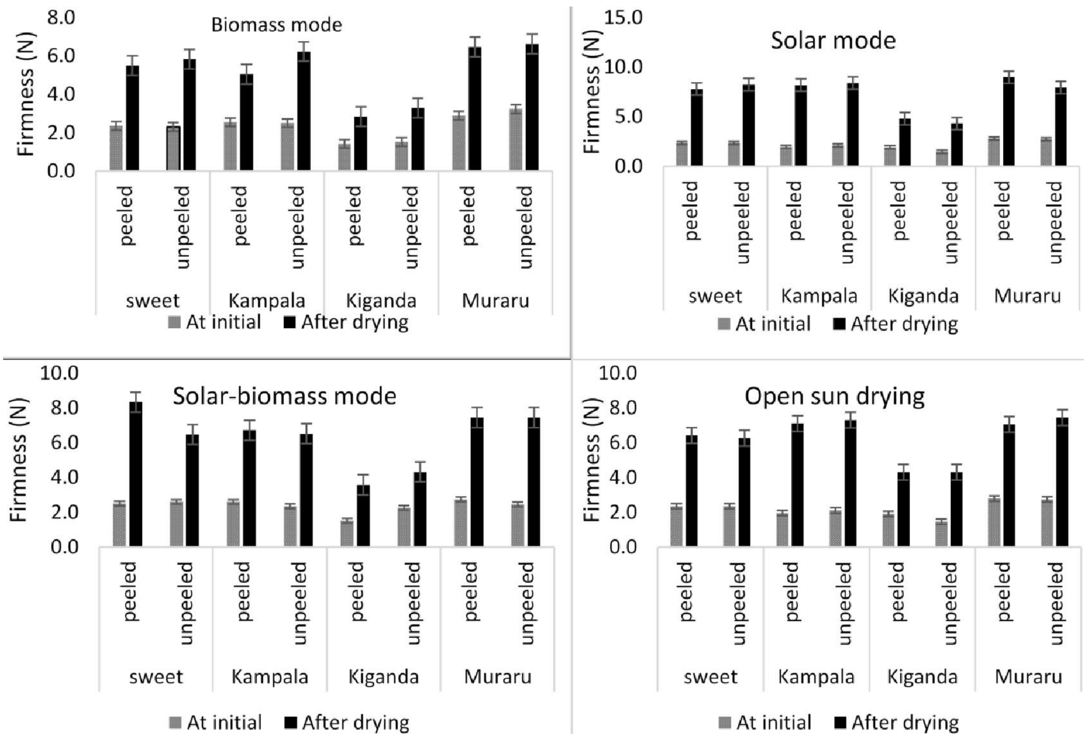

Figure 2: Comparison of banana slice firmness before and after drying under different drying methods.

Table 6: Percentage increase in firmness of banana slices dried under different drying methods

Banana variety	Increase in firmness (%) for each drying method				
	Solar mode	Biomass mode	Solar-biomass mode	Open sun	LSD
			Peeled		
Apple banana	231.25±61.87 ^{ab}	133.33±18.13 ^{c}	233.33±26.07 ^{a}	172.92±23.26 ^{abc}	86.17
Gros Michel AAA	317.50±8.92 ^{a}	98.08±14.96 ^{d}	158.49±22.89 ^{c}	262.50±12.62 ^{b}	26.07
Kiganda AAA	151.28±56.04 ^{a}	100.00±37.71 ^{a}	135.48±33.01 ^{a}	125.64±36.26 ^{a}	-
Muraru AAA	221.05±48.01 ^{a}	123.73±29.00 ^{b}	171.43±21.49 ^{ab}	152.63±9.15 ^{b}	64.71
			Unpeeled		
Apple banana	250.00±58.93 ^{a}	153.19±60.54 ^{a}	149.06±28.97 ^{a}	166.67±58.93 ^{a}	-
Gros Michel AAA	297.67±3.30 ^{a}	149.01±23.27 ^{c}	177.08±35.36 ^{c}	246.51±27.27 ^{b}	44.38
Kiganda AAA	193.33±34.75 ^{a}	116.13±10.46 ^{ab}	91.30±61.49 ^{b}	193.33±39.74 ^{a}	96.01
Muraru AAA	189.29±12.06 ^{a}	104.55±25.54 ^{b}	204.00±0.24 ^{a}	171.43±58.59 ^{ab}	69.27

Mean values within rows with different superscripts are significantly different ($p<0.05$; one-way ANOVA, LSD post hoc test).

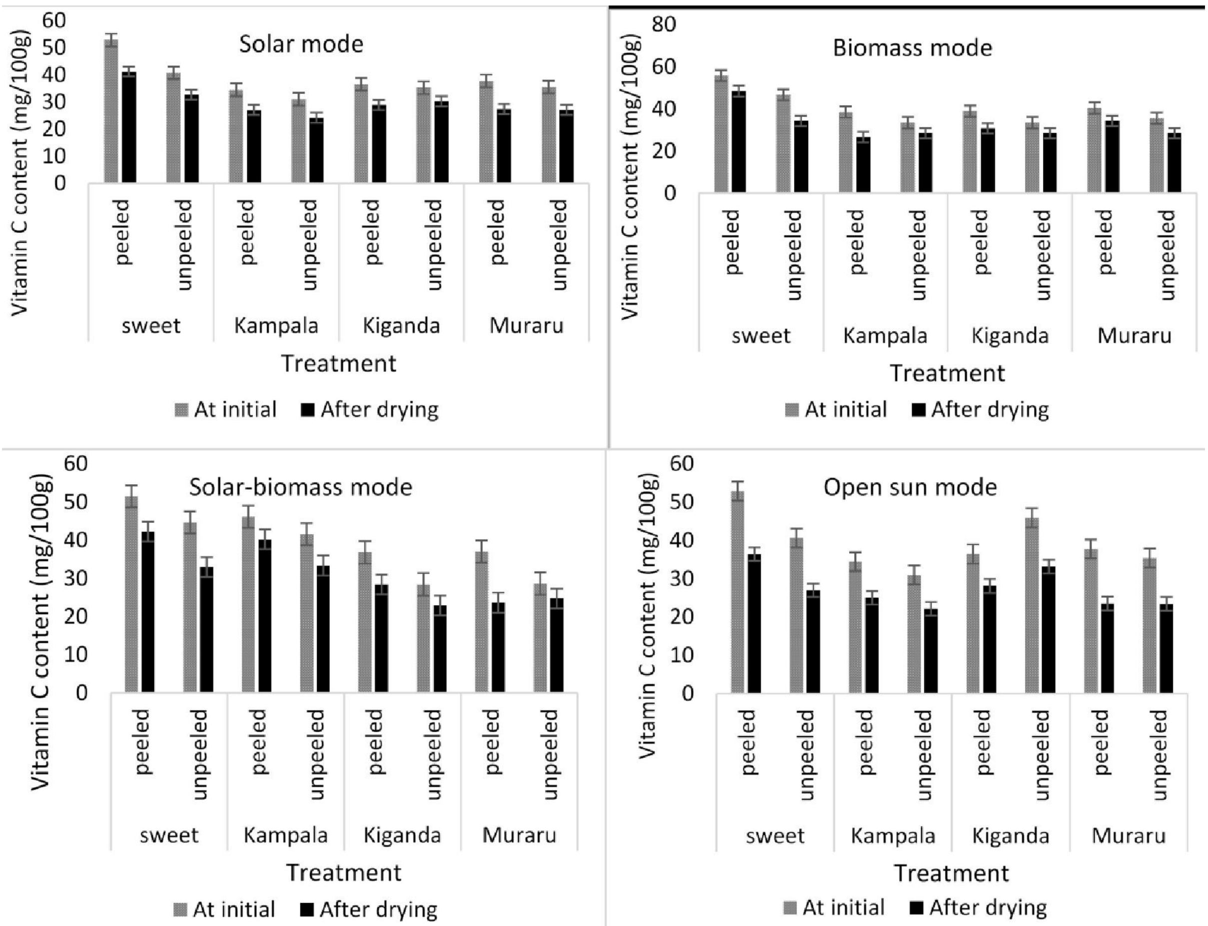

Figure 3: Comparison of vitamin C content before and after drying under different drying methods.

Table 7: Percentage retention of vitamin C for banana slices dried under different drying methods

Banana variety	Retention of vitamin C (%) for each drying method				
	Solar mode	Biomass mode	Solar-biomass mode	Open sun	LSD
			Peeled		
Apple banana	77.84±11.88 [ab]	86.90±2.84 [a]	82.08±7.85 [a]	68.86±7.14 [b]	15.52
Gros Michel AAA	78.40±1.96 [a]	69.23±14.14 [a]	87.19±13.97 [a]	72.60±1.48 [a]	-
Kiganda AAA	79.19±8.41 [a]	79.20±5.96 [a]	77.10±7.32 [a]	77.14±6.38 [a]	-
Muraru AAA	72.44±3.96 [b]	84.98±4.14 [a]	63.85±3.19 [c]	62.32±4.82 [c]	5.43
			Unpeeled		
Apple banana	80.30±10.41 [a]	73.44±5.27 [a]	73.74±1.27 [a]	66.38±14.78 [a]	-
Gros Michel AAA	77.89±7.13 [a]	85.19±11.18 [a]	80.19±5.92 [a]	71.43±7.49 [a]	-
Kiganda AAA	85.87±2.64 [a]	85.19±4.12 [a]	80.53±16.31 [a]	72.36±2.53 [a]	-
Muraru AAA	76.53±6.06 [ab]	80.02±2.32 [a]	86.33±3.46 [a]	66.07±10.52 [b]	10.59

Mean values within rows with different superscripts are significantly different ($p<0.05$; one-way ANOVA, LSD post hoc test).

Conclusions

Effects of different drying methods on color, firmness and vitamin C of banana slices of four cultivars were evaluated in this study. Regardless of the drying method, the results obtained showed that the dried products were darker, firmer and had lower vitamin C content compared to those of corresponding fresh products. Apple banana had the best color retention, highest vitamin C content before and after drying and equally higher values of firmness. Drying banana slices in the solar-biomass hybrid greenhouse dryer resulted in better conservation of color and vitamin C as compared to open sun drying. Overall, drying of products in the hybrid greenhouse dryer has advantages of continuous drying despite changes in weather and time as well as protecting the product from contamination.

Recommendation

Further research should be carried out on other quality attributes such as aroma, taste, rehydration properties and acceptability of dried banana slices in the market. Banana slices should be dried in a protected environment such as greenhouse dryer to reduce contamination and help conserve their quality attributes.

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