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Effect of Drying on the Nutritional and Organoleptic Characteristics of African Leafy Vegetables, Jute Mallow (*Corchorus olitorius L.*) and Cowpea (*Vigna unguiculata*)

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Abstract

Purpose: The present study investigated the nutritional and organoleptic characteristics of two African leafy vegetables (ALVs)—jute mallow (*Corchorus olitorius L*) and cowpea (*Vigna unguiculata*)—at various drying temperatures. **Methods:** The thin-layer drying of cowpea leaves and jute mallow was studied at various temperatures (40–100°C) in a convective laboratory dryer, and the nutrient profiles of the dried vegetables were determined. The nutrients considered were vitamins B2 and C, and β-carotene. The level of vitamin C was determined by high-performance liquid chromatography (HPLC), whereas the levels of β-carotene and vitamin B2 were determined by titration. **Results:** β-carotene was the most stable nutrient, whereas vitamin C was the least stable nutrient in both cowpea leaves and jute mallow. The drying parameters—temperature and time—revealed that temperature had the most profound effect on vegetable nutrient stability. Organoleptic tests were carried out on the fresh and dried vegetable; there were no significant differences in preference between the fresh and dried ALVs (95% confidence interval). **Conclusions:** The present study revealed that the vegetables can be preserved by drying, and the study could be used as a guide for effective drying of those vegetables.

Keywords: African leafy vegetables, Drying, Nutrients, Organoleptic test

Introduction

Food drying is an ancient and widely used method of preservation. It can be applied to a wider variety of agricultural produce than any other preservation method to improve shelf life, reduce packing costs and shipping weights, enhance appearance, encapsulate the original flavor, and maintain nutritional value (Golob et al., 2002). The drying technology varies from simple to sophisticated methods such as freeze drying, which is used for high-value products. The drying of agricultural produce in Sub-Saharan Africa is problematic owing to a lack of adequate technical packaging for food preservation, resulting in significant post-harvest losses (Shiundu and Oniang'o, 2007). Annual episodes of malnutrition, drought, and famine in Sub-Saharan Africa are well documented. Indigenous knowledge shows that leafy African vegetables can be dried; this would help mitigate post-harvest losses and improve product shelf life, thereby increasing availability during times of drought (Chew et al., 2011). These vegetables have been identified as promising for up-scaling and addressing food security (Mbugua et al., 2008). They have nutritional value—they contain vitamin A, vitamin C, folic acid, riboflavin, and minerals such as iron and calcium—and medicinal value; they also have the advantages of local adaptation, market availability, and are an important component in the diets of the African population. These factors would help address the deficiency in important nutrients in most diets, especially during drought (Gido et al., 2017).

Vitamins are complex organic molecules that are required by the body in small amounts to maintain health and wellbeing. They are classified as either water-soluble or fat-soluble. Vitamins C (ascorbic acid) and B_2 are water-soluble, whereas vitamin A is fat-soluble and is an

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important component of the protein rhodopsin, which is a light-absorbing pigment found in the retina of the eyes. β-Carotene, which has the chemical formula $C_{40}H_{56}$, is often used as a dietary source of vitamin A. It is a non-polar, lipophilic compound. When humans consume vegetables and fruits, β-carotene enters the human body and is converted into vitamin A (retinol) (Sikorski, 2002; MacDougall, 2010).

Although the primary objective of food drying is preservation, quality aspects must be considered during the process to preserve the integrity of the final product. Depending on the composition of the food, the material is more or less prone to nutrient degradation during drying (Achanta et al., 1997; Chou and Chua, 2001). Temperature, moisture content, and interaction with water all influence the chemistry and biochemistry of the food product during drying and storage. Water is an important medium for heat transfer and heat storage, and also takes part in various biochemical reactions in food (Chieh, 2007). Therefore, the presence of water in dehydrated foods is important because it affects several deterioration reactions such as non-enzymatic browning, lipid oxidation, vitamin degradation, enzyme activity, microbial activity, and pigment stability (Osuna-Garcia and Wall, 1998). Moreover, dissolved species in the food matrix become more concentrated as the water is removed during drying. Generally, reaction rates increase with temperature and reactant concentration. Therefore, the simultaneous concentration of dissolved solutes and the elevation of temperature during drying can accelerate the reaction between species, thereby increasing the rate of nutrient destruction (Golob et al., 2002; MacDougall, 2010).

In the present study, we specifically investigated cowpeas leaves (fibrous) and jute mallow (non-fibrous) vegetables. The main objective of the study was to investigate the nutritional and organoleptic changes that occur during the drying of these leafy African vegetables. More specifically, we:

- investigated the phytochemical and nutritive profiles (vitamins B2 and C, and β-carotene) of the African leafy vegetables after drying; and
- profiled the organoleptic consumer preferences of the fresh and dried vegetables.

Materials and Methods

Sampling

The jute mallow and cowpea leaves were grown under controlled conditions, and harvested prior to experimentation. The vegetables were sampled randomly from the farm (1000 g each sample) for experimentation on the same day. Once sampled, the leaves were manually plucked from their stems. The bruised, soiled, or imperfect leaves were all discarded and placed in a labelled sampling bag to avoid sample contamination. The drying experiments were carried out in the Department of Environmental and Biosystems Engineering at the University of Nairobi. The nutrient profiles of the food samples were determined in the Department of Food Science at the University of Nairobi, and the organoleptic preference tests were conducted at the Arziki restaurant in the University of Nairobi.

Drying experiment

A calibrated standard laboratory dryer (Binder)—operated at an air speed of 0.5 $m \cdot s^{-1}$ and a temperature of 0–125 ± 0.1°C)—was switched on 1 h prior to use to ensure uniform heat distribution at the required temperature. The prepared African leafy vegetables were weighed in triplicate on a clean, dry tray using a calibrated analytical laboratory scale with a sensitivity of 300 ± 0.05 gm (Sartorius).

The vegetable leaves were evenly spread on perforated trays and placed in the dryer. The drying rate was determined using the continuous weighing method (Jayaraman and Gupta, 2006), which involves determining the initial mass of the product and the bone-dry mass after drying to constant weight. During drying, the mass of the product was measured every 10–20 min (depending on the drying temperature) for the first hour, and every hour thereafter until the vegetables were dry and the mass change was negligible (to three decimal places) for two consecutive readings at the specific drying temperature (equilibrium moisture content). The vegetables were dried at 40, 50, 60, 70, 80, 90, and 100°C.

The obtained data represented the drop in moisture content over time. The moisture ratio was calculated and plotted against time to obtain the drying curves. The moisture ratio (MR) was calculated according to the following equation:

$$MR = \frac{M - Me}{Mo - Me} \quad (1)$$

where MR is the moisture ratio, M is the moisture content at a given time, Me is the equilibrium moisture content, and Mo is the initial moisture content.

Nutrients determination

To determine the content of vitamin C, an extract was made from 2 g of the weighed sample, 50 mL of 10% trichloroacetic acid (TCA) solution, and 5 mL of 4% potassium iodide solution using a mortar and pestle. A few drops of a starch indicator were added to 5 mL of the extract, and the solution was titrated against *N*-bromosuccinimide solution. The calculation and methodology were adopted from Ciancaglini et al. (2001).

Calculation

$$Vitamin\ C = \left(\frac{176}{178}\right) \times (CV) \times \frac{100}{wt} \quad (2)$$

where V is the titer value, C is the concentration of *N*-bromosuccinimide solution (0.1 N), and wt is the mass of the sample.

To determine the level of β-carotene, 1 g of the sample was mixed with acid-washed sand, ground in a mortar and pestle, and extracted completely with acetone. The volume of the combined extracts was made up to 50 mL by adding acetone, then dewatered with anhydrous sodium sulfate. This extract (25 mL) was evaporated to near dryness in a rotary vacuum evaporator. The separation was carried out in a chromatographic column packed with silica gel. The evaporated sample was dissolved in 2 mL of petroleum spirit (40–60°C), then quantitatively spotted into the column and eluted with petroleum spirit. The first yellow eluate was collected in a 25-mL flask and made up to the mark with petroleum spirit. The optical densities of the β-carotene fraction were measured at 450 nm using a CE 440 UV/vis double beam scanning spectrophotometer that had been calibrated with standard solutions of pure β-carotene in petroleum spirit. The results were calculated as β-carotene equivalents.

The levels of vitamin B2 were determined in Nairobi, Kenya by high-performance liquid chromatography (HPLC) using a µBondapak C18 10 µm 125 Å (3.9 × 300 mm) column (Waters) with a Shimadzu UFLC 20AB solvent delivery system with the UV-detector set at 275 nm.

Organoleptic test

A panel of sixty assessors simultaneously compared the vegetables before and after processing, and ranked them according to the perceived magnitude of a given sensory characteristic. The products were presented simultaneously (dried and freshly cooked vegetables), the assessors tasted as much as they needed, and a five-point scale was used to rank the vegetable characteristics: dislike very much; dislike; neither dislike nor like; like; or like very much. The tested parameters were: taste, texture, and rewetting characteristics. Sufficient quantities of vegetables were prepared. These vegetables were dried and freshly cooked by a chef in the Arziki restaurant at the University of Nairobi, using conventional methods. The vegetables were served in small portions, and the assessors were allowed to sample the vegetables and complete the questionnaire provided. The results of the test were subjected to statistical analysis to determine the assessors' preferences with regard to the vegetables. For the rewetting test, the vegetables were soaked in water for approximately 1 h prior to testing.

Results and Discussion

Microsoft Excel 2013 and SPSS 20 statistical software were used to model the experimental data. The drying curves, nutrient profile charts, and organoleptic frequency graphs were plotted using Microsoft Excel 2013.

Drying curves

The drying data are represented as moisture ratio versus drying time (Fig. 1 and 2). The moisture ratio was

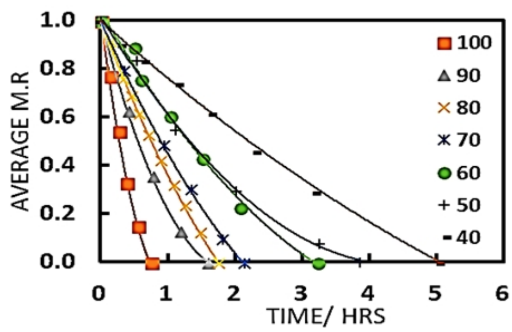

Figure 1. Drying curves of the cowpea leaves at various temperatures

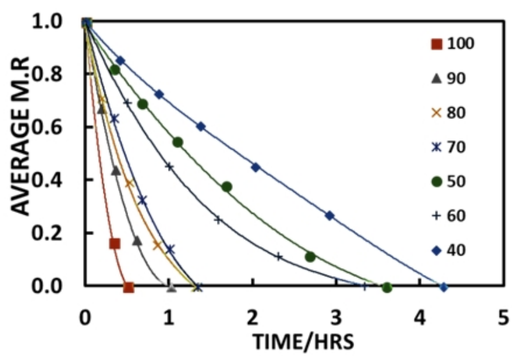

Figure 2. Drying curves of the jute mallow at various temperatures

calculated from the vegetable moisture content and dry mass using Equation 1. The drying characteristics of the vegetables at temperatures in the range 40–100°C adopted a decaying curve model. The effect of the air-drying temperature was apparent: higher drying temperatures generally translated into progressively shorter drying times, as expected. The longest drying time was at 40°C; the cowpea leaves took just over 5 h and the jute mallow took 4.2 h. The shortest drying time was at 100°C; the cowpea leaves took 0.7 h and the jute mallow took 0.5 h. The jute mallow drying time was shorter because it had a lower average moisture content of 0.738 based on its dry mass compared to the cowpea leaves, which had an average moisture content of 0.8 based on dry mass.

Vegetable drying occurred in the falling rate period, and exhibited a similar trend to that observed for thin-layer drying of potato slices (Akpinar et al., 2003). It can be postulated that the movement of moisture on the surface of the product was due to vaporization, causing the observed linear decrease in drying rate with time. This phenomenon would correspond to water transfer (diffusion) from the interior of the food matrix to the surface. It is important to note that when all of the multilayer water has diffused, the drying process should be ended to avoid thermal deterioration of the food.

The decay curve adopted by the drying curves can be described by the following equation:

$$MR = kexp^{-wt} \tag{3}$$

The drying curves were modelled against thin-layer drying models by fitting the moisture ratio drying data into the model equations. The model that returned the highest R^2 value and the lowest values of standard error estimate (SEE) was selected.

The Page model was selected as the most appropriate model for predicting the drying behavior of the vegetables following a comparison of Tables 1 and 2.

Nutrient profiles

An analysis of the nutrient profiles of the vegetables at various drying temperatures is represented in Figures 3 and 4.

Tables 3 and 4 show the models adopted by the thermal degradation of the nutrients. The models adopted are power models that are comparable to the Arrhenius equation. There is a decay constant and an activation energy coefficient. The decay constant is a

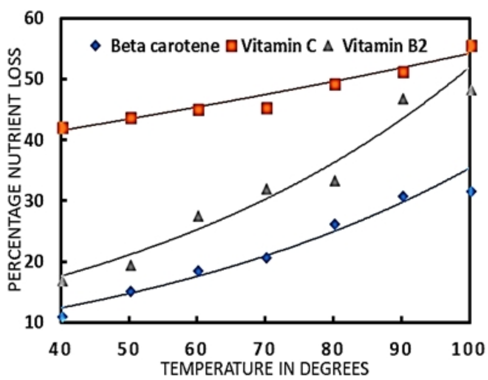

Figure 3. Nutrient loss profiles of cowpea leaves at various drying temperatures

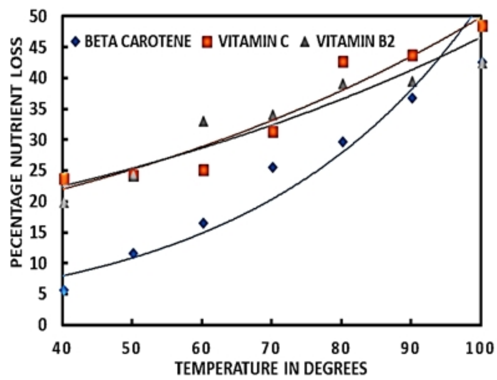

Figure 4. Nutrient loss profiles of jute mallow at various drying temperatures

Table 1. Comparison of fitted models for cowpea leaves according to their best fit frequency

	Page	Lewis	Henderson & Pabis	Modified Page
R^2			0	0
SEE	5	3	0	0

Table 2. Comparison of fitted models for jute mallow according to their best fit frequency

	Page	Lewis	Henderson & Pabis	Modified Page
R^2	4	2	0	2
SEE	4	2	0	2

function of temperature; Tables 3 and 4 show a high decay constant for the most labile nutrient (vitamin C) in both vegetables. The activation energy coefficient is lower for the nutrient that endured the greatest degradation. The most labile nutrient required less energy for the enzymatic reaction required for degradation to proceed. Both coefficients were as expected from the literature.

Effect of temperature on nutrient stability

There was a notable nutrient deterioration with an increase in drying temperature in both the vegetables, as shown in Figures 3 and 4. High temperatures catalyze reactions that would otherwise occur more slowly at ambient temperature. Moreover, the dissolved species in the food matrix are concentrated as water is removed during drying. Generally, the reaction rate is a function of temperature and reactant concentration, as described by the Arrhenius equation. The simultaneous concentration of dissolved solutes and elevated temperature during drying results in accelerated reaction between species, thereby increasing the rate of nutrient destruction. Vitamin C is the most labile nutrient owing to its low activation energy (Osuna-Garcia and Wall, 1998), implying that it is most susceptible to thermal degradation.

Figures 3 and 4 show that vitamin C underwent the greatest thermal degradation, followed by vitamin B2 and β-carotene. The trend is similar in both vegetables. Previous studies (Jangam et al., 2010) revealed similar trends: enzymatic reactions caused by the increase in temperature cause a deterioration in nutrient levels.

Effect of time on nutrient stability

The jute mallow required a slightly shorter drying time and had a lower moisture content than the cowpea leaves. During drying, undesired loss of nutrients can occur owing to reactions and transport phenomena. The latter scenario was not applicable to the present study. Chemical reactions affecting the nutritional quality of food are mainly caused or enhanced by temperature, oxygen, and light. Variation in the continuous exposure of vegetables to these conditions causes variation in the degradation levels of the nutrients. This explains why exposure to thermal degradation was minimal in the jute mallow compared to that in the cowpea leaves. A study by Igwemmar (2013) on the effect of heating on the vitamin C content of selected vegetables showed that nutrients

Table 3. Nutrient loss parameters of cowpea leaves

Nutrient	R^2 value	Equation
β-carotene	0.9622	$y = 6.1536e^{0.0175x}$
Vitamin C	0.9477	$y = 34.819e^{0.0044x}$
Vitamin B2	0.9627	$y = 8.5653e^{0.018x}$

Table 4. Nutrient loss parameters of jute mallow

Nutrient	R^2 value	Equation
β-carotene	0.9302	$y = 2.2632e^{0.0314x}$
Vitamin C	0.9242	$y = 12.74e^{0.0136x}$
Vitamin B2	0.8833	$y = 10.825e^{0.0121x}$

Table 5. Regression parameters for jute mallow

Nutrient	R^2 value	Temperature coefficient	Time coefficient	Intercept
β-carotene	0.996	0.636 ($p = 0.0005$)	0.006 ($p = 0.809$)	−21.28 ($p = 0.05$)
Vitamin C	0.961	0.575 ($p = 0.05$)	0.041 ($p = 0.62$)	−13.03 ($p = 0.47$)
Vitamin B2	0.971	0.517 ($p = 0.02$)	0.055 ($p = 0.352$)	−12.51 ($p = 0.41$)

Table 6. Regression parameters for cowpea leaves

Nutrient	R^2 value	Temperature coefficient	Time coefficient	Intercept
β-carotene	0.986	0.239 ($p = 0.047$)	−0.028 ($p = 0.405$)	10.871 ($p = 0.51$)
Vitamin C	0.947	0.377 ($p = 0.038$)	0.037 ($p = 0.36$)	14.12 ($p = 0.477$)
Vitamin B2	0.968	0.903 ($p = 0.045$)	0.08 ($p = 0.32$)	−46.434 ($p = 0.262$)

are lost more during longer processing times. There is therefore a direct correlation between temperature and time and nutrient stability in vegetable drying.

Factor analysis of temperature and time on nutrient stability

A regression analysis was carried out using Microsoft Excel 2013 at a 98% confidence interval level to produce the model parameters for temperature and time for each particular nutrient. The nutrient parameters were considered dependent variables, whereas the temperature and time coefficients were considered independent variables. The results are provided in Tables 5 and 6.

In Tables 5 and 6, the R^2 values represent the strengths of the relationships between the analyzed parameters. The obtained values reveal that the relationships between the parameters were close in both vegetables. The values in brackets are the significance values of the F statistic for the respective coefficients. For both the jute mallow and cowpea leaves, the p-values were below 0.05 for the temperature coefficients and above 0.05 for the time coefficients. It is therefore postulated that the effect of temperature on nutrient degradation is more pronounced than that of time, and therefore when modelling the drying characteristics with regard to vegetable nutrients the temperature would be the key factor to consider. The intercept coefficient does not adopt a defined pattern and the F statistic value is greater than 0.05 in all except one case. It is therefore not a significant factor in this regression model. The general form of the model is expressed as follows:

$$\mathrm{Y} = \mathrm{Temperature} \times \mathrm{KT} + \mathrm{Time} \times \mathrm{KTM} + \mathrm{Q} \quad (4)$$

where Y is the % nutrient degradation, K_T is the temperature coefficient, K_{TM} is the time coefficient, and Q is the intercept.

Organoleptic tests

Organoleptic tests on jute mallow and cowpea leaves, both dried and fresh, were conducted for taste, texture, and rewetting. The results of the ranking were averaged and are represented in Figures 5 and 6. The five-point scale used for ranking the vegetable characteristics was as follows: dislike very much (1); dislike (2); neither dislike nor like (3); like (4); and like very much (5).

A null hypothesis: “distributions of the test parameters are the same” was tested using a Friedman’s rank test at a

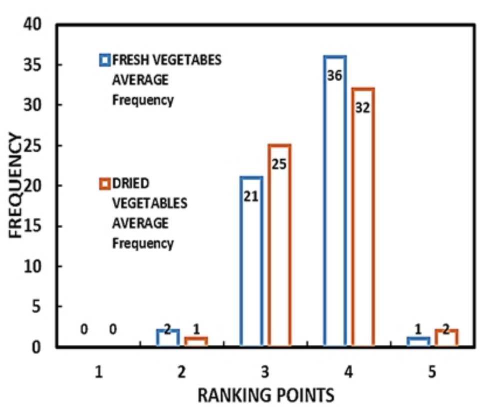

Figure 5. Average results for the jute mallow organoleptic test

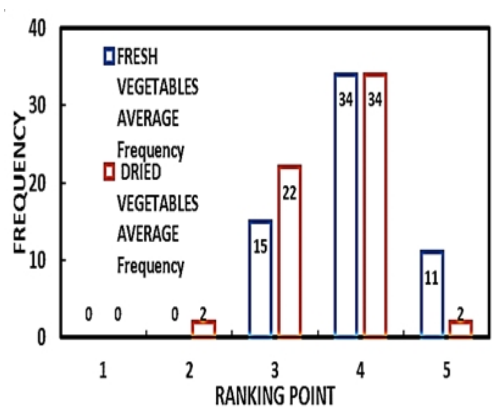

Figure 6. Average results for the cowpea leaves organoleptic test

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distributions of AVERAGE 1 and AVERAGE 2 are the same.	Related-Samples Friedman's Two-Way Analysis of Variance by Ranks	1.000	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Figure 7. Null hypothesis test summary for the cowpea leaves

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distributions of AVERAGE 1 and AVERAGE 2 are the same.	Related-Samples Friedman's Two-Way Analysis of Variance by Ranks	.564	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Figure 8. Null hypothesis test summary for the jute mallow

95% confidence interval for taste, texture, and rewetting. The null hypothesis was retained for the named quality parameters. The average frequency for all the test parameters was subjected to a Friedman's rank test at a 95% confidence interval using SPSS 20 for each of the vegetables. Fresh vegetables are represented by 1, whereas dried vegetables are represented by 2.

Analysis of organoleptic test data shown in Figures 5, 6, 7, and 8 revealed that there were no significant differences in the preferences between the fresh and dried ALVs with regard to the physical and sensory attributes, as reflected in the average test analyses for both vegetables.

Conclusions

It can be concluded from the experimental results that there was a change in nutrient profile of the ALVs when dried. The deterioration of the nutrients is a function of the drying temperature and of the drying time. Temperature was found to have a more profound effect than time on nutrient degradation. This would explain the observations: the highest temperature (100°C) was accompanied by the greatest nutrient deterioration in both vegetables, compared to the lowest temperature (40°C). The jute mallow exhibited a lower percentage nutrient loss than the cowpea leaves at all temperatures owing to a shorter drying time.

The stability of the nutrients varied during drying. β-carotene was most stable, whereas vitamin C was least stable for both cowpea leaves and jute mallow, and was therefore the most labile of the three nutrients profiled.

Conflicts of Interest

The authors have no conflicting financial or other interests.

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