NUTRIENT COMPOSITION, COLOR, REHYDRATION RATIO AND MICROSTRUCTURE OF *MORINGA OLEIFERA* LEAVES: THE EFFECT OF VARIOUS DRYING METHODS

Nuria Chinonyeren **Amaechi** [*1], Loveline Adaku **Ihechere** [1], Pius Uluocha **Isaac** [2]
[1] Department of Food Science and Technology, Abia State University, Uturu-Abia State, Nigeria.
[2] Department of Food Science and Technology, Akanu Ibiam Federal Polytechnic, Ebonyi State, Nigeria.
* E-mail: chinonyeremwog@yahoo.com

Abstract
Moringa oleifera leaves can be dried and consumed for different purposes such as tea and garnishes on meals. This work evaluated the effects of oven drying at 40ºC, 50ºC and 60ºC, freeze drying and shade drying on proximate composition, vitamins, minerals, rehydration ratio, microstructure and color parameters. The various drying methods had varied effects on proximate composition. Shade and freeze drying had the best effect in retaining minerals and vitamins. Oven drying at 50ºC and shade drying had the best effect on rehydration ratio. Scanning Electron Micrographs of fresh and dehydrated leaves showed a clear distinction in microstructure. Parenchyma thickness varied with the different drying methods. At all drying conditions, the closest L^*, hue (α) and ΔE values to the color of fresh M. oleifera leaves was obtained at 50ºC while freeze drying gave a product with the highest chroma value, color saturation (ΔC^*) and total hue difference (ΔH^*). An increase in oven drying temperature of 60ºC resulted to increased redness indicated by the a value of 1.76 which signifies browning reactions. Therefore, freeze drying, shade drying and oven drying at 50°C will be of good use in producing dried Moringa oleifera leaves with good nutritional and color attributes.*

Keywords: *Moringa oleifera* leaves, drying, color, rehydration ratio, microstructure

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1. INTRODUCTION

Drying is one of the oldest method of preservation profitable to mankind as dried foods play an important role in the food chain supply (Ahmed *et al*., 2013). Drying removes moisture from the food so bacteria, yeast and mold cannot grow and cause spoilage alongside decreasing the enzyme activities (Harrison and Andress, 2019). Postharvest handling and processing technology is required to maintain quality, reduce loss and utilize all of agricultural products (Singh, 2011). Vegetables are highly perishable due to high moisture content which make them susceptible to microbial spoilage, hence there is need for good postharvest handling such as drying. They are considered as one food source that can be classified as protective foods since they supply vitamins and minerals and they play important metabolic roles. Dried vegetable powder is added to meals in certain geographical regions such as in India to keep up quality and taste (Naikwade, 2014). It is envisaged that the use of dried vegetable foods will provide food security, alleviate hidden hunger hence reduce the prevalence of degenerative diseases.

There are documented losses of nutrients from vegetables during drying (Yadav and Sehgal, 1997). Drying may alter the microstructure of vegetables and influence the release of bioactive compounds during digestion (Dalmau *et al*., 2019). Rehydration ratio is among the most important parameters of dried product quality (Raghavan *et al*., 2008) while color is an important quality attribute in the food and bioprocess industries as it influences consumer's choice and preference (Pathara *et al*., 2017).

Moringa oleifera belongs to the family Moringacea and it is a native plant from Asia and Africa (Padayachee and Baijnath, 2012). It is grown for its nutritious pods, edible leaves and flowers which can be utilized for food, medicine, cosmetic oil or forage for livestock

(Vergara-Jimenez *et al.*, 2017). Dried *M. oleifera* leaf powder is dissolved in water and taken as "tea" while some human populations add it to cereal gruel "ogi". In Nigeria, the most popular drying method for *Moringa oleifera* leaves is air/shade drying at room temperature (Adejumo and Dan, 2018). It is view of this that a study was carried out to determine the effect of freeze drying, shade drying and oven drying at different temperatures on nutrients, rehydration ratio, color and microstructure of fresh and the various dried vegetable samples.

2. MATERIALS AND METHODS

Collection and preparation of samples

Fresh leaves of *Moringa oleifera* were harvested from farmyard of Michael Okpara University of Agriculture, Umudike, Abia State. The leaves were picked, washed well in water to remove dirt and allowed to drain of water. After which, the leaves were divided into 5 portions of 1kg. Each portion of washed leaves was subjected to various drying methods namely oven drying at 40ºC, 50ºC and 60ºC respectively, shade and freeze drying. For freeze drying the leaves were freeze dried at a temperature of -20ºC for 11h 8mins at a vacuum pressure of 30Pa in a freeze dryer (Techmel 725N, South Korea). A sixth portion of fresh leaves was used as control. After drying, the respective dehydrated samples were pulverized using a blender (Master Chef), stored in labeled dark colored containers and were kept in cool, dark place prior to analysis. Analysis was done on the various dehydrated samples and the fresh leaves.

Proximate composition analysis

Proximate composition of the fresh and dried samples was assessed using established AOAC protocols (AOAC, 2005). Crude protein was determined by the micro Kjedhal method(AOAC 939.02). The nitrogen content of the sample digest was multiplied by 6.25 and expressed as percentage protein. Ash content was determined gravimetrically after muffle furnace (SX2-2.5-12, England) incineration at 550ºC for 6 h. Crude fat was also determined gravimetrically after solvent extraction using hexane. Crude fiber was determined by the Weende method while moisture determination was done by drying the pulverized vegetables in a convection oven at 105ºC for 5h to a constant weight. Nitrogen free extract (carbohydrate) was calculated by applying the formula: 100 - [%Moisture + %Ash + %Fat + %Crude fiber + %Crude protein]. Energy values of the respective fruit bars in kcal/100g were obtained by multiplying the percentage of crude protein, fat and carbohydrate by the factor of 4, 9 and 4, respectively and summing them up.

Mineral analysis

The ash obtained from the ash content experiment was used for the minerals assay (James, 2013). Briefly, each ash sample was transferred to 100 mL glass tubes and 2mL of 2M hydrochloric acid was added. The digest in each tube was made up to mark with deionized water. The diluted digest was used to analyze the different mineral elements. Sodium and potassium were analyzed using Type 128 Flame photometer (Systronics, Gujarat India). Phosphorus and zinc were analyzed by determining the absorbance of color complex formed molybdovanadate and Zinc, respectively. The absorbance was read at 400 nm for phosphorus and 615 nm for zinc (Säbel, 2010) using UV/Vis SpectroArt 200 spectrophotometer(Wealtec Bioscience, New Taipei City, Taiwan). EDTA titration was used for the determination of calcium and magnesium. Iron was analyzed by Orthophenanthroline red ferrous complex method.

Vitamin analysis

The B vitamins, vitamin A and Vitamin E contents of the vegetable samples were estimated spectrophotometrically (UV/Vis SpectroArt 200, Wealtec Bioscience, New Taipei City, Taiwan) using 1 cm pathlength cuvette, according to the methods described by Okwu and Emenike (2006) with some modifications. Briefly, 5g of each sample was homogenized and extracted using a mixture of

absolute ethanol and 5% potassium hydroxide (10:1) and boiled for 30mins under reflux before adding petroleum ether. The extract mix was evaporated to dryness on a rotary evaporator. Small amounts of the residue was re-dissolved in appropriate carrier solvents for each vitamin. Vitamin standards were prepared in the carrier solvents at different concentrations. Their absorbance was read and used to create the calibration curves used to calculate the concentration of the vitamin on a dry weight basis. The absorbances of the vitamins were monitored as follows: thiamin (vitamin B1) at 360 nm, riboflavin (vitamin B2) at 510 nm, niacin (vitamin B3) at 470 nm, vitamin A at 450 nm and vitamin E at 295 nm.
Vitamin C was determined titrimetrically after homogenizing each sample in 50mL 5.6 mM EDTA solution. The homogenized samples were filtered using Whatman no.1 filter paper. Approximately 10mL of 30% potassium iodide was added to 20mL of filtrate and mixed thoroughly. The mixture was titrated against 0.1M $CuSO_4$ to a dark end point using 1% starch solution as the indicator (Okwu and Emenike, 2006).

Rehydration ratio measurement

Rehydration ratio (RR) is among the most important parameters of dried product quality. Rehydration measurement was determined thus: 3±0.1g of each dried product was immersed in a glass beaker containing 400ml distilled water at 20^0C (±1°C) for 4h (Doymaz, 2012). After which the sample was dewatered, blotted with tissue paper and weighed using electronic digital balance (LabTech BL 20001, Italy) with ± 0.001g accuracy. Rehydration ratio was calculated as:

$R = \frac{M2-M1}{M1}$ (Raghavan *et al*., 2008).

Color measurement

The color of both fresh and the various dried leaves were assessed using a Chroma meter (CR – 14, Konica Minolta, Japan). It was calibrated using a standard white tile. The pulverized *Moringa oleifera* leaf samples were uniformly packed in clean Petri plates with lid. The instrument head was placed on the plate and exposures were conducted based on CIE system of color measurement where by L^* ranged from 0 (black) to 100 (Lightness/white), a^* values ranged from -80 (green) to +100 (red) and b^* values ranged from -80 (blue) to +70 (yellow). L_o^*, a_o^* and b_o^* values of the fresh leaf samples and L^*, a^* and b^* values of the dried samples were recorded respectively. The indices Chroma (C^*) and hue angle (α) values which pertains to color perception of consumers (McGuire, 1992) were calculated from the a and b values stated by Karaaslan and Tunçer (2008) as:

$$C = \sqrt{(a^*)^2 + (b*)^2} \quad (1)$$

$$h^o = \text{Arc tan}\frac{b}{a} \quad (2)$$

ΔE* (measuring total color difference), ΔC* (total saturation difference) and ΔH* (total hue difference) indicating color changes during processing were calculated using equations (3) to (5) stated by (Hutchings, 1999).

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad (3)$$

Where:

$\Delta L^* = L_{fresh} - L_{dried}$ (i.e L_o-L)
$\Delta a^* = a_{fresh} - a_{dried}$ (i.e a_o-a)
$\Delta b^* = b_{fresh} - b_{dried}$ (i.e b_o-b)

$$\Delta H^* = \sqrt{(\Delta E^*)^2 - (\Delta L^*)^2 - (\Delta C^*)^2} \quad (5)$$

Scanning Electron Microscopy (SEM): Scanning electron microscope (Thermo Fisher Scientific, Phenom 800-07334, Netherlands) was used to examine the microstructure of pulverized fresh and dehydrated *Moringa oleifera* leaves respectively. Each pulverized sample was fixed on the SEM stub and was fixed on 8mm X 20m specific carbon film support and their shape and surface characteristics were observed using a gaseous secondary electron detector in environmental mode at 15KV (Gasmalla *et al*., 2017).

Statistical analysis was done using SPSS version 20 and test was carried out by one way analysis of variance. Statistical significance was determined by $p < 0.05$.

$$\Delta C^* = \sqrt{(a)^2_{\text{dried sample}} + (b^*)^2_{\text{dried sample}}} - \sqrt{(a^*)^2_{\text{fresh sample}} + (b^*)^2_{\text{fresh sample}}} \quad (4)$$

Table 1: Effect of different drying methods on proximate composition of *Moringa oleifera* leaves.

Sample	Dry Matter (%)	Moisture (%)	Ash (%)	Fat (%)	Crude Fiber (%)	Crude Protein (%)	CHO (%)	Energy Value (KCal/100g)
MOL 40	93.10^{b}±0.14	6.90^{d}±0.14	8.80^{c}±0.28	6.00^{d}±0.00	22.20^{b}±0.28	19.50^{c}±0.35	36.60^{ab}±0.35	278.40^{b}±2.83
MOL 50	93.40^{ab}±0.00	6.60^{d}±0.00	8.40^{cd}±0.28	770^{b}±0.14	23.70^{a}±0.14	21.63^{b}±0.18	31.48^{c}±0.53	281.70^{b}±4.10
MOL60	94.00^{a}±0.00	6.00^{e}±0.00	8.10^{d}±0.14	8.10^{a}±0.14	24.10^{a}±0.14	22.98^{a}±0.18	30.73^{c}±0.32	287.70^{a}±0.71
SDMOL	91.70^{c}±0.14	8.30^{c}±0.14	9.50^{b}±0.00	640^{c}±0.00	18.00^{d}±0.00	16.00^{d}±0.35	41.80^{a}±0.50	288.80^{a}±0.57
FMOL	30.60^{e}±0.28	69.40^{a}±0.28	2.90^{e}±0.14	2.50^{e}±0.00	4.13^{e}±0.18	8.48^{e}±0.39	12.60^{d}±0.42	247.7^{c}±2.97
FDMOL	89.40^{d}±0.57	10.60^{b}±0.57	10.20^{a}±0.28	2.30^{e}±0.14	20.40^{c}±0.28	22.93±0.25	28.58^{c}±0.2	106.92^{d}±0.31

Values are means ± standard deviation. Values with different superscript in the same column are significantly different ($p<0.05$) MOL 40: *Moringa oleifera* leaves oven dried at 40°C, MOL 50: *Moringa oleifera* leaves oven dried at 50°C, MOL 60: *Moringa oleifera* leaves oven dried at 60°C, SDMOL: Shade dried *Moringa oleifera* leaves, FMOL: Fresh *Moringa oleifera* leaves, FDMOL: Freeze dried *Moringa oleifera* leaves, CHO- carbohydrate.

3. RESULTS AND DISCUSSION

Proximate composition

Table 1 shows results on the effect of drying methods on proximate composition of *Moringa oleifera* leaves. All the dried samples had higher ash, crude fiber, crude protein and carbohydrate content than the fresh samples. Results indicated a significant difference ($p<0.05$) in dry matter content of the vegetable samples. *M. oleifera* oven dried at 60°C (MOL60) had the highest dry matter content of 94% while the fresh leaves (FMOL) had the least value. Oven drying at varied temperatures (40°C, 50°C and 60°C) resulted to higher dry matter content than shade drying or freeze drying. This is in contrast to the findings of Adeyemi *et al.*(2014) who reported that shade drying resulted to a higher dry matter content than oven drying at 60°C.

Oven drying at varied temperatures resulted to lower moisture content than either shade drying (8.30%) or freeze drying (10.60%). The higher the oven temperature, the lower the moisture content. Moisture content observed in the dehydrated leaves were lower than moisture content of *M. oleifera* leaves dehydrated by oven drying at 60ºC or shade dried mentioned elsewhere (Moyo *et al.*, 2011; Adeyemi *et al.*, 2014).

Moisture content of fruits and vegetables could be influenced by humidity in the geographical location. However, moisture content of the dehydrated leaves were less than 14% maximum moisture content that can be tolerated for dried products to keep well in storage.

Freeze drying resulted to higher ash content (10.20%) than shade drying (9.50%) and oven drying at 40°C, 50°C and 60°C which had values of 8.80%, 8.40% and 8.10% respectively. Higher oven temperature resulted to lower ash content which could be due to high oxidation rate as oven temperature increased. Oven drying at 50^{0}C and 60^{0}C resulted to significantly higher ($p<0.05$) fat content than oven drying at 40^{0}C. There was no significant difference ($p>0.05$) in fat content of the fresh (FMOL) and freeze dried leaves (FDMOL). Freeze and shade drying resulted to low fat content than oven drying at varied temperatures This could be attributed to high temperature effect which lowered the turgidity of lipid organelles hence increasing the rate of organelle disintegration. Fat content of shade dried leaves observed in our work was similar to the value reported by Moyo *et al.* (2011) for shaded dried M. *oleifera* leaves from Tooseng-Limpopo South Africa.

There was no significant difference ($p>0.05$) in crude protein content of leaves subjected to

freeze drying and leaves oven dried at 60°C (MOL60) which had values of 22.93% and 22.98% respectively. Gradual increase in oven temperature resulted to increased crude protein content and it was observed that oven dried samples had higher crude protein content than shade dried samples. This was in contrast to the findings of Oni *et al*. (2015) who reported higher values in crude protein content of shade dried vegetables than in oven dried common Nigerian edible botanicals.

Oven drying resulted to higher crude fiber contents than either shade drying or freeze drying. Crude fiber content of all the dried leaves irrespective of drying method was higher than crude fiber content of *Adansonia digitata* leaves subjected to various drying methods and ranged between 8.05-11.96% (Abioye *et al.*, 2014). The various drying methods resulted to variations in carbohydrate content of the various dehydrated vegetable samples. Shade dried samples had the highest carbohydrate content of 41.80% while the freeze dried samples had the least carbohydrate content of 28.58%. There was no significant difference ($p>0.05$) in carbohydrate content of samples oven dried at 50°C, 60°C or freeze dried. Energy Values ranged between 247.7 KCal/100g (FDMOL) and 288.807 KCal/100g (SDMOL) for the dehydrated *M.oleifera* leaf products while the fresh leaves had a value of 106.927KCal/100.

Mineral content

Table 2 shows results on mineral content of dehydrated *M. oleifera* leaf products subjected to various drying methods and compared with mineral content of fresh leaves. Freeze dried samples had the highest mineral content except sodium. Drying resulted to moisture loss with increase in mineral nutrient concentration. Drying temperature had varied effects on mineral concentration such that low temperature employed in freeze drying and shade drying retained minerals than the oven drying temperatures. Increased oven temperature resulted to a gradual decrease in mineral concentration which could be attributed to higher oxidation rate of minerals with increase in oven temperature. Variations in mineral concentration with respect to drying method decreased in this order: Freeze drying> shade drying> Oven drying at 40°C> oven drying 50°C> Oven drying 60°C.

The abundance of minerals in the fresh and dehydrated samples was in this order: Calcium> Potassium > Sodium >Magnesium> Phosphorus > Zinc > Iron. Similarly, Moyo *et al.* (2011) reported calcium to be the most abundant mineral element followed by Potassium while Phosphorus was the least among the macro-elements found in *M. oleifera* leaves. Calcium, Magnesium and potassium contents of fresh *M. oleifera* leaves were higher than calcium, magnesium and potassium of fresh (raw) *Telfaira occidentalis* leaves which had values of 1.50, 4.30 and 3.45mg/100g respectively (Okpalama *et al*., 2013). However Zinc (2.00mg/100g) and Iron (8.90mg/100g) contents of fresh *T. occidentalis* were higher than 0.87 and 0.80mg/100g observed for zinc and iron contents of fresh *M. oleifera* leaves.

Table 2: Effect of different drying methods on mineral content of *Moringa oleifera* leaves

Sample	Calcium (mg/100g)	Magnesium (mg/100g)	Potassium (mg/100g)	Phosphorus (mg/100g)	Sodium (mg/100g)	Iron (mg/100g)	Zinc (mg/100g)
MOL40	$208.28^{c}\pm0.25$	$53.45^{e}\pm0.25$	$201.75^{c}\pm0.61$	$38.53^{c}\pm0.18$	$184.46^{b}\pm0.28$	$1.50^{b}\pm0.13$	$2.42^{c}\pm0.00$
MOL50	$196.48^{d}\pm0.32$	$54.20^{d}\pm0.00$	$200.24^{d}\pm0.30$	$35.50^{d}\pm0.26$	$181.06^{c}\pm0.47$	$1.22^{c}\pm0.06$	$2.18^{d}\pm0.00$
MOL60	$192.39^{e}\pm0.00$	$56.42^{c}\pm0.27$	$194.40^{e}\pm0.29$	$33.27^{e}\pm0.22$	$176.54^{d}\pm0.00$	$1.08^{c}\pm0.06$	$2.08^{d}\pm0.06$
SDMOL	$214.15^{b}\pm0.10$	$61.77^{b}\pm0.57$	$209.54^{b}\pm0.00$	$39.71^{b}\pm0.19$	$187.26^{a}\pm0.08$	$1.63^{b}\pm0.05$	$2.58^{b}\pm0.00$
FMOL	$86.29^{f}\pm0.13$	$11.26^{f}\pm0.00$	$82.78^{f}\pm0.00$	$8.30^{f}\pm0.00$	$69.15^{e}\pm0.61$	$0.80^{d}\pm0.03$	$0.87^{e}\pm0.07$
FDMOL	$224.75^{a}\pm1.22$	$69.03^{a}\pm0.47$	$243.70^{a}\pm0.00$	$43.32^{a}\pm0.76$	$183.23^{b}\pm1.18$	$2.28^{a}\pm0.18$	$3.94^{a}\pm0.12$

Values are means ± standard deviation. Values with different superscript in the same column are significantly different ($p<0.05$) MOL 40: *Moringa oleifera* leaves oven dried at 40°C, MOL 50: *Moringa oleifera* leaves oven dried at 50°C, MOL 60: *Moringa oleifera* leaves oven dried at 60°C, SDMOL: Shade dried *Moringa oleifera* leaves, FMOL: Fresh *Moringa oleifera* leaves, FDMOL: Freeze dried *Moringa oleifera* leaves CHO- carbohydrate.

Table 3: Effects of different drying methods on vitamin content of *Moringa oleifera* leaves

Sample	Vitamin A ug/g)	Vitamin B_1 (mg/100g)	Vitamin B_2 (mg/100g)	Vitamin B_3 (mg/100g)	Vitamin C (mg/100g)	Vitamin E (mg/100g)
Mol 40	$4.34^{c}\pm0.07$	$1.81^{c}\pm0.02$	$0.95^{b}\pm0.04$	$2.07^{c}\pm0.04$	$18.30^{b}\pm0.14$	$3.66^{bc}\pm0.33$
Mol 50	$3.74^{d}\pm0.03$	$1.74^{d}\pm0.00$	$0.74^{d}\pm0.03$	$1.88^{d}\pm0.00$	$16.64^{c}\pm0.30$	$3.23^{c}\pm0.00$
Mol 60	$3.08^{e}\pm0.09$	$1.55^{e}\pm0.04$	$0.64^{e}\pm0.03$	$1.66^{f}\pm0.05$	$13.35^{d}\pm0.35$	$2.64^{d}\pm0.00$
SDMOL	$4.70^{bc}\pm0.13$	$2.51^{b}\pm0.02$	$1.29^{a}\pm0.00$	$2.52^{b}\pm0.00$	$19.30^{a}\pm0.00$	$3.83^{b}\pm0.18$
FMOL	$5.15^{b}\pm0.00$	$1.40^{f}\pm0.00$	$0.83^{c}\pm0.03$	$1.87^{d}\pm0.11$	$19.34^{a}\pm0.16$	$4.72^{a}\pm0.00$
FDMOL	$10.86^{a}\pm0.57$	$2.65^{a}\pm0.00$	$1.31^{a}\pm0.06$	$2.74^{a}\pm0.06$	$19.03^{ab}\pm0.60$	$5.13^{a}\pm0.32$

Values are means ± standard deviation. Values with different superscript in the same column are significantly different ($p<0.05$). MOL 40: *Moringa oleifera* leaves oven dried at 40°C, MOL 50: *Moringa oleifera* leaves oven dried at 50°C, MOL 60: *Moringa oleifera* leaves oven dried at 60°C, SDMOL: Shade dried *Moringa oleifera* leaves, FMOL: Fresh *Moringa oleifera* leaves, FDMOL: Freeze dried *Moringa oleifera* leaves.

Vitamin content: Table 3 shows results on the effect of different drying methods on vitamin contents of *Moringa oleifera* leaves. Drying resulted to a significant difference ($p<0.05$) in vitamin contents of the various samples. Results indicated that freeze drying had the best effect in retaining and concentrating the various vitamins analyzed especially vitamins A, B1, B2, B3 and E while shade drying was more effective in retaining Vitamin C than the other drying methods. Vitamin A content of both fresh and dehydrated *M. oleifera* leaves ranged between 3.08-10.86 µg. Therefore, there is need for adequate intake of *Moringa oleifera* leaves either in the dried or fresh state so as to provide dietary allowance of 300 to 400µg/day for children, 600-900µg/day for males and females of healthy individuals (FNB/IMN/NA, 2001).

The various drying methods increased the concentration of Vitamin B_1 by 29.29%, 24.29%, 10.71%, 79.29% and 82.29% for oven drying at 40^0C, 50^0C, 60^0C, shade drying and freeze drying respectively. Vitamin B_1 (thiamin) content observed for fresh *M. oleifera* leaves was higher than thiamin content of fresh *T. occidentalis* leaves (0.08mg/g) as well as 0.25mg/100g for raw *Pterocarpus mildbraedii (*Okpalama *et al.*, 2016). Vitamin B_1 content of both raw and the various dried samples will be sufficient to provide nutritional needs of infants and children (0.02-0.06mg/d), male and female of various age groups (0.09-1.1mg/day), pregnant and lactating females (1.4mg/d) of healthy individuals (FNB/IM/NA, 1998). Thiamin functions as co-enzymes in carbohydrate and branched chain amino acid metabolism (FNB/IM/NA,1998). Vitamin B_2 ranged between 0.64 and 1.31 mg/100g. Vitamin B_2 present in dehydrated *M. oleifera* leaves may be sufficient to provide nutritional needs of Vitamin B_2 for infants and children (0.03 -0.06mg/day) alongside male and female (0.9 – 1.1mg/day) of healthy individuals (FNB/IM/NA, 1998).Vitamin B_3(niacin) content of both fresh and dehydrated samples may not be sufficient to supply niacin to meet with nutritional needs of 6-8mg/day for children or 12-16mg/day for male and female of healthy individuals (FNB/IM/NA, 1998). Therefore it needs supplementation from other food sources.

Vitamin C content of fresh and dehydrated leaves will not be sufficient to supply vitamin C needs of 45 to 75mg/day for male and female of healthy individuals but can go to an extent to provide nutritional needs of 15 to 25mg/day for children between 1 to 8 years (FNB/IM/NA, 2000). Vitamin C is required for reactions which need reduced or iron metalloenzyme and serve as an antioxidant (FNB/IM/NA, 2000). The various drying methods caused a reduction in Vitamin E content of *M. oleifera* leaves except freeze drying. Vitamin E content of both fresh and dried leaves could be sufficient to supply about 37.71 to 73.29% of RDA of 7mg/d for children and 17.40 – 46.64% RDA of 11-15mg/day for male and female of healthy individuals (FNB/IM/NA, 2000). Vitamin E functions as a chain breaking antioxidant in lipid bi-layers of cells.

Rehydration Ratio (RR): Figure 1 shows results on rehydration ratio of the various dried *Moringa oleifera*. Rehydration ratio an important attribute considered in understanding the quality of dried material (Izli and Polat, 2019). The rehydration ratio (RR) of the dehydrated samples ranged between 3.40 and 4.49. Rehydration was highest for samples oven dried at 50°C (MOL50) and lowest for samples oven dried at 40°C (MOL40). There was no significant difference ($p>0.05$) in rehydration ratio of MOL50 and shade dried (SDMOL). Rehydration was in this order: Oven drying at 50°C = Shade drying> Freeze drying> Oven drying at 60°C> Oven drying at 40°C. This could be explained that the various drying methods had varied effects on tissue integrity loss with intense formation of largely shrunken cellular constituents such as parenchyma with diminished hydrophilic properties. Higher rehydration ratios were obtained for leaves oven dried at 50°C, shade dried and freeze dried than leaves oven dried at 60°C. This was in contrast to the report of Sacilik and Elicin (2006) who reported that rehydration ratio increases with rise in drying temperatures since moisture removal rate is very quick and this induces less contraction, hence, catalyses rehydration. Aksoy *et al.* (2019) reported a moderate drying time produces a food matrix having less deformation. It was expected that lower oven drying temperature of 40°C could have resulted to a higher rehydration ratio. it is envisaged that oven drying at 40°C could have activated endogenous enzymes which catalyzed the production of compounds with diminished hydrophilic properties.

Scanning Electron Micrograph (SEM) of fresh and dehydrated Moringa oleifera leaves

Figure 2a-f presents micrographs of fresh and dehydrated leaves of *Moringa oleifera*. The SEM of samples indicated a clear distinction in microstructure of fresh and dehydrated leaves. The cells of fresh leaves (a) were flat with irregular parenchyma shape while cells of the dehydrated samples (b-f) were thick with irregular parenchyma shape. Parenchyma thickness varied with different drying methods. Shade drying and oven drying at 50°C resulted to almost similar parenchyma thickness.

There could be the reason for insignificant difference ($p>0.05$) in rehydration ratios reported for MOL50 and SDMOL as shown in Fig.1. Parenchyma of freeze dried samples was thick but showed mild distortions as shown by the arrow while oven drying at 40°C resulted to thin walled parenchyma.

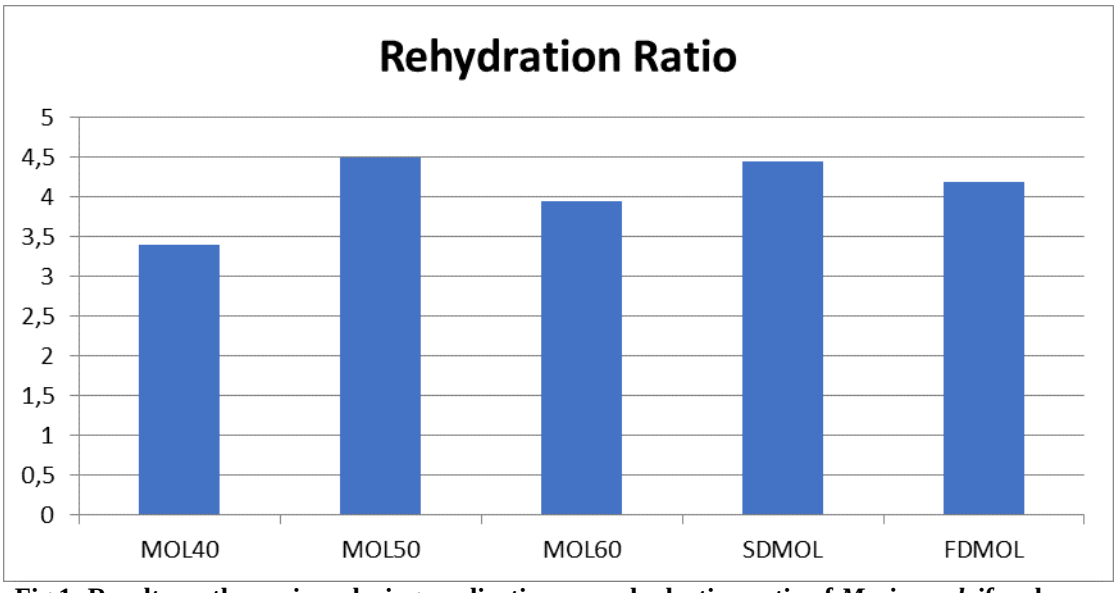

Fig 1: Results on the various drying applications on rehydration ratio of *Moringa oleifera* leaves

MOL 40: *Moringa oleifera* leaves oven dried at 40°C, MOL 50: *Moringa oleifera* leaves oven dried at 50°C, MOL 60: *Moringa oleifera* leaves oven dried at 60°C, SDMOL: Shade dried *Moringa oleifera* leaves, FDMOL: Freeze dried *Moringa oleifera* leaves

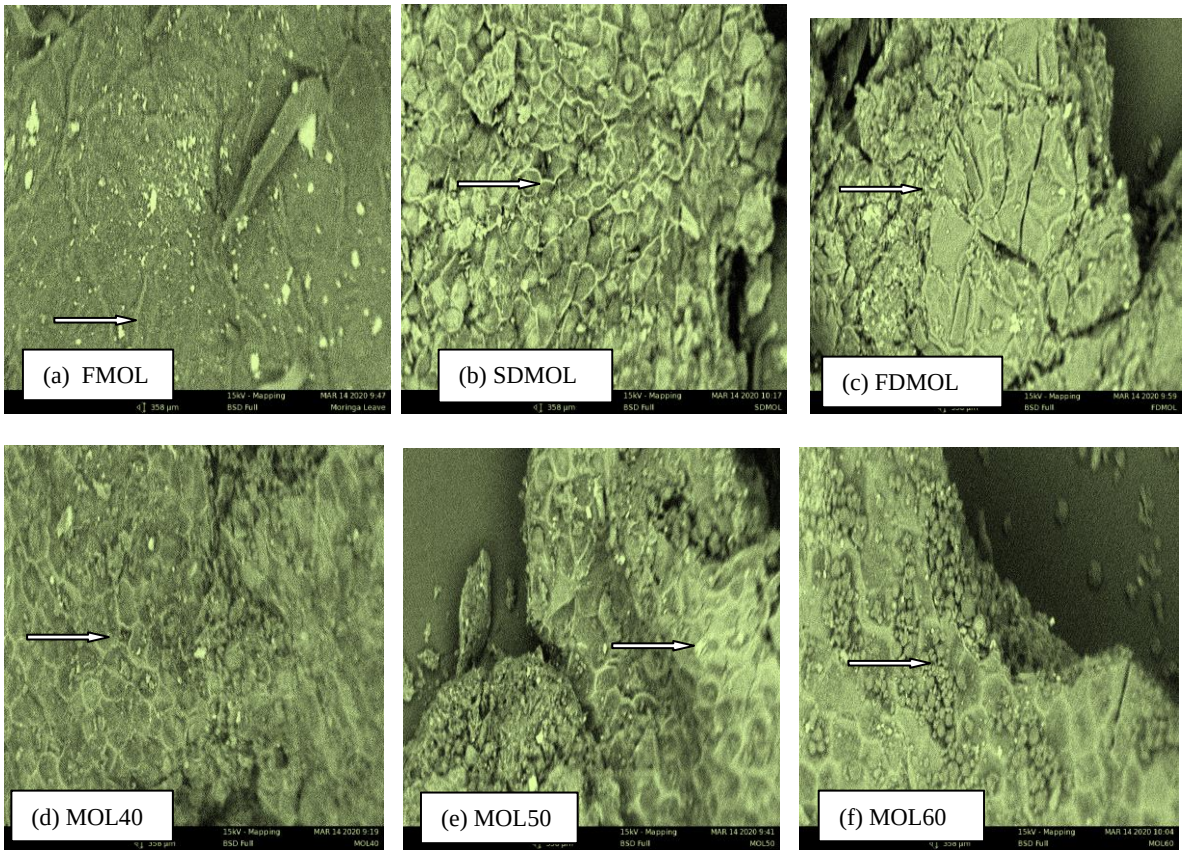

Fig 2a-f: Scanning Electron Micrographs of fresh and dehydrated *Moringa oleifera* leaves
FMOL: Fresh *Moringa oleifera* leaves, SDMOL: Shade dried *Moringa oleifera* leaves, FDMOL: Freeze dried *Moringa oleifera* leaves. MOL 40: *Moringa oleifera* leaves oven dried at 40°C, MOL 50: *Moringa oleifera* leaves oven dried at 50°C, MOL 60: *Moringa oleifera* leaves oven dried at 60°C, Arrows pointing at parenchyma cells.

Generally, there was complete parenchyma without significant cell wall damage for all the dehydrated samples except sample oven dried at 60°C (MOL60). Oven drying at 60°C resulted to higher structural deformation of parenchyma which led to intensified water evaporation, hence undermining starch-protein matrix of the cell wall resulting to structural damage (Izil and Isik, 2014).

Results on Color

Color determination was done using the CIELAB color scale to evaluate color characteristics of the dyhydrated *Moringa oleifera* leaf samples by estimating L^*, a^*, b^* parameters. These were used to calculate chroma (C^*) and hue angle (α) while ΔE (total color difference), ΔC (total saturation difference) and ΔH (total hue difference were calculated for measuring color differences and tracking color changes during processing (Zirlinska and Mankowski,2012). L_o^*, a_o^*, b_o^* values of the fresh samples were 40.06, -10.85 and 13.68 respectively. All the drying applications significantly ($p<0.05$) affected L^*, a^*, b^* parameters when compared with that of the fresh leaves. L^* values indicating brightness was in this order: Freeze dried *Moringa oleifera* leaves (FDMOL) > Fresh leaves (FMOL) = *Moringa oleifera* oven dried at 50ºC (MOL50) > Shade dried *Moringa oleifera* leaves (SDMOL) >*Moringa oleifera* leaves oven dried at 40ºC (MOL40) >*Moringa oleifera* leaves oven dried at 60ºC (MOL60). This indicates that freeze drying increased the brightness of the leaves while leaves oven dried at 60ºC had a darker color.

Oven drying at 50ºC gave a dried product with similar brightness as that of the fresh leaves.

Results on a* coordinate indicating greenness/redness showed that oven drying at 40°C, 50°C, shade drying and freeze drying gave products with greener color than leaves oven dried at 60°C which tend to have tinges of redness. Low oven drying temperatures as well as environmental temperature (as for shade drying) preserved chlorophyll and other colour pigments while at 60°C, the temperature induced the production of reddish brown pigments such as the melanoidins characteristic of Maillard reactions.

Considering the b* coordinate indicating yellowness/blueness, the effect of various drying application on *Moringa oleifera* leaves compared with fresh samples was in this order: FDMOL>MOL50>MOL40>SDMOL>FMOL >MOL60. This is an indication of the rate of retention and unfolding of carotenoid molecules which are yellow pigments. This indicates that freeze drying had the best effect while oven drying at 60ºC (MOL60) could have brought about higher degradation, hence loss of carotenoid as indicated by low b* value (12.06). Junqueira *et al*.(2017) reported a decrease L*, b* values (darkness and less yellowness) and an increase in a* values (more reddish) for convective drying of cape gooseberry fruits and this indicates browning reactions.

There was a significant difference ($p<0.05$) on the effect of drying applications on chroma value (C*) and hue angle (α) of the various dried *M. oleifera* leaf products. Chroma changes was in this order: FDMOL>MOL50> MOL40>SDMOL>MOL60. Chroma value indicates color saturation and is proportional to its intensity (Izli and Isik, 2015). This indicated that freeze drying had the highest effect on color saturation of dried *M. oleifera* leaves. Hue angle (α) characterizes the color of food products to aid in describing color changes (Izil and Isik, 2015).

Drying significantly ($p<0.05$) influenced the total difference in hue such that the dried products had a different color from that of the fresh vegetable which had the least hue value of 51.56. The closeness of hue values of the various dehydrated products to that of the fresh leaves was in this order: fresh leaves >MOL50>SDMOL>MOL40>FDMOL>MOL60. The higher the hue color, the farther away from the color of the fresh samples.

Izil and Isik (2015) gave a similar report whereby tomatoes oven dried at 50ºC had a closer hue (α) color to that of the fresh samples.

The various drying applications significantly ($p<0.05$) affected ΔE^*, ΔC^* and ΔH^*.ΔE indicates color difference from those of the fresh samples and was in this order: MOL60>FDMOL>MOL40>SDMOL>MOL50. Therefore oven drying at 50ºC gave a product that was closer in color to the fresh samples while oven drying temperature of 60ºC and freeze drying gave products with more intense color change.

A similar report on the effect of drying treatments on pumpkin and pepper indicated that freeze drying and oven drying at 70ºC gave products with more intense color changes than lower air drying at 30ºC (Guine and Barroca, 2012). ΔC* indicating difference in color saturation ranged between -5.27 for leaves oven dried at 60ºC and 5.96 for the freeze dried leaves when compared to that of the fresh leaves (i.e the standard).

When ΔC is positive then the sample is more saturated than the standard and negative then the sample is less saturated than the standard (HunterLab, 2001). The difference in color saturation was in this order: FDMOL>MOL50>MOL40> SDMOL>MOL60. ΔH^* is absolute color difference between two samples and it indicates the magnitude of a change in hue (HunterLab, 2001).

Total hue difference (ΔH^*) compared to that of the fresh leaves was in this order: FDMOL>MOL60>MOL40>SDMOL> MOL50. This indicated that hue color change of freeze dried *Moringa oleifera* leaves was quite different from that of the fresh leaves while oven drying at 50ºC had the least effect in inducing change in hue when compared with the fresh leaves.

Table 4: Effect of different drying applications on L*, a*, b*, Chroma, Hue, ΔE*, ΔC* and ΔH values of dried and fresh *Moringa oliefera* leaves.

Sample	L*	a*	b*	Chroma (C*)	Hue (α)	ΔE*	ΔC*	ΔH*
MOL40	35.76^{d}±0.11	-5.53^{c}±0.02	16.13^{c}±0.03	17.05^{d}±0.02	71.09^{c}±0.10	7.91^{c}±0.19	-0.41^{c}±0.12	5.85^{c}±0.03
MOL50	40.72^{b}±0.28	-8.86^{e}±0.01	20.38^{b}±0.15	22.22^{b}±0.17	66.51^{e}±0.06	7.00^{e}±0.04	4.63^{b}±0.10	5.23^{e}±0.15
MOL60	33.73^{e}±0.01	1.76^{a}±0.01	12.06^{f}±0.01	12.19^{f}±0.02	81.72^{a}±0.02	11.80^{a}±0.16	-5.27^{e}±0.09	7.59^{b}±0.01
SDMOL	36.33^{c}±0.26	-5.18^{b}±0.04	14.70^{d}±0.02	15.59^{e}±0.20	70.59^{d}±0.10	7.47^{d}±0.32	-1.87^{d}±0.30	5.45^{d}±0.06
FDMOL	43.26^{a}±0.11	-5.93^{d}±0.03	22.66^{a}±0.07	23.42^{a}±0.04	75.33^{b}±0.05	10.48^{b}±0.06	5.96^{a}±0.06	8.33^{a}±0.01
FMOL	41.06^{b}±0.20	-10.85^{f}±0.05	13.68^{e}±0.09	17.46^{c}±0.10	51.56^{f}±0.06	-	-	-

Values are means ± standard deviation. Values with different superscript in the same column are significantly different ($p<0.05$) MOL 40: *Moringa oleifera* leaves oven dried at 40^{0}C, MOL 50: *Moringa oleifera* leaves oven dried at 50^{0}C, MOL 60: *Moringa oleifera* leaves oven dried at 60^{0}C, SDMOL: Shade dried *Moringa oleifera* leaves, FDMOL: Freeze dried *Moringa oleifera* leaves, FMOL: Fresh *Moringa oleifera* leaves.

4. CONCLUSIONS

The findings of this study indicated that the various drying methods had varied effects on proximate composition while shade and freeze drying had very good effects on mineral and vitamin retention than the oven drying temperatures employed. With respect to rehydration ratio and color, results indicated that oven drying at 50°C and shade drying of *M. oleifera* leaves had the best effects on rehydration ratio. Oven drying at 50°C gave a product with the least color difference from that of the fresh leaves with respect to L*, ΔE and α values while freeze drying gave a product with the brightest color, Chroma value, color saturation (ΔC) and total hue difference (ΔH).

Scanning electron micrographs of the samples indicated a clear distinction in microstructure of fresh and dehydrated leaves. Parenchyma thickness varied with different drying methods. Therefore, freeze drying, shade drying and oven drying at 50°C will be of good use in producing dried *Moringa oleifera* leaves with good nutritional and color attributes.

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