European Journal of Agriculture and Food Sciences
www.ejfood.org

Effects of Slice Thickness and Pre-Treatment Concentration on the Quality Characteristics of Solar Dried Pineapple

Musoke Yekoyada, Julia Kigozi, Agnes Nabubuya, and Paddy Ainebyona

ABSTRACT

The overall goal of this study was to determine the quality changes (vitamin C retention, browning, rehydration ratio) that occur during solar drying of pineapple as influenced by different processing conditions (slice thickness and pre-treatment concentration). Pineapple fruits were sliced to varying thicknesses (5 and 10 mm), pre-treated at different concentrations of citric acid (2, 5, and 10 g/l), and dried for 2 days in a Hohenheim model type solar tunnel dryer until a safe moisture level about ≤15% was reached. Samples were analyzed for changes in quality characteristics using standard AOAC methods. Dried pineapple slices were found to differ significantly in terms of browning scores and vitamin C retention (p≤0.05) while no differences were observed in the rehydration ratio (p>0.05). Slice thickness and pre-treatment concentration were observed to have a significant interaction effect on the browning score/index of pineapple slices during drying (p≤0.05). Overall vitamin C concentration increased for samples during the drying process with the maximum vitamin C concentration being 36.85 mg/100 g recorded in 5mm thickness samples pre-treated with 5% citric acid solution. Maximum vitamin C retention was recorded in samples sliced to 5mm thickness and pre-treated with 5 g/l citric acid solution (15.68) while minimum vitamin C retention (2.41) was recorded in 5mm slices treated with a 10 g/l citric acid solution. Rehydration ratio ranged from 1.60 to 2.53. There was no significant difference between the rehydration ratio between the different treatments at P≤0.05. The lowest browning index was observed in samples sliced to 10 mm thickness and treated at 5 g/l while the highest browning index was observed in samples sliced to 5mm and treated at 5 g/l of citric acid. The best-optimized conditions obtained for the given criteria were 5 mm slice thickness and 2 g/l pre-treatment concentration based on a maximum desirability of 0.639. For the optimized combination of drying parameters, the vitamin C content, the rehydration ratio, and the browning were 9.14, 2.43 and 0.47, respectively.

Keywords: Browning, Pineapple, Rehydration Ratio, Solar Drying.

Submitted : January 29, 2022
Published : August 24, 2023
ISSN: 2684-1827
DOI: 10.24018/ejfood.2023.5.4.454

M. Yekoyada
Department of Food Technology and Nutrition Makerere University, Uganda.
(e-mail: yemusoke@gmail.com)
J. Kigozi*
Department of Agricultural and Bio Systems Engineering Makerere University, Uganda.
(e-mail: jbulyakigozi@yahoo.com)
A. Nabubuya
Department of Food Technology and Nutrition Makerere University, Uganda.
(e-mail: agnesnabubuya@yahoo.co.uk.)
P. Ainebyona
Department of Agricultural and Bio Systems Engineering Makerere University, Uganda.
(e-mail: paddyainebyona@gmail.com)

****Corresponding Author***

I. INTRODUCTION

Pineapple drying demands special attention for retention of the nutritional aspects of the subsequent product. Typically, most fruits or any agriculture products can be dried for the purpose of preservation using different drying technologies [1]. Drying however, has an impact on the structure of fruits, which in turn influences quality attributes (sensory and other physico-chemical) of the final product. The most common changes include browning reactions, lipid oxidation, color losses; loss of rehydration abilities, loss of texture; and nutritional losses such as vitamin C degradation [2]-[4]. Good understanding of the drying processes therefore plays a vital role in increasing the drying efficiency as well as in maintaining product quality [5]. Solar drying is one of the most common technologies employed in the preservation and processing of fruits such as pineapple in Uganda [6]. The history of its application can be traced back to the 1980's when pineapple and banana farmers adopted it to add value to their produce [7]. The technology, however, results into inferior quality products and a large proportion of rejects after drying [7]. The manipulation of processing conditions and application of pre-treatments has gained much attention in the retention of quality characteristics of solar dried products over the past years [8]. Pre-treatment prior to drying is usually carried out to preserve the nutrients and to enhance the product quality in terms of appearance and taste and to improve process efficiency by shortening drying time [5], [8], [9]. Pretreatments serve to minimize the adverse changes that occur during drying and subsequent storage [2]. Some of the main pre-treatments that are commonly applied during drying include blanching, acid dips and sulphiting [8]. Pre-treatment followed by solar drying may provide a practical method for preservation of pineapples during bumper harvest seasons in rural areas where energy intensive technologies are not easily accessed [9]. Since pre-treatments are common in most drying processes to improve or retain product quality or process efficiency, this study was carried out investigate product quality of pre-treated solar dried pineapple slices in terms of vitamin C retention, rehydration ratio and the browning score (index). This research is a significant resource to producers of solar dried pineapple.

II. Materials and Methods

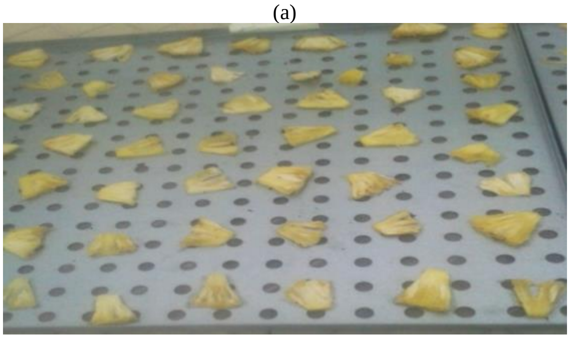
A. Sample Collection and Preparation

Pineapple samples of the Smooth Cayenne cultivar for this study were purchased at the local fruit market in Gayaza town, Wakiso District, Uganda. The fruits were washed, peeled, cored, and roughly sized into quarter slices of different thicknesses (5 and 10 mm) with the help of Vernier calipers. The pineapple slices were pre-treated at different concentrations of citric acid (CA) solution (2, 5, and 10 g/l) for 1 hour, rinsed in potable water for 5 minutes and drained. The slices were then loaded onto the drying trays in a single layer before loading in the dryer.

B. Dryer Setup and Drying Conditions

The pineapple slices were dried in a *Hohenheim* model type tunnel solar dryer located at MUARIK for 2 days until safe moisture levels were reached. The drier measures about 18m long and 2 m wide (Fig. 1 (a)). The drier has two components i.e., the collector area of about 16 m^2 and a drying area of about 20 m^2. The drier has a loading capacity of about 200-500 kg of fresh produce with a temperature range of 30-80 °C and a convective airflow velocity of about 400-1200 m^3/h delivered by two fans powered by an 85 W photovoltaic solar panel. The drier was loaded with about 5 kg of fresh produce laid properly on porous metallic trays (Fig. 1 (b)) for each experiment and after drying; the samples were packed in high-density polyethylene bags and kept at room temperature for further quality analysis.

(a)



(b)

Fig. 1. A section of the Hohenheim model solar drier at MUARIK (a) and Pineapple slices during drying (b).

C. Experimental Design

The study adopted a completely randomized factorial experimental design where slice thickness at two levels (5 and 10 mm) and a pre-treatment concentration of citric acid at three levels (2, 5 and 10 g/l) were the selected quantitative factors

D. Evaluation of Vitamin C Changes and Retention during Drying of Quality Dried Pineapple

Ascorbic acid content was evaluated using the 2,6-dichloroindophenol titrimetric method (AOAC Method 967.21) according to [10]. Five (5) grams of the samples were accurately weighed and ground using mortar and pestle with an additional of 20 ml of metaphosphoric acid-acetic acid solution. The mixture was further ground and strained through muslin and the extract made up to 50 ml with the metaphosphoric-acetic acid mixture. About 10 ml of the metaphosphoric acid-acetic acid solution was pipetted into three of the 50 ml Erlenmeyer flasks followed by 2 ml of the samples extract. The samples were titrated separately with the indophenol dye solution until a light rose pink persisted for 5seconds. The amount of dye used in the titration was determined and used in the calculation of vitamin C content using (1) below.

$$\text{Vit. C (mg/100g)} = \frac{(0.0189 \times T \times P \times 100)}{(V \times W)} \quad (1)$$

where T is the net titer value, P is the total volume made-up, and V is the volume pipetted and W is the sample weight

The vitamin C retention was expressed as C/C_o [3], where C = mg of ascorbic acid per g of dry solid (mg/g of dry matter) and C_o =mg of ascorbic acid per g of solid prior to drying (mg/g of dry matter)

E. Evaluation of Rehydration Ratio Changes during Drying of Quality Dried Pineapple

The rehydration ratio was evaluated according to methods by [20]. Twenty (20) grams of pre-treated dried pineapple samples were weighed out, placed in 500 ml of water, and boiled 80±5ºC for 15 minutes. The excess water was poured and the wet pineapple samples blotted using filter paper. The weight of the samples after rehydration was measured and recorded. The rehydration ratio was then calculated according to (2).

$$\text{R.R} = \frac{\text{weight of sample after rehydration (in g)}}{\text{weight of sample before rehydration (in g)}} \quad (2)$$

F. Evaluation of Browning Levels during Drying of Quality Dried Pineapple

The browning compounds formed during drying in the study by enzymatic browning were evaluated according to methods suggested by [11]. The extract was prepared by soaking 10 g of dried sample for a period of 12 hours in a solution containing 60% ethanol v/v. The samples were then filtered using filter paper to obtain a clear extract. Absorbance of the filtrate was then measured using a Spectroquant Pharo-300M, EU model type UV-spectrophotometer at a frequency of 420 nm. Results were then recorded as absorbance and the browning index expressed as the optical density (OD 420).

G. Statistical Analysis

The data was collated, coded, and analyzed using SPSS version 23.0 software. A two-way Analysis of Variance (ANOVA) at a p-level≤0.05 was used to analyze for interaction between the two factors (slice thickness and pre-treatment concentration) on the quality of solar dried pineapple. Response surface methodology was used to obtain surface regression models for each measured response as a function of slice thickness and pre-treatment concentration. The multi-level categorical factorial design was selected for use in this study with actual values used presented in Table I. below. The three key responses rehydration ratio; browning and vitamin C retention were monitored during the experiment. The two factors of the design, slice thickness and pre-treatment concentration of citric acid, were coded as x and y, respectively. The equation below shows the quadratic polynomial model that was fitted to each response, where b0, b1, b2, b11, b12 and b22 are the regression coefficients; x and y are the values of the factors slice thickness and pre-treatment concentration of citric acid, respectively:

$$Z = b_0 + b_1x + b_2y + b_{11}x^2 + b_{22}y^2 + b_{12}xy \qquad (3)$$

The analysis of variance (ANOVA) tables was generated and regression coefficients of individual linear, quadratic and interaction terms were determined by using design expert software 11.0. The significances (p≤0.05) of all terms in the polynomial model were judged statistically by computing the F-value

TABLE I: THE EXPERIMENTAL AND ACTUAL LEVELS OF THE VARIABLE PARAMETERS IN THE DRYING STUDY

Factor	Symbol	Actual levels		
		Low	Intermediate	High
Slice thickness (mm)	ST	5	-	10
Pre-treatment concentration (g/l)	PTC	2	5	10

III. RESULTS AND DISCUSSION

The influence of slice thickness and pretreatment concentration on the color, rehydration ratio and Vitamin C retention of solar dried pineapple is presented in Table II. Browning values ranged from 0.27 to 1.08. Rehydration ratio ranged from 1.6 to 2.5. Vitamin C retention ranged from 2.37 to 15.71. Vitamin C retention and Browning index values were found to be significantly different at p<0.05. Rehydration ratio on the other hand was found not significantly differ amongst all the treatments. Browning was reported to be significantly influenced by slice thickness and the interaction between slice thickness and pretreatment concentration (Table III). Vitamin C retention was significantly influenced by slice thickness, pretreatment concentration and the interaction between slice thickness and pretreatment concentration (Table III).

TABLE II: EFFECT OF DIFFERENT PROCESSING PARAMETERS ON THE FINAL QUALITY OF SOLAR DRIED PINEAPPLE

ST (mm)	PTC (g/l)	Browning Index (OD_{420nm})	Rehydration Ratio	Vitamin C Retention
5	2	0.47 ± 0.00^a	2.43 ± 0.38^a	9.14 ± 1.59^c
	5	1.08 ± 0.00^b	2.53 ± 0.21^a	15.71 ± 0.68^d
	10	0.57 ± 0.00^a	1.60 ± 1.47^a	11.90 ± 1.77^c
10	2	0.49 ± 0.00^a	2.20 ± 0.09^a	2.37 ± 0.82^a
	5	0.27 ± 0.00^a	1.90 ± 0.17^a	2.54 ± 0.52^a
	10	$0.62 \pm 0.00^{a,b}$	2.33 ± 0.15^a	5.99 ± 0.44^b

*Means of parameters in the same column having different superscripts are significantly different at *p*<0.05.

TABLE III: ANOVA SUMMARY TABLE FOR QUALITY CHANGES DURING SOLAR DRYING OF PINEAPPLE

Source of variation	Browning Index	Rehydration Ratio	Vitamin C Retention
Slice thickness (A)	9.62±0.01 **	0.02±0.88*	274.97±0.00**
Pre-treatment concentration (B)	1.95±0.18 *	0.48±0.63*	17.74±0.00**
A × B	12.91±0.00 **	1.84±0.20*	19.49±0.00**

*Not significant at *p*<0.05, **Significant at *p*<0.05.

A. Vitamin C Retention during Solar Drying of Pre-Treated Pineapple

Maximum Vitamin C retention (15.71) was recorded in 5 mm thick and 5 g/l CA treated samples while minimum vitamin C retention (2.54) was recorded in 5mm thick and 10 g/l CA treated samples (see Table II). Vitamin C levels at all levels of the citric acid pre-treatment concentration were relatively higher in samples of slice thickness 5 mm than for all 10 mm samples (Fig. 3). Ascorbic acid is a water-soluble vitamin, which is lost during cutting of pineapple fruit in preparation for drying and further during drying [12]. The stability of vitamin C is dependent on a number of factors that include oxygen, pH, temperature, presence of metallic ions among many others. Vitamin C stability is largely affected by oxidation reactions and as such the application of anti-oxidant pre-treatments during fruit processing has been reported to hinder these deteriorative reactions [13]. As the ascorbic acid is highly sensitive towards high temperatures and rapidly degrades in the presence of heat, the samples with more thickness need a longer drying time and are more exposed to heat as compared to the samples with less thickness and as such, they do not retain maximum ascorbic acid as observed in this study. Vitamin C being water-soluble also implies that thinner slices contain less water and as such are more likely to lose less vitamin C as compared to thicker slices that contain more water.

Similarly, [14], attributed the increase in vitamin C content to the concentration effect brought about by moisture evaporation during the drying process. The study by [15], investigated effects of sample thickness on vitamin C retention in solar dried okra. Results from the study revealed that slice thickness directly had no effect on the vitamin C retention in dried samples of okra. However, this variable affected the drying time and consequently the vitamin C retention in dried samples. According to findings by [16], pretreated samples dried faster than the control samples, thus confirming the fact that pretreatment reduces the resistance to the movement of moisture, thereby increasing the drying rate. According to [17], the retention of vitamin C is not only dependent on the kind of product but also on the drying procedure. To improve vitamin C retention, several authors have studied a number of pre-treatments in fruit processing. The effect of citric acid pre-treatment was studied in straw berry [18] and sweet potato chips [19] processing. Findings revealed that in both studies citric acid dipping before processing enhanced the retention of ascorbic acid in subsequent products, which is consistent with observations from this study.

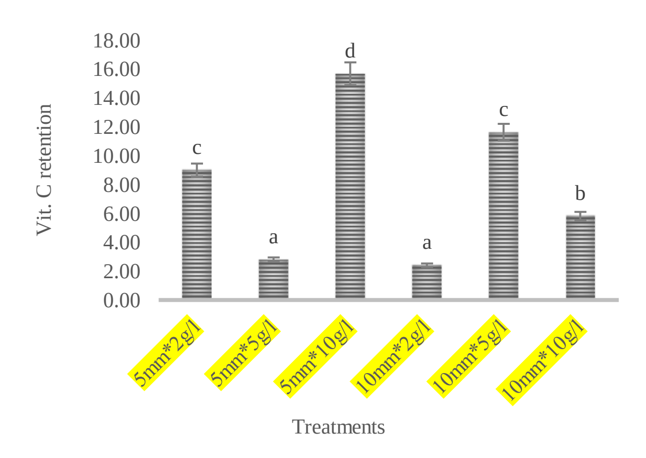


Fig. 3. Vitamin C Retention in Solar Dried Pineapple Slices
Different letters represent significant differences in vitamin C retention of solar dried pineapple slices ($p \leq 0.05$).

B. *Rehydration Ratio of Dried Slices*

The rehydration ratio in this study ranged from 1.60 to 2.53 (see Table II). There were no significant differences in the rehydration ratios of pineapple slices of varying thicknesses treated with different concentrations of citric acid $p>0.05$ (see figure 4). Slice thickness ($p = 0.88$) and pre-treatment concentration ($p = 0.63$) were found not to have a significant effect on the rehydration ratio of dried pineapple slices i.e., $p>0.05$. There was no significant interaction effect of slice thickness and pre-treatment concentration on the rehydration ratio of solar dried pineapple slices ($p = 0.20$). However, the rehydration ratio was much lower than that reported for solar dried pineapple in earlier studies by [2], 3.6 for non-treated tunnel solar dried pineapple samples. This is possible because acidic pre-treatments have been cited as having the ability to promote tissue softening and collapse of the internal cellular structure which in turn might decrease the rehydration capacity of the pre-treated solar dried pineapple snacks [20]. According to [2], the solar tunnel dryer provides for higher drying rates and as such does not allow for the internal cellular structure of the product to collapse before it dries up. This allows for formation of a more porous structure and retention of inherent hydrophilic properties, hence the high capacity to imbibe water. Rehydration ratio is a widely used quality index for dried products. rehydration values provide information about the changes in physical and chemical properties of a dried sample attributed to drying and treatments preceding dehydration [21]. The effect of pre-treatment and slice thickness on rehydration ratio has been studied in a number of fruits; tomato [16], Jerusalem artichokes [21], carrots [22], Banana [23] among many others. Pre-treatment was found to improve rehydration characteristics of tomato and Jerusalem artichoke and it was also observed that the rehydration ratio was higher in pretreated tomato slices than in other samples [16]. In a study involving the drying of onions on the other hand, rehydration efficiency was found to be higher at a lower thickness [24]. This can be explained by the fact that thin slices take a shorter drying time and therefore degree of shrinkage is minimal which agrees with findings from this study [21].

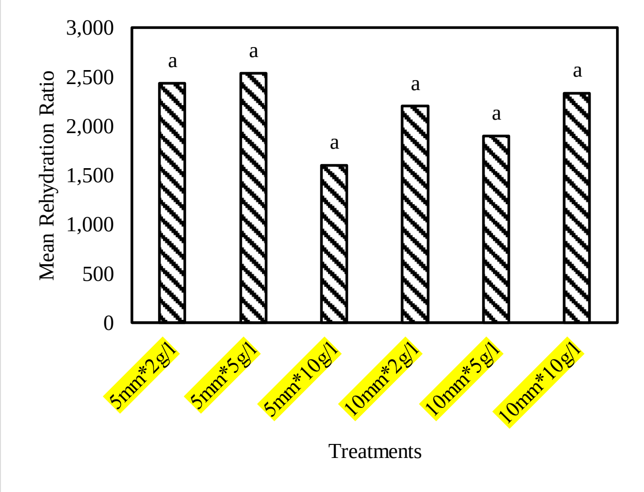


Fig. 4. Mean rehydration values of pre-treated solar dried pineapple slices. Different letters represent significant differences in browning levels of solar dried pineapple slices ($p \leq 0.05$).

C. *Browning Index of Solar Dried Samples*

The browning index expressed as optical density (OD at 420nm) in this study ranged from 0.27 to 1.09nm (Table II). 5 mm pineapple sample slices treated with a 5 g/l citric acid solution had the highest browning index of 1.08 nm while the 10 mm pineapple sample slices treated with a 5 g/l citric acid solution expressed the lowest absorbance values 0.27 nm (Fig. 5). Significant differences were observed in the browning scores/index of pineapple slices of varying thicknesses treated with different concentrations of citric acid (Table II) slice thickness ($p = 0.01$) had a significant effect on the browning index while pre-treatment concentration ($p = 0.18$) did not have a significant effect on the browning index of pineapple slices during drying (Table III). Both slice thickness and pre-treatment concentration had a significant interaction effect on the browning score/index of pineapple slices during drying ($p \leq 0.05$). Pineapple colour is a decisive factor used for forming maturity indices and acceptability of the final product. Browning reactions mainly due to enzymatic browning, maillard reactions, caramelization and pigment discolouration often occur during pineapple processing [2]. These can be slowed/prevented using a number of pre-treatments such as blanching, sulphiting and acid dips which inactivate enzyme activity, kill cells or form complexes with atmospheric oxygen [2]. Acidic pre-treatments such as citric acid, sulphites, ascorbic acid among many others are known to be effective retardants of polyphenol oxidase (PPO) activity by reacting with available atmospheric oxygen and chelating bivalent cations such as copper among many others [25]. Therefore, there is a need to treat fruits with certain pretreatments before the drying operation. Results from this study were not in agreement with findings by [24] who suggested that thicker slices produce a greater response (browning) since they require more drying time and as such, they get exposed longer to oxidizing browning agents.

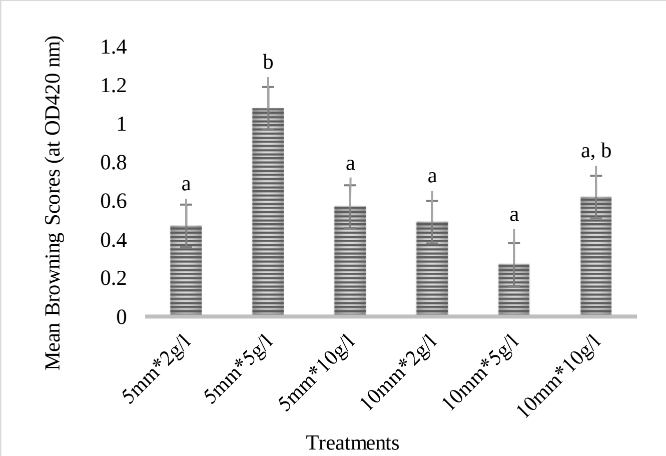


Fig. 5. Browning Scores of Pre-Treated Solar Dried Pineapple Slices. Different letters represent significant differences in browning values (p≤0.05).

D. *Effect of Drying Parameters on Responses*

The response variables vitamin C retention, rehydration ratio, and browning index were analyzed with the help of RSM to ascertain the effects of the two factors i.e., slice thickness of pineapple and pre-treatment concentration of citric acid and visualized using three-dimensional response surface plots. Multilevel categorical design was used for the experimental data and data were fitted to a second order polynomial model and regression coefficients obtained. Mathematical models were evaluated for each response by means of multiple regression analysis to yield second order polynomial models for predicting responses. ANOVA was employed to identify the significant effects of the process variables on each response and to fit appropriate models to the experimental data. Regression equation coefficients of the proposed models with statistical significance of the main responses were calculated for each response and their significance ($p \leq 0.05$) were judged as shown in Table VII. R^2, Adjusted R^2, Predicted R^2, PRESS Value, Adequate precision, and coefficient of variation (C.V.) were evaluated to check the suitability of the model. The CV was greater than 10 (Table VIII). Design Expert software was used to fit response surfaces and optimize the drying process.

E. *Vitamin C Retention*

Vitamin C retention as a function of slice thickness and pre-treatment concentration was visualized using a 3-D surface plot (Figure 6). Vitamin C retention was found to be significantly dependent on linear terms of slice thickness ($p \leq 0.05$) and pre-treatment concentration ($p = 0.0003$). Analysis of variance also showed that vitamin C retention was significantly dependent on the linear terms of pre-treatment concentration (PTC, $p = 0.0003$), the quadratic terms of pre-treatment concentration (PTC, $p = 0.0003$) and the interaction term (STPTC, $p = 0.0001$). However, the linear coefficient of slice thickness is negative implying that the lower the ST the less vitamin C is retained (Equation 1). This can be attributed to maximum surface area that exposes the pineapple to Vitamin C oxidative agents. The linear and quadratic coefficients of pre-treatment concentration are positive implying that the greater the concentration of the pretreatment the more vitamin C is likely to be retained in solar dried pineapple. Vitamin C retention was found to be maximum (15.71) in solar dried pineapple processed with a combination of 5 mm slice thickness and 5 g/l concentration of citric acid but decreased significantly when slice thickness was increased to 10 mm. This could possibly because of the longer drying times brought about by the large slices.

TABLE VI: EXPERIMENTAL VALUES OF RESPONSE VARIABLES FOR THE MULTILEVEL CATEGORICAL DESIGN

Factors			Response variables		
Treatment	Slice Thickness (ST) (mm)	Pretreatment Concentration (PTC) (g/l)	Rehydration Ratio	Browning Index (nm)	Vitamin C Retention
1	10	10	2.50	0.61	6.49
2	5	5	2.60	1.45	16.48
3	10	2	2.15	0.42	1.57
4	5	10	2.90	0.75	13.63
5	5	10	1.90	0.44	11.96
6	10	5	2.10	0.35	1.99
7	5	2	2.00	0.57	7.99
8	10	10	2.20	0.69	5.85
9	10	5	1.80	0.28	1.99
10	10	10	2.50	0.57	5.65
11	10	5	1.80	0.16	3.03
12	5	5	2.70	0.76	15.21
13	10	2	2.30	0.47	2.34
14	5	10	1.90	0.52	10.08
15	5	5	2.30	1.05	15.42
16	5	2	2.60	0.43	10.96
17	10	2	2.15	0.58	3.21
18	5	2	2.70	0.41	8.47

TABLE VII: REGRESSION COEFFICIENTS FOR FITTED MODELS

Parameter	Intercept	ST	PTC	PTC^2	STPTC	$STPTC^2$
Rehydration ratio	2.283	-0.117	0.001	0.008	0.010	0.022
p-values		0.1397	0.818	0.818	0.128	0.128
Browning index	0.584	-0.124	0.004	-0.012	0.004	0.035
p-values		0.0092*	0.184	0.184	0.001*	0.001*
Vitamin C retention	7.906	-4.338	0.119	-0.169	0.042	0.283
p-values		< 0.0001*	0.0003*	0.0003*	0.0001*	0.0001*

Does not necessarily follow processing order, * statistically significant terms of the model at p≤0.05.

European Journal of Agriculture and Food Sciences
www.ejfood.org

TABLE VIII: ANOVA EVALUATION OF LINEAR, QUADRATIC AND INTERACTION TERMS FOR RESPONSES, AND COEFFICIENT OF PREDICTION MODELS

Source	Response								
	Rehydration Ratio			Browning Index			Vitamin C Retention		
	d.f.	Coefficient	Sums of squares	d.f.	Coefficient	Sums of squares	d.f.	Coefficient	Sums of squares
Model	5		0.765	5		1.12	5		430.41
ST	1	-0.117*	0.245	1	-0.124*	0.275	1	-4.338*	338.71
PTC	2	0.001**	0.040	2	0.004**	0.112	2	0.119*	41.62
STPTC	2	0.010**	0.480	2	0.004**	0.738	2	0.042**	50.09
Residual									
Lack of fit									
Pure error	12		0.098	12		0.343	12		14.72
Std. Dev.			0.313			0.169			1.11
Mean			2.28			0.584			7.91
R^2			0.394			0.766			0.967
Adj. R^2			0.142			0.669			0.953
Predicted R^2			-0.363			0.474			0.926
Adeq. precision			3.506			8.396			20.903
C.V.%			13.70			28.95			14.01
PRESS			2.64			0.772			33.12

** Significant terms of the model; * Non-significant terms of the model.

exposing vitamin C more to degradation resulting in less amounts being retained in the solar dried pineapple. Larger slices on one hand contain more water than thinner slices which implies that on drying since the larger slices are exposed longer to solar radiation to reduce the moisture to safe levels they lose more vitamin C as compared to thin slices since it is a water-soluble vitamin. It is therefore more likely that Vitamin C is retained in thinner slices and much less in thicker slices because these have less water and therefore have less vitamin C to lose.

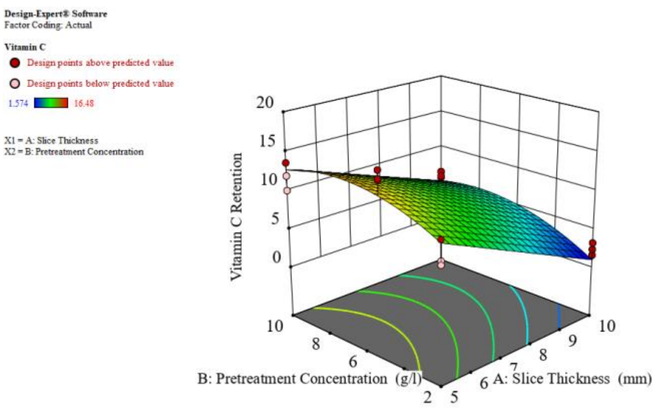


Fig. 6. Response surface plots for vitamin C retention as a function of slice thickness and pre-treatment concentration.

$$\text{Vit. C retention} = 7.91-4.34X_1+0.12X_2+0.17X_2^2+0.04X_1X_2+0.28X_1X_2^2 \quad (4)$$

F. *Rehydration Ratio*

Effect of independent variables (ST, PTC) on rehydration ratio (RR) predicted from regression model is shown in Fig. 7 in the form of 3-D plot. ANOVA showed that rehydration ratio was not significantly dependent on linear, quadratic and interaction terms of slice thickness and pre-treatment concentration i.e., $p \leq 0.05$ (Table V & VI). From equation (2) above, the rehydration ratio was negatively affected by the slice thickness implying that a lower ST resulted into a lower rehydration ratio. The linear terms of PTC, quadratic terms of PTC and the interaction STPTC all had a positive effect on the rehydration ratio of solar dried pineapple slices implying that an increase in these parameters produced a greater rehydration ratio. Rehydration ratio was maximum for 5 mm pineapple slices pre-treated with 5 g/l citric acid solution. These findings agree with results reported by [23] in the drying of banana which showed that rehydration ratio decreases with increasing slice thickness. Pretreatment on the other hand was reported to have the capability to enhance rehydration of dried products.

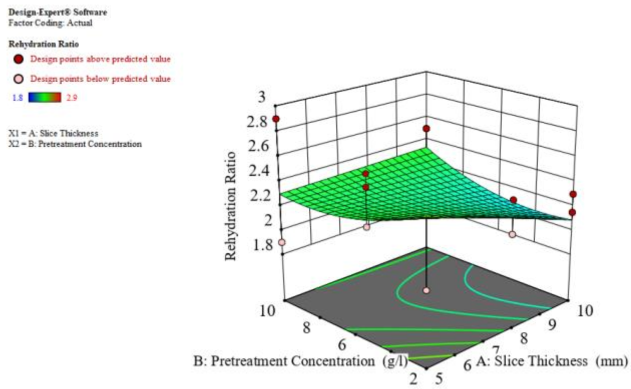


Fig.7. Response surface plots for rehydration ratio as a function of slice thickness and pre-treatment concentration.

$$\text{Rehydration ratio} = 2.28-0.12X_1+0.01X_2^2 + 0.01X_1X_2+ 0.02X_1X_2^2 \quad (5)$$

G. *Browning Index*

Effect of slice thickness and pre-treatment concentration on browning of solar dried pineapple is presented in Figure 8 below. Analysis of variance showed that browning was significantly dependent on linear terms of slice thickness (ST, $p = 0.0092$), their interactions (STPTC, $p = 0.001$) and the quadratic effects of the interaction terms (STPTC2, $p = 0.001$) (Table VI). The equation (6) shows that the linear coefficient for slice thickness is negative; indicating that lower thickness slices produce a less response (browning). Fig. 8 below however clearly depicts that generally thicker slices produce a lower response (browning) as compared to the thinner slices. This is contrary to findings by [23], in the drying of banana which showed that slice thickness indeed has a direct relationship with non-enzymatic browning as compared to the inverse relationship observed in this study. The linear coefficient of pre-treatment concentration was positive implying that a higher concentration results in greater browning. This is contrary to findings by [23], which suggested an increase in concentration of citric acid resulted in decrease of non-enzymatic browning value. Hence the browning score can be minimized by adopting higher concentration of pretreatment.

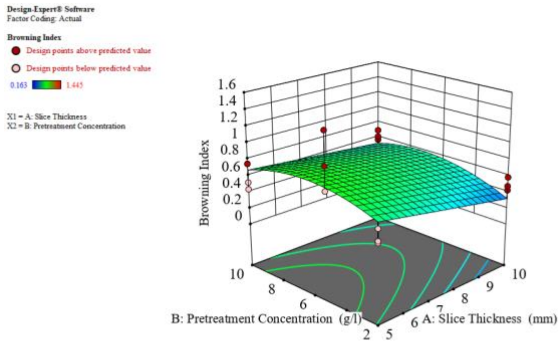


Fig. 8, Response surface plots for browning index as a function of slice thickness and pre-treatment concentration.

$$\text{Browning index} = 0.58 - 0.12X_1 + 0.00X^2 + 0.03X_1X_2^2 \quad (6)$$

IV. Optimization of Process Parameters

Optimum conditions for drying pineapple were determined based on the following criteria: minimum browning, and maximum vitamin C retention and rehydration ratio. The second order polynomial models obtained in this study were utilized to obtain the optimized drying parameters to meet the above stated criteria. Process Parameters were optimized to minimize non-enzymatic browning and to maximize vitamin C content and rehydration ratio within the range of slice thickness and pre-treatment concentration studied. RSM desirability function was applied, and two optimized combinations of drying process parameters were obtained (Table IX). The best-optimized conditions obtained for the given criteria were 5 mm (ST) and 2 g/l (PTC) based on maximum desirability (0.639). For the optimized combination of drying parameters, the vitamin C content, the rehydration ratio, and the browning were 9.138, 2.433 and 0.471, respectively.

V. Conclusion

Solar drying is an effective method for producing dried pineapple snacks. However, knowledge of the processing factors and drying kinetics is essential to producers of these pineapple snacks given that the solar drying process is largely detrimental in terms of nutrient loss, shrinkage, loss of rehydration abilities among many others. Slice thickness, pre-treatment concentration and the combined effect of these two parameters are very important factors to consider in producing dried pineapple snacks. From this study, different drying parameters for pineapple were evaluated to find out the effect of these parameters on responses: vitamin C retention, rehydration ratio, and browning of the dehydrated pineapple. Vitamin C retention was found to be significantly affected by the main effects of slice thickness, pre-treatment concentration. Browning was found to be significantly influenced by the main effects of slice thickness (ST), their interactions (STPTC) and the quadratic effects of the interaction terms ($STPTC^2$). ST, PTC and the effects of their interaction, did not significantly affect rehydration ratio. Optimization process was employed to find out the best combination of process parameters. The The desirability factor for the combination was 0.639. From this study it can be concluded that a slice thickness of 5mm and 2 g/l of citric acid would be suitable for producing solar dried pineapple snacks. These optimum drying conditions can be used for solar drying of pineapple with retention of desired quality attributes.

TABLE IX: Results of Optimization by Desirability Function of RSM

Process	Target	Experimental Range		Optimum value	Desirability
		Min	Max		
Slice Thickness	Is in range	5	10	5	
Pre-treatment Concentration	Is in range	2	10	2	
Responses		Min	Max	Predicted values	0.639
Vitamin C retention	Maximize	2.37	15.71	9.1389	
Browning score/index	Minimize	0.27	1.084	0.471	
Rehydration ratio	Maximize	1.60	2.533	2.433	

Acknowledgment

The Authors acknowledge Associate Professor Susan Balaba Tumwebaze of Makerere University, School of Forestry and Natural Resources Conservation for encouragement while performing the activities of this research and also for managing the funds of this project.

Funding

This study was funded by the Federal Ministry of Education and Research (BMBF), Germany through the Reduction of Post-Harvest Losses and Value Addition in East African Food Value Chains (RELOAD).

Conflict of Interest

Authors declare that they do not have any conflict of interest.

References

[1] Hii CL, Ogugo JF. Effect of pre-treatment on the drying kinetics and product quality of star fruit slices. *Journal of Engineering Science and Technology*, 2014; 9(1): 123-125.

[2] Mongi RJ. *Solar drying of fruits and vegetables: Dryers' thermal performance, quality and shelf life of dried mango, banana, pineapple and tomato*. Morogoro, Tanzania. 2013; 4: 140-223.

[3] Ramallo LA, Mascheroni RH. Quality evaluation of pineapple fruit during drying process. *Food and Bioproducts Processing*, 2012; 90(2): 275-283.

[4] Wakjira M. Solar drying of fruits and windows of opportunities in Ethiopia. *African Journal of Food Science*, 2010; 4(13): 790-802.

[5] Maisnam D, Rasane P, Dey A, Kaur S, Sarma C. Recent advances in conventional drying of foods. *Journal of Food Technology and Preservation*, 2017; 1(1): 25-34.

[6] Svenneling J. *Constructing a solar dryer for drying of pineapples*. Implementing a solar dryer for sustainable development, Karlstads University, Ghana, April 2012.

[7] Kiggundu N, Wanyama J, Galyaki C, Banadda N, Muyonga JH, Zziwa A, Kabenge I. Solar Fruit Drying Technologies for small holder farmers in Uganda. A Review of Design Constraints and Solutions". *Agricultural Engineering International: CIGR Journal*, 2016; 18(4): 200-210.

[8] Kadam DM, Samuel DV, Parsad R. Optimisation of pre-treatments of solar dehydrated cauliflower. *Journal of food engineering*. 2006; 77(3): 659-764.

[9] Macías-Ganchozo ER, Bello-Moreira IP, Trueba-Macías SL, Anchundia-Muentes XE, Anchundia-Muentes ME, Bravo-Moreira CD. Design, development and performance of solar dryer for pineapple (Ananas comosus (L.) Merr.), mamey (Mammea americana L.) and banana (Musaparadisiaca L.) fruit drying". *Acta Agronómica*. 2018; 67(1): 30-38.

[10] Nielsen SS. *Food analysis laboratory manual*; 3rd ed. New York, NY, USA: Kluwer Academic/Plenum Publishers; Jan 2003

[11] Gupta MK, Sehgal VK, Arora S. Optimization of drying process parameters for cauliflower drying. *Journal of Food Science and Technology*, 2013; 50(1): 62-69.

[12] Babajide JM, Olaluwoye AA, Taofik Shittu TA, Adebisi MA. Physicochemical Properties and Phytochemical Components of Spiced Cucumber-Pineapple Fruit Drink. *Nigerian Food Journal*, 2013 31(1): 40-52.

[13] Chulaki MM, Pawar CD, Khan SM, Khan AM. Effects of ascorbic acid and calcium chloride on chemical properties of firm flesh jackfruit bulbs". *Journal of Pharmacognosy and Phytochemistry*. 2017; 6(5): 654-658.

[14] Kadam DM, Lata, Samuel DVK, Pandey AK. Influence of different treatments on dehydrated cauliflower quality. *International Journal of Food Science and Technology*, 2005; 40(8): 849-856.

[15] Adom KK, Dzogbefia VP, Ellis WO. Combined Effect of Drying Time and Slice Thickness on the Solar Drying of Okra. *Journal of the Science of Food and Agriculture*, 1997; 73(3): 315-320.

[16] Doymaz I, Ozdemir O. Effect of air temperature, slice thickness and pretreatment on drying and rehydration of tomato. *International Journal of Food Science and Technology*, 2014; 49(2): 558-564.

[17] Santos PHS, Silva MA. Retention of Vitamin C in Drying Processes of Fruits and Vegetables — A Review. *Drying Technology*, 2008; 26(12): 1421-1437.

[18] Abd-Elhady M. Effect of citric acid, calcium lactate and low temperature pre-freezing treatment on the quality of frozen strawberry. *Annals of Agricultural Sciences*, 2014; 59(1): 69-75.

[19] G.A.G. Abedullah, "Effect of pre-drying, blanching and citric acid treatments on the quality of fried sweet potato chips". *American Journal of Food Technology*, 2014; 9(1): 39-48.

[20] James JB, Ngarmsak T. Processing of fresh-cut tropical fruits and vegetables: A technical guide. *Food and Agriculture Organization of the United Nations*. RAP Publication eng no. 2010/16, 2010.

[21] Karacabey E, Baltacioglu C, Cevik M, Kalkan H. Optimization of microwave-assisted drying of Jerusalem artichokes (Helianthus tuberosus L.) by response surface methodology and genetic algorithm. *Ital J Food Sci*, 2016; 28(1): 121-130.

[22] Sra SK, Sandhu KS. Effect of processing parameters on physico-chemical and culinary quality of dried carrot slices. *J Food Sci Technol*, 2011; 48(2): 159-166.

[23] Khawas P, Dash KK, Das AJ, Deka SC. Modeling and Optimization of the Process Parameters in Vacuum Drying of Culinary Banana (Musa ABB) Slices by Application of Artificial Neural Network and Genetic Algorithm, Drying Technology. *An International Journal*, 2016; 34(4): 491-503.

[24] Attkan A, Raleng A, Alam M. Process Optimization and Changes in Quality Characteristics of Hot Air-Dried Onion Slices (Allium Cepa L.)". *Vegetos- An International Journal of Plant Research*. 2017; 30(3).

Yekoyada Musoke was born in Kampala on 29th June 1993. He holds a Bachelor's degree in Agriculture from Gulu University Uganda, 2015 and is currently pursuing a Master of Science Degree in Food Science and Technology from Makerere University Uganda**.** He primarily focused on reducing post-harvest losses along the pineapple value chain in Uganda by processing them into value added products using low cost technologies. He served previously as an Agronomist for 2 years and is currently serving as a Quality Control and Phytosanitary Compliance Officer at Zahra Food Industries Limited Uganda. The author boasts of more than 3 years working experience in the implementation of food safety management systems, agronomy systems, and organic certification schemes. Yekoyada has worked as a project trainer for the MAMA Africa Organization for skilling the youth, women and village members under the Skills Development Facility (SDF) funded by Private Sector Foundation Uganda (PSFU) in 2019.

Dr. Julia Kigozi, is trained as an Agricultural Engineer, specializing in Food Process Engineering. Julia attained a BSc. Agricultural Engineering from Makerere University, Msc. Agricultural Engineering from University of Pretoria, and a PhD from Makerere University. She is a senior lecturer at Makerere University where she has been since 1997. She is involved in training and supervision of both undergraduate and graduate students in the Department of Agricultural and Biosystems Engineering. She specifically focusses on Post handling of crops, design and optimization of Food engineering operations, design of food processing equipment and plant Design. She has been involved in the design and construction of a soymilk machine, Groundnut Sheller, soya roaster, Soya steamer and fruit pulper, a batch pasteurizing equipment, vegetable/root chopping machine, Biomass Solar dryer, rice planter, soya steamer, continuous pasteurizer, and juice packing machine, Refractance Window Dryer among others. Other areas of research have included; A study of the drying kinetics, quality and shelf stability of dried Rastrineobola Argentea (mukene fish) under varying processing and storage methods, development of Shelf table Fish sausage and Cracker, development of commercial products from sorghum, millet, matooke flour, Technical Inspection and Verification of Agricultural Equipment and Machineries. Julia also works with Agro-processors to facilitate their growth in production; specifically, in setting up their infrastructure and optimizing their processing chain. Dr. Julia is a member of Member of African Women in Science and Engineering (AWSE), American Society of Agricultural and Biological Engineers (ASABE), Pan African Society for Agricultural Engineering (AfroAgEng)

Dr. Agnes Nabubuya is a senior Lecturer in the Department of Food Technology and Nutrition (FTN). She has been a faculty member since 2015. Dr. Nabubuya teaches a number of undergraduate and graduate courses and is heavily involved in research. Her primary research interest areas are Influence of social, behavioral and environmental determinants on health status and Sustainable nutrition intervention programs, especially for low-income family and children. Her other interests are Infant feeding, Nutrition and Diabetes and Nutrition and Cardiovascular diseases. Dr. Nabubuya received her Ph.D. from Norwegian University of Life Sciences, Norway in 2013. Prior to pursuing her doctorate, she earned a M.Sc. in Applied Human Nutrition from Makerere University in 2008 and a Bachelor of Veterinary Medicine from Makerere University in 2001.

Paddy Ainebyona was born in Sembabule, Uganda on 21stApril, 1990. He holds a Bachelor degree in Agricultural Engineering from Makerere University Kampala, Uganda, 2016 and a Master of Science Degree in Agricultural Engineering from Makerere University, Kampala, Uganda, 2021. His major focus was on post-harvest handling in order to reduce the post-harvest losses in Uganda and developing countries' food value chain. He is currently a researcher at the department of Agricultural and Bio systems Engineering of Makerere university Kampala, Uganda. He has worked as a project administrator for several projects under the Makerere University Research and Innovation Fund (Mak-RIF), Kampala Uganda, since 2019. Ainebyona had been also a programs Coordinator at Engineers Without Borders USA Uganda Country Office, Kampala Uganda, 2018 and an Agricultural Engineer at Global Solutions and Resources Consortium, Buikwe, Uganda. He is currently serving as the Senior Agricultural Engineer at Lyantonde District Local Government, Uganda.