

Original Paper

Effects of roasting temperature and storage options on the nutritional and sensorial properties of Macadamia nuts (*Macadamia intergrifolia*)

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Abstract— Macadamia nuts are a largely untapped potential source of nutrients, income, and livelihoods. There is low utilisation of this crop due to palatability issues and storability challenges. We explored the effects of roasting and storage options on the palatability, nutrient retention and subsequent storage stability of the nuts. Specifically, we investigated the effects of dry roasting macadamia nuts at different temperatures and their subsequent storage using different storage options on the nutritional and sensorial properties. The nuts were dry-roasted for 25 minutes at three different temperature regimes: 150, 160 and 170 °C, and were analyzed for nutritional composition, antioxidant activity and peroxide value. Sensorial evaluation was conducted to determine the acceptability of the dry-roasted nuts. The nuts roasted at 160 °C had the highest sensorial scores. These were then stored under three different storage conditions, [open storage (control); plastic containers and glass containers] for 3 months. Samples were collected at 2-week intervals and analysed for proximate composition, peroxide value, and sensorial properties. Results showed that an increase in roasting temperature of macadamia nuts from 150 to 170 °C caused a significant increase ($p < 0.05$) in ash, crude fat, peroxide value, and moisture content, while crude protein and carbohydrates significantly decreased. Roasting macadamia nuts at 170 °C significantly reduced their nutritional quality, while roasting at 150 and 160 °C retained the nutrients. Glass jars retained the most nutrients and organoleptic properties as compared to open storage and plastic containers where deterioration started after two and six weeks' storage, respectively. Dry roasting of macadamia nuts is a viable way of value addition, while storage in glass jars is recommended for long-term preservation.

Keywords — Macadamia nuts processing, macadamia nuts storage, hermetic storage, macadamia nuts value addition

I. INTRODUCTION

Macadamia is a collection of four species of the Proteaceae family that are indigenous to Australia where production is huge as in tropical climates of Brazil, Indonesia, Kenya, South Africa and New Zealand (1–3). The macadamia is famously important for its fruit, the macadamia nut (3). Only two species, *Macadamia intergrifolia* and *Macadamia tetraphyll* are of commercial importance. The fruit is covered by a thick husk and an extremely hard shell. It has a subtle, buttery flavour, and velvety-soft crunch that make them highly regarded by consumers (2). They are good as a snack, can be consumed as breakfast topping, in salads or as part of a main meal, either raw, roasted and salted (3). In addition, they blend well with many different flavours, making them an extremely versatile ingredient in many sweet and savory dishes. Apart from their acceptable taste and versatility, macadamia nuts are high in monounsaturated fatty acids (such as omega-7 fatty acids)(1,4,5), fibre, magnesium, copper, manganese and thiamin, and are a source of vitamins B6, niacin and minerals such as iron, phosphorus, potassium and selenium (6).

Macadamia nuts are harvested at high moisture content (up to 24 %) which makes them prone to quality deterioration as a result of enzymatic and chemical reactions (3). The high concentrations of monounsaturated fatty acids in the nut makes it prone to oxidative reactions which leads to quality deterioration through rancidity (7). Processing of the nuts could be key to enhance storability and shelf life. Common processing methods include dehusking, cracking, sorting, roasting and packaging. The quality and storage stability of the tree nuts is largely dependent on the harvesting time, variety, initial composition of the nuts, processing methods and storage techniques employed (3,5). Roasting is known to reduce

rancidity, while improving palatability (8,9). To our knowledge, there is limited data on the ideal roasting temperature and appropriate subsequent storage methods of macadamia nuts. Roasting was also shown to lower polyphenol oxidase activity, peroxide value and improve sensory properties and shelf life in macadamia nuts, while the most ideal roasting temperature was not determined (7). Previous studies involving pistachios and hazelnuts have shown that roasting significantly reduce moisture content, peroxide value, free fatty acids, thiamine and amino acid composition while heat resistant nutrients such as minerals remain highly concentrated (8,10).

Shelled nuts should be protected from moisture and oxygen influx during storage through the use of appropriate storage techniques in order to prolong shelf life and retard rancidity (11). While different types of plastic packaging have been investigated as options for macadamia nut storage (12), glass storage has not been specifically explored as a viable alternative storage option for the nuts. Our study aims to understand the effects of roasting and storage conditions on the nutritional, antioxidant activity and sensorial properties of macadamia nuts.

II. MATERIALS AND METHODS

A. Nut Preparation and Treatment

Dried macadamia nuts in shells (5 kg) were procured from Norton, Zimbabwe, and dried in an oven drier for 2 weeks at 35 °C from kernel moisture content dry basis (d.b.) of 20% to 2%. The nuts were mechanically cracked and a yield of 1.5 kg shelled nuts per 5 kg was obtained. The shelled, dry nuts were subsequently used for experimentation in this study.

B. Experimental Design, Sampling and Sample Analysis

The nuts were divided into three homogenous batches of 450g each and dry roasted for 25 min at three different treatment temperatures: 150; 160 and 170 °C, respectively. A 150g sample of raw nuts was retained at a mean temperature of 25 °C and RH of 44% (control) for comparative analysis. The roasted nuts were allowed to cool by ambient air flow. The nuts from the four treatments were analysed in triplicate for moisture, ash, crude fibre, crude protein, carbohydrates content, antioxidant activity and peroxide value. Descriptive sensory analysis was conducted for oiliness, crunchiness, taste and colour assessment. The dry roasting treatment that exhibited the best combination of nutrient retention and superior sensory qualities was selected and subjected to three different storage treatments: open storage (control); closed plastic containers and closed glass containers for a period of 3 months. Sampling was conducted at 2-week intervals and the samples were analysed for nutritional content, peroxide value and sensorial properties in the Food Science Laboratory, Department of Nutrition, Dietetics and Food Sciences, University of Zimbabwe.

C. Nutritional Analysis

Samples were firstly ground manually before analysis. Moisture content was determined using a pre-calibrated moisture meter (Model GMK-303CF, GrainPro., Subic Bay, Philippines). Protein analysis was done using the Kjeldahl

method, whereas ash, crude fibre and carbohydrate content was determined using dry ashing, gravimetric analysis and the difference method, respectively (13).

D. Antioxidant Activity and Peroxide Value

Antioxidant activity was determined using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging assay as described by (14). Absorbance was measured on Spectronic 20[®] Genesys™ spectrophotometer at 517nm. The peroxide value as expressed in milliequivalents of active oxygen in a kg of oil was determined using AOCS (1990) method Cd 8b-90.

E. Sensory Evaluation

A descriptive sensory panel with fifty untrained panellists was used. The panellists evaluated the oiliness, texture, taste and colour of the macadamia nuts using a 9-point hedonic scale, which ranged from 1 (dislike extremely) to 9 (extremely like). Sensory evaluation was conducted up to 6 weeks due to the occurrence of moulds in the openly stored nuts after 6 weeks.

F. Data Analysis

Data on proximate composition, antioxidant activity and peroxide value of the roasted nuts and that of stored nuts were subjected to one-way analysis of variance using Genstat 18th edition. Mean separation was done using Fishers Protected LSD test wherever significant differences were found. Visual charts (radar charts) plotted in MS Excel were used to present the descriptive sensory evaluation data.

III. RESULTS

A. Proximate composition

Significant differences were observed between the different treatments with regard to moisture content ($p < 0.001$). There was an inverse relationship between roasting temperature and moisture content of the nuts, with nuts roasted at 170 °C having the lowest moisture content (0.6 %), while raw nuts had the highest moisture content (1.8%) (Table 1). Ash content significantly increased at the roasting temperature increased from 160 °C ($p < 0.001$), and was highest in nuts roasted at 170 °C (1.9 g/100 g). Crude fat significantly increased with the increase in roasting temperature ($p = 0.004$), from 75.6 % in raw nuts to 79.1 % in nuts roasted at 170 °C, with no significant differences between nuts roasted at 160 and 170 °C, whereas protein content significantly decreased with increase in roasting temperature ($p < 0.001$). On the other hand, fibre significantly increased in nuts roasted at 170 °C ($p = 0.006$) (Table 1). Carbohydrate was significantly lower in nuts roasted at 170 °C only ($p = 0.012$), whereas peroxide value was significantly higher in nuts roasted at 160 °C (1.8 meq/kg) ($p = 0.016$) as compared to 1.2 and 1.5meq/kg for raw and other roasted nuts (Table 1). The Peroxide value significantly increased by 2.1 meq/kg of oil as the temperature of dry roasting increased while antioxidant activity significantly increased by 33.08% as the temperature of dry roasting increased (Table 2).

TABLE I. PROXIMATE COMPOSITION (MEAN ± S.D) OF RAW AND DRY ROASTED NUTS AT DIFFERENT TEMPERATURES FOR 25 MIN.

Treatment	Moisture (%)	Fat (%)	Fibre (%)	Protein (%)	Carbohydrate (%)	Ash (%)
Raw nuts	1.8 ± 0.05 ^d	75.6 ± 0.37 ^a	7.6 ± 0.10 ^a	8.0 ± 0.08 ^d	5.7 ± 0.35 ^b	1.3 ± 0.03 ^a
Roasting at 150 °C	1.4 ± 0.03 ^c	76.0 ± 0.88 ^a	7.7 ± 0.04 ^a	7.1 ± 0.09 ^c	5.8 ± 0.31 ^b	1.4 ± 0.04 ^a
Roasting at 160 °C	1.2 ± 0.03 ^b	77.7 ± 0.30 ^b	7.9 ± 0.06 ^a	6.6 ± 0.10 ^b	5.5 ± 0.45 ^b	1.5 ± 0.05 ^b
Roasting at 170 °C	0.6 ± 0.08 ^a	79.1 ± 0.20 ^b	8.4 ± 0.19 ^b	6.2 ± 0.10 ^a	3.8 ± 0.31 ^a	1.9 ± 0.03 ^c
P value	<0.001	0.004	0.006	<0.001	0.012	<0.001
F_{3,8}	89.16	9.99	9.19	71.8	7.04	54.24

Means were separated per column using Tukey's test, and those which do not share the same superscript letter are significantly different from one another

B. Antioxidant Activity and Peroxide Value

There were significant differences in peroxide value and antioxidant activities ($p < 0.05$) in the nuts roasted at the different temperature regimes. Peroxide value increased by 2.7 meg/kg of oil from raw nuts to a roasting temperature of at 170 °C, while that of antioxidant activity increased by 33.10% (Table 2).

TABLE II. ANTIOXIDANT ACTIVITY (%) AND PEROXIDE VALUE OF RAW AND NUTS DRY ROASTED FOR 25 MINUTES AT DIFFERENT TEMPERATURES.

Treatment	Antioxidant activity (%)	Peroxide value (meg/kg)
Raw nuts	44.00±0.36 ^a	1.2±0.05 ^a
Roasted at 150°C	63.60±0.45 ^b	1.9±0.04 ^b
Roasted at 160°C	67.98±1.72 ^c	2.8±0.12 ^c
Roasted at 170°C	77.10±0.58 ^d	3.9±0.06 ^d
P value	0.011	0.016
F_{3,8}	26.59	18.75

Fig. 5 presented are the means of each treatment. Means within a column are compared and separated using Tukey's test at $p < 0.05$ and different superscript letters indicate significant differences.

C. Sensory properties of macadamia nuts

Oiliness increased significantly with an increase in roasting temperature up to 160 °C (with a score of 6.0) and then dropped at 170 °C (3.8). Crunchiness, taste and colour exhibit the same trend with the score increasing up to 160 °C and then sharply decreasing at 170 °C (Table 3).

TABLE 3. SENSORY EVALUATION OF RAW AND DRY ROASTED MACADAMIA NUTS FOR 25 MINUTES AT DIFFERENT TEMPERATURES.

Attributes	Treatments			
	Raw nuts	Roasted at 150°C	Roasted at 160°C	Roasted at 170°C
Oiliness	4.80±1.48 ^a	6.00±1.22 ^b	6.00±2.00 ^b	3.80±1.30 ^a
Crunchiness	3.00±1.00 ^a	5.60±1.67 ^b	6.20±1.30 ^b	2.40±1.14 ^a
Taste	4.60±0.55 ^a	6.60±1.14 ^b	6.40±0.89 ^b	4.80±0.84 ^a
Colour	4.00±1.00 ^a	7.20±0.83 ^b	8.00±0.45 ^b	5.00±0.70 ^a
P value	<0.001	<0.001	<0.001	<0.001

Fig. 5 presented are the means of each treatment. Means within a column are compared and separated using Tukey's test at $p < 0.05$ and different superscript letters indicate significant differences.

D. Effects of different storage treatments of Macadamia Nuts

a. Nutritional Changes

Overall treatment effects had significant effects on ash content ($p < 0.001$), carbohydrate ($p < 0.001$), fat ($p < 0.001$), fibre ($p < 0.001$); peroxidase ($p < 0.001$), moisture ($p < 0.001$) and protein ($p < 0.001$) (Table 4a,b). Highest ash was recorded in raw macadamia nuts stored in glass containers, followed by those roasted at 160 °C and stored in glass jars. There were no significant differences with regards to ash between the roasted nuts stored in the open and those stored in plastic containers. Storage time had significant effects on ash content ($p < 0.001$), with a significant decrease observed from week 4 of storage.

Overall, carbohydrates were significantly higher in roasted nuts stored in glass containers than those in plastic containers. Fat content was significantly higher in raw macadamia nuts stored in glass jars as well as in roasted nuts stored in the open, whereas peroxide value and fibre were significantly lower in raw nuts stored in glass jars. Moisture content was highest in roasted nuts stored in plastic bags, with the least being those stored in glass jars, while protein content was highest in roasted nuts stored in glass jars, followed by those stored in plastic bags (Table 4b).

TABLE 4A. OVERALL STORAGE TREATMENT (N = 15) AND TIME (N = 12) EFFECTS ON MACADAMIA NUT NUTRITIONAL COMPOSITION.

Treatment	Ash (%)	Carbohydrate (%)	Fat (%)	Fibre (%)
Glass (raw)	1.8 ± 0.04 ^c	3.9 ± 0.09 ^a	81.3 ± 0.54 ^c	8.3 ± 0.04 ^c
Glass (160 °C)	1.4 ± 0.04 ^b	4.6 ± 0.17 ^c	79.8 ± 0.64 ^a	7.7 ± 0.08 ^b
Open (160 °C)	1.3 ± 0.06 ^a	4.3 ± 0.24 ^b	83.1 ± 1.00 ^c	7.7 ± 0.08 ^b
Plastic (160 °C)	1.3 ± 0.05 ^a	4.4 ± 0.24 ^{b,c}	81.3 ± 0.92 ^b	7.4 ± 0.08 ^a
P	<0.001	<0.001	<0.001	<0.001
F_{3,40}	250.52	9.71	58.01	71.49
Time (weeks)				
0	1.6 ± 0.05 ^d	5.1 ± 0.29 ^e	78.0 ± 0.22 ^a	8.0 ± 0.08 ^c
2	1.6 ± 0.06 ^d	4.7 ± 0.12 ^d	79.5 ± 0.38 ^b	7.8 ± 0.08 ^b
4	1.5 ± 0.07 ^c	4.3 ± 0.09 ^c	81.1 ± 0.48 ^c	7.7 ± 0.12 ^{ab}
6	1.4 ± 0.06 ^b	4.0 ± 0.05 ^b	82.1 ± 0.70 ^d	7.6 ± 0.13 ^a
12	1.2 ± 0.08 ^a	3.4 ± 0.09 ^a	86.2 ± 0.54 ^e	7.7 ± 0.15 ^a
P value	<0.001	<0.001	<0.001	<0.001
F_{4,40}	127.39	36.94	234.68	11.23

TABLE 4B. OVERALL STORAGE TREATMENT (N = 15) AND TIME (N=12) EFFECTS ON MACADAMIA NUT NUTRITIONAL COMPOSITION.

Treatment	Parameter		
	Peroxide Value (meg/kg)	Moisture (%)	Protein (%)
Glass (raw)	5.8 ± 2.10 ^a	2.9 ± 0.82 ^a	5.9 ± 0.04 ^a
Glass (160 °C)	7.1 ± 2.79 ^b	3.2 ± 0.85 ^a	6.5 ± 0.04 ^c
Open (160 °C)	8.7 ± 3.50 ^c	3.9 ± 1.46 ^b	6.0 ± 0.10 ^a
Plastic (160 °C)	8.7 ± 3.36 ^c	5.6 ± 1.21 ^c	6.4 ± 0.06 ^b
P value	<0.001	<0.001	<0.001
F_{3,40}	244.06	113.56	56.85
Time (weeks)			
0	1.8 ± 0.05 ^a	1.0 ± 0.07 ^a	6.5 ± 0.07 ^d
2	1.9 ± 0.09 ^a	1.5 ± 0.17 ^b	6.3 ± 0.10 ^c
4	2.7 ± 0.34 ^b	2.0 ± 0.16 ^c	6.1 ± 0.08 ^b
6	4.9 ± 1.11 ^c	3.0 ± 0.37 ^d	6.0 ± 0.09 ^a
12	30.0 ± 1.77 ^d	11.9 ± 0.92 ^e	6.2 ± 0.08 ^b
P value	<0.001	<0.001	<0.001
F_{4,40}	5180.86	1299.84	24.08

Means followed are separated per column using Fisher's Protected LSD test, and those which do not share the same letter are significantly different from one another.

b. Moisture content

The moisture content of the nuts increased significantly over the 12-week period in all the storage environments. The moisture content increased from approximately 1.2 % to at least 9 % in all the treatments. The highest moisture content was recorded in the openly stored nuts (~16.2 %), followed by those stored in plastic containers. There were no significant differences between roasted and raw nuts stored in glass jars ($p > 0.05$) (Fig 1.)

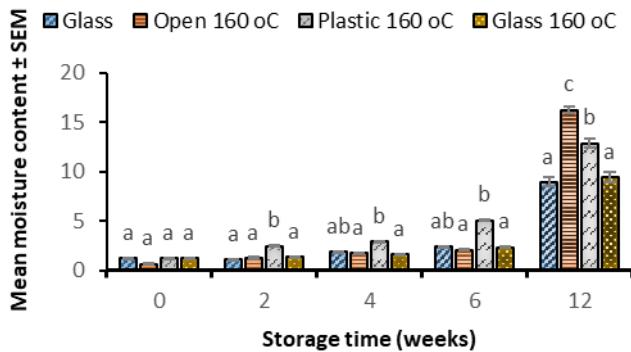


Fig. 1: Mean moisture content (± SEM) of raw and roasted macadamia nuts over 12 weeks storage period.

c. Fat content

Fat content significantly increased in all treatments over time ($p < 0.05$). There were significant differences in fat content among the different storage treatments ($p < 0.05$), with the highest fat content being recorded in the nuts stored in the open (88.2%) and in plastic containers (87.5 %). There were no

significant differences in fat content between raw and nuts roasted at 160 °C ($p > 0.05$) (Fig 2.).

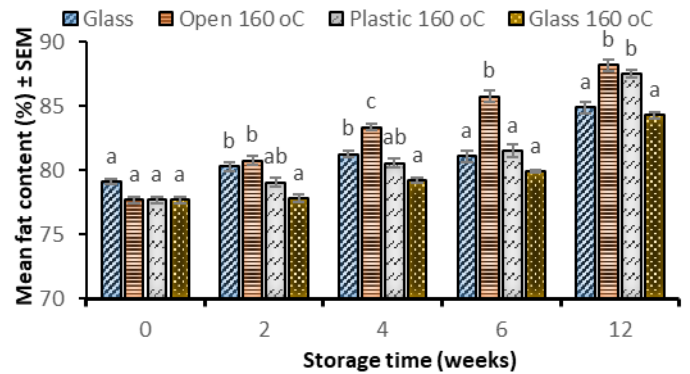


Fig. 2: Mean fat content (± SEM) of roasted macadamia nuts over a 12-week storage period.

d. Crude fibre

The initial crude fibre concentration in all the treatments was ~7.9 g/100g. There was a significant decrease in crude fibre concentration in openly stored nuts to ~7.0 g/100g. Crude fibre in openly stored nuts decreased by 0.6 g/100g and those in the glass container increased by 0.01 g/100g (Fig 3).

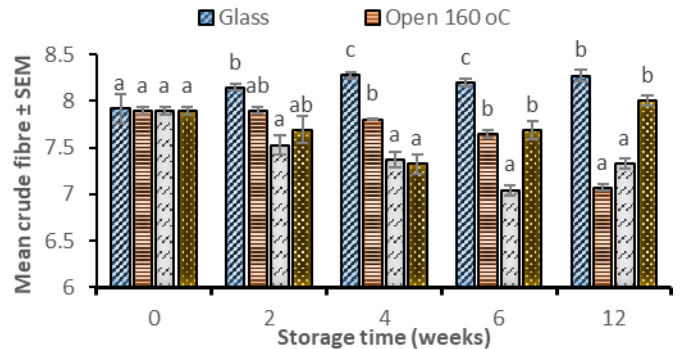


Fig. 3: Mean crude fibre content (± SEM) of roasted macadamia nuts over a 12-week storage period.

e. Ash content

The change in ash content was similar with the highest change of 0.22 g/100g in the open storage and 0.17 g/100g in the glass container over the first 6 weeks of storage. During the entire storage period however, the ash content significantly decreased ($p < 0.05$) to 0.88 g/100g, 1.06 g/100g and 1.17 g/100g in the open, plastic and glass storage respectively from an initial of 1.57 g/100g (Fig 4).

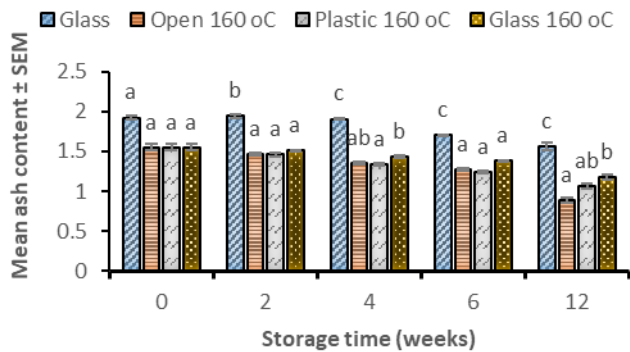


Fig. 4: Changes in mean ash (\pm SEM) of roasted macadamia nuts over 12 weeks' storage period.

f. Protein and Carbohydrate content

The protein content did not change significantly ($p < 0.05$) in all the storage treatments with the protein decreasing by 0.6 g/100g, 0.2 g/100g and 0.2 g/100g in the open, plastic and glass storage respectively, from an initial of 6.5 g/100g. A significant decrease in carbohydrate content was observed in all three storage treatments ($p < 0.05$) over the 12-week storage period. The highest decrease was observed in the plastic stored nuts (5.5 g to 3.0 g) and the lowest decrease in the glass stored nuts (5.5 g to 3.8 g) over the 12-week storage period (Fig 5).

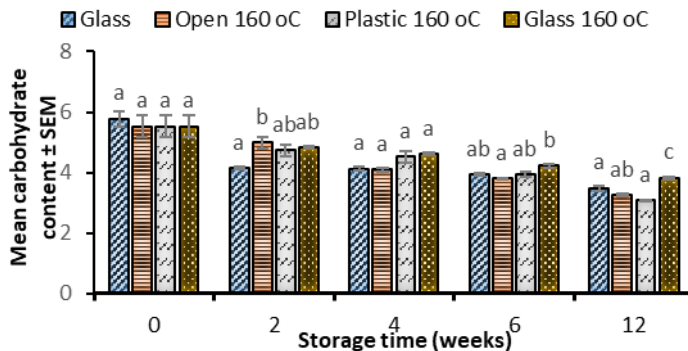


Fig. 5: Mean Carbohydrate Content (\pm SEM) of roasted macadamia nuts over 12 weeks' storage period.

g. Peroxide value

Peroxide value increased significantly ($p < 0.05$) in the openly stored nuts with a total increase in peroxide value of 9.4 meq/kg oil in six weeks. Peroxide value also increased significantly in the plastic stored nuts to 3.7 meq/kg oil, with the nuts in the glass container increasing slightly to 2.2 meq/kg oil from an initial of 1.8 meq/kg oil. However, over 12-weeks peroxide value increased significantly ($p < 0.05$) to 36.6 meq/kg oil, 33.8 meq/kg oil and 27.9 meq/kg oil in open, plastic and glass storage respectively (Fig 6).

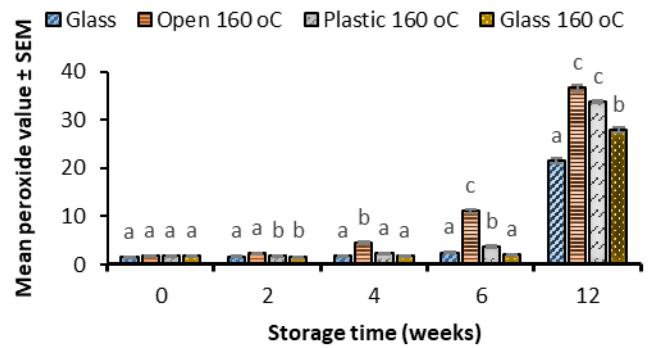
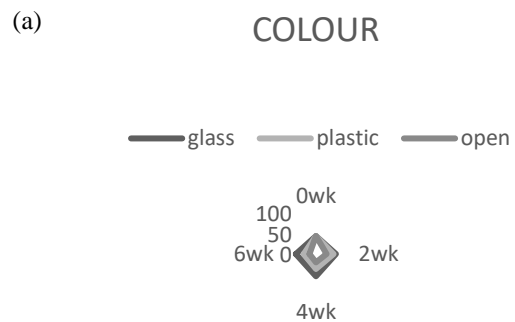


Fig. 6: Mean peroxide value (\pm SEM) of roasted macadamia nuts over 12-weeks storage period.

E. Sensorial Changes

A significant difference in colour between treatments was observed at 4 weeks, as nuts stored in glass jars scored a mean percentage of 49% followed by the nuts stored in plastic jars with a score of 43.1% and lastly those in open storage with a score of 26%. The most acceptable roasted macadamia nuts were the one stored in the glass jar, with likeness of 49%. The macadamia nuts stored openly significant changed in colour to an undesirable dark brown colour throughout the storage period of 6 weeks (Fig 7a). A significant difference in oiliness was observed at 4 weeks, for all the three storage treatments, with the least acceptance oiliness and rancid smell being recorded in nuts openly stored (Fig 7b). A significant difference in taste was observed at 4 and 6 weeks for all the storage treatments. The glass jar treatment had the highest mean taste score (20%) therefore the most acceptable, followed by plastic jar treatment (10%) and lastly the control (2%) at 6 weeks of storage (Fig 7c). Significant difference in nut crunchiness between the treatments was observed over the 6-week storage period. The glass jar treatment had the most preferred crunchiness (33%), while the control treatment had the lowest (9%) i.e. soft and less crunchy (Fig 7d). Sensory evaluation was conducted up to 6 weeks due to visible moulding observed at 12 weeks.



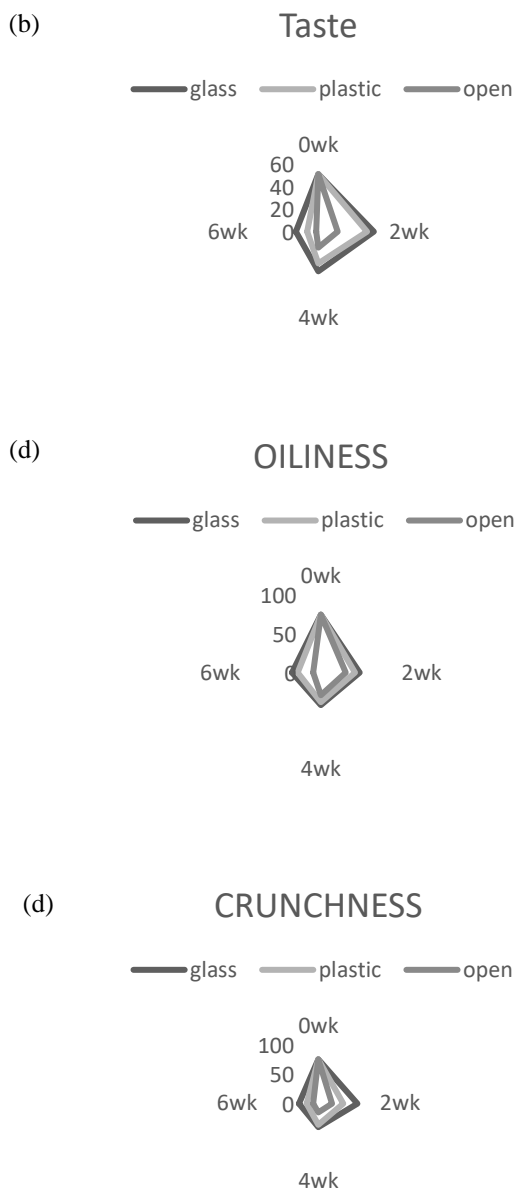


Fig. 7: Mean colour (a), oiliness (b), taste (c) and crunchiness (d) scores (\pm S.D) of macadamia nuts roasted at 160°C for 25 minutes during the storage period (conducted only up to 6 weeks).

IV. DISCUSSION

The increase in the concentration of crude fat, crude fibre and ash in macadamia nuts with the increase in roasting temperature, while moisture, protein and carbohydrate content decreased is similar to findings in experiments involving cashew and hazel nuts (10,15). A significant reduction in moisture content lengthens the shelf life of the nuts whereas high moisture content is associated with increased development of microbes, as well as increased chemical reactions which results in spoilage and browning (3,7).

The decrease in protein content with increase in roasting temperatures is attributed to structural and conformational changes that nut proteins undergo as a result of Maillard reactions (16). High temperatures encountered during roasting contribute to protein denaturation, thus reducing the protein content of the nuts (16). These findings are in line with findings by Tu et al., (2021) who also recorded significant protein decrease following roasting of two varieties of macadamia nuts. This has implications of decreasing protein solubility, while increasing roasting times at a given temperature (18). Moreover, high temperature processing enhances protein digestibility, but can degrade proteins, hence reduces the content of essential amino acid such as lysine (19). Likewise, the loss of carbohydrates as roasting temperature increased can also be attributed to the Maillard reactions between amines, aldehydes, amino acids, and the carbonyl group of reducing sugars. These reactions result in flavor enhancement in the nuts (9,16). Roasting, thus, reduces the bioavailability of carbohydrates, but results in the development of flavour compounds that are desirable to the consumer (9).

Our results showed an increase in ash content as the roasting temperature increased. These findings are similar to those of (20) in roasted cashew nuts and peanuts. The increase in ash content shows that the proportion of minerals was on the increase. This is beneficial as they help retard the growth of microorganisms in foods (21). Roasted nuts, thus, have reduced risk of microbial contamination and as a result have increased shelf life.

The increase in crude fat content of macadamia nuts as the dry roasting temperature increased can be attributed to the disintegration of cell structures, complex organic compounds, and membranes of the nut kernel to release free fat molecules (6). On the other hand, a significant increase in crude fibre as the temperature increased can be attributed to the altered chemical and physical properties of nut cell walls, which affects dietary fibre content. High temperatures results in disruption of bonds between the glycosidic linkages cleavage and polysaccharides, which leads to greater availability of dietary fibre. As a result, nuts roasted at 170 °C have a higher bioavailability of the dietary fibre.

The increase in antioxidant activity and peroxide value of macadamia nuts as the dry roasting temperatures increased means that roasting nuts at higher temperatures increases the risk of rancidity, an undesirable quality attribute (4,7,9). On the other hand, the production of Maillard browning products have inherent antioxidant activities that have the potential to protect the tocopherols from degradation (9) The increase in peroxide value is an indicator of primary lipid oxidation which can start immediately after roasting. The findings of this study shows that increasing the roasting temperature of macadamia nuts reduces the shelf life of the product.

The texture, taste and colour of nuts roasted at 160 °C was preferred the most, while the oiliness of the nuts roasted at 150 °C was preferred the most. Although the oiliness of nuts roasted at 150 °C was the most preferred, the nuts roasted at 160 °C retained most nutrients. This shows that 160 °C is the optimum roasting temperature for macadamia nuts. Reduction of moisture during dry roasting of nuts usually makes them crunchy (9,20).

Non-enzymatic browning reactions (Maillard reactions) as well as caramelisation occurs during roasting, and may result in the formation of brown pigments, and development of pleasant flavour substances thereby enhancing the attractive colour of the roasted nuts (9,10,16,22,23).

The nuts roasted at 160 °C and stored in glass jars retained favourable nutritional and sensorial properties as compared to those stored in plastic containers and in the open. Following these findings, we recommend the storage of roasted macadamia nuts in glass containers for extended storage periods and for good nutrient retention.

The significant increase in moisture content from 0 to 12 weeks in all the storage methods is similar to findings by (6) who reported that almonds picked up moisture depending on their initial moisture content and the humidity of the surrounding environment and the storage temperature can play a critical role (6). In this study, macadamia nuts stored in glass jars showed the least moisture content gain as compared to nuts stored in open crucibles and plastic jars. Similarly, in studies by (24) where the shelf life of integral biscuits (snacks) made from cashew nuts were stored in plastic packaging, an increase in moisture content was recorded over the storage duration. This was attributed to high relative humidity which resulted in yeast development and moulding.

In our study, we recorded a significant increase in the fat content of the nuts over the 12-week storage period. These results followed the same trend as those by (25) and (26) who recorded an increase in triacylglycerols with monounsaturated and saturated fatty acids over time in Pistachio nuts and hazelnuts. In addition, fat content was also higher in nuts stored in the open and in plastic jars. This could be attributed to higher oxidative changes that occur in thin plastic packaging which results in increased concentration of hexanals under high oxygen concentrations (27,28). Hexanals have been reported as one of the main products of oxidation affecting storage stability of roasted peanuts, almonds and other nuts (29–32).

Fibre content decreased significantly over the first 6 weeks of storage in all the treatment units, with greatest decrease in the open storage. This can be attributed to high moisture content in open storage, which accelerates fibre degradation. The sharp decrease in fibre content in openly stored nuts (control treatment) corresponded with a higher increase in moisture over the storage period, unlike in other storage treatments (glass and plastic) which have minimal interactions with the outside environment. In another study by (33) on storage of processed cashew nuts over 20 weeks' period in plastic jars, crude fibre also decreased over time. Over the entire storage period, the nuts stored in glass showed the best fibre retention than both plastic and open storage. There was no significant difference in protein content over the 12 weeks' storage period. However, this is in disagreement with other authors who reported a decrease in protein content over time during storage in cashew nuts (33) and ginkgo nuts (34).

Similar studies also reported an increase in peroxide value of stored roasted peanuts similar to our study (35,36). Lipid oxidation occurs during storage of macadamia nuts and contributes to the development of undesirable flavours in foods where macadamia nuts are an ingredient (17). The Peroxide

value of macadamia nuts stored in open crucibles increased the most and over the recommended value of 10.0 meg/kg of oil by the FAO and WHO over the first six-weeks (37). However, over the entire period the peroxide value of all the nuts increased significantly exceeding the maximum permissible limit.

Macadamia nuts stored in glass jars had the highest sensory scores in all the attributes investigated. This is attributed to the strict control of storage humidity through minimized water vapour transmission. This preserves acceptability to consumers since texture attributes are more susceptible to moisture absorption, as water softens the structure and decreases the fracturability associated with firm, crunchy nuts. This explains the lowest scores in the crunchiness attribute recorded in the macadamia nuts stored in the open in our study as it was more susceptible to moisture gain hence increasing the nut's water activity. It was reported that limiting moisture and oxygen transfer through polypropylene packaging of hazel nuts may not effectively reduce the rate of chemical reactions within the nuts (38). This is in agreement with this study as the macadamia nuts that were stored in plastic jars showed a decrease in the overall acceptance of the nuts from the 0 week to 6 weeks of the storage period.

Poor taste scores were reported mostly for macadamia nuts stored in the open from the 2nd to the 6th week of storage and at the 6-week storage period of nuts stored in plastic containers. This can be attributed to the development of cardboardy and other off flavours due to increased rancidity and lipid deterioration in these environments as opposed to glass. Lipid oxidation is responsible for off-flavours in nut products and lead indirectly to the formation of numerous aliphatic aldehydes, ketones, and alcohols (29,35,39). Overall, proper value addition of the nuts and other produce is vital in mitigating postharvest losses and improving income earnings.

V. CONCLUSION

The fat, fibre, ash content, peroxide value and antioxidant activity of macadamia nuts increased with an increase in roasting temperature. Increasing roasting temperature beyond 160 °C leads to rancidity and loss of proteins and carbohydrates in macadamia nuts. The optimum roasting temperature for macadamia nuts is 160 °C. It is recommended to ensure nutrient retention and consumer preference in terms of taste, oiliness and crunchiness of the nuts. However, higher roasting temperature improves organoleptic properties and keeping quality of the macadamia nuts. Glass jars are most effective packaging for storing roasted macadamia nuts for a period of 12-weeks since they retained the highest levels of nutrients and organoleptic properties followed by plastic jars and open jars. The use of glass jars is recommended as it increases the shelf life of the roasted nuts. This may promote export as freshness of the product is preserved, thereby ensuring income, and food and nutrition security.

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