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Effects of Drying Methods and Packaging Materials on Protein and Carbohydrate Contents of Dried Mango Chips

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Abstract: This study was carried out to determine the effects of drying methods (sun, solar and oven) and packaging materials (glass bottle, corn-starch, plastic and polyethylene) on the protein and carbohydrate content of mango chips stored for four months. Kieth and Julie varieties of mango were obtained from Sebore Farms in the Mayo Belwa Local Government Area of Adamawa State, Nigeria and from the orchard of Modibbo Adama University, Yola. After washing, pre-cooling, blanching, and chips preparation at the Department of Crop Production and Horticulture at MAU**, the samples were weighed and then dried in the open sun, solar cabinet dryer, and oven at temperatures of** 31.69°C**, RH 58.41%, 32.65^{0}C, RH 56.19%, and** 70°C**, respectively. The effects of drying methods and packaging materials on the nutritional value of dried mango chips were determined using protein and carbohydrate content as parameters. The experimental design was a split-split plot with three replications. Data collected were subjected to Analysis of variance using Genstat Discovery Edition software, and the means separated using Least Significant Difference (LSD) at 5% level of probability (P≤0.01). The results indicated that oven-dried samples had higher concentrations of retained nutrients than solar and sun-dried samples, both before and after the commencement of storage, while glass bottle packaging material retained the highest percentage of nutrients compared to corn, starch plastic, and polyethylene packaging materials. Therefore, when choosing drying methods and packaging materials for food products, it is necessary to give attention and careful consideration to factors that are detrimental to maintenance of quality and integrity of food materials during storage, especially moisture and air (gasses); as these will impact on shelf-life, safety and quality of stored products.**

Keywords: *Effects, Drying, Packaging, Safety, Quality and Shelf-Life.*

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I. INTRODUCTION

Mangifera indica, L., is the most important species of the genus *Mangifera*, and it produces the most delicious fruits known as mango (Deependra and Singh 2017). The Highest concentration of this species is found in the western part of Malaysia (Malay Peninsula, Sumatra, Java, and Borneo). The primary center of origin of the genus Mangifera is considered in the region of Myanmar (Burma)-Siam- Indochina or Malay Archipelago and the secondary center in the Sunda island (Java, Sumatra, Borneo)- the Philippines and Celebs-Banda-Timor group (Mukherjee, 1985).

Flowering typically starts 3–6 years after planting, but this timing can vary depending on environmental factors and the specific variety of mango (Singh et al., 2022). The tree begins bearing fruit at the age of 5 to 8 years, with full

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production typically achieved after 10 years (Thimmappaiah & Kumar, 2021). The fruit is ovoid to oblong in shape and varies in size from small to large, depending on the cultivar, with some mangoes weighing up to 2 kg (Litz, 2009). The fruits are harvested by hand or with a long stick and hook at the top, typically during the late spring to early summer months (Medlicott & Thompson, 2005). Harvesting methods are crucial to avoid damage to delicate skin and ensure that the fruits reach consumers in optimal condition (Yahia & Serrano, 2020).

As with other fruits and vegetables, great losses are incurred in mangoes due to the lack of adequate storage infrastructure, poor transportation systems, inadequate industries, and the lack of technological know-how by farmers in developing countries. These factors result in huge numbers of mango fruits that are wasted, especially during the bumper harvest, which results in a market glut of the fruit. To address this issue and make the fruits available year-round, (especially in the tropics, where the fruit is seasonal) drying, which extent shelf-life, comes handy.

In this study, Keith and Julie mango varieties were used. Keitt (Keith) mangoes are large and oval shaped, with a tangy, citrus flavor and juicy flesh. They turn medium green when ripe and have thin seeds. Keitt mangoes are mainly grown in Mexico, Ecuador, Brazil, and the US (healthcare media UK Ltd, Brighton UK 2024).

Julie mango, on the other hand, is much smaller in size than the Keitt. It is characterized by its flat, oval shape, sweet, and rich flavor, with a hint of spice that makes it distinct. The skin of Julie mango is usually deep yellow with occasional red blush when ripe, and the flesh is soft and fiberless. This variety is especially popular in the Caribbean, where it is often grown in home gardens and is valued for its unique taste and texture (Mangoes of the Caribbean, 2023).

Drying is the process by which moisture is removed from a product to prevent spoilage and extend its shelf life. This process is crucial for the preservation of various agricultural products, including fruits, vegetables, and grains. Drying involves the application of heat to vaporize water and remove water vapor after separation from food tissues, (Afolabi, 2014). Therefore, the water activity level of the product is reduced. This makes the environment less favorable for microbial growth and enzymatic reactions, which are the primary causes of spoilage. After the drying process is complete, packaging and eventual storage are performed, typically in warehouses or on shelves to protect the dried product from moisture reabsorption and contamination.

Packaging entails enclosing the dried product in materials that prevent exposure to air, moisture, and contaminants, thereby ensuring its long-term preservation. The packaging material must be selected based on its barrier properties, mechanical strength, and suitability for the product's storage conditions. For example, vacuum sealed or nitrogen-flushed packaging is often used to extend the shelf life of dried goods by minimizing oxygen exposure, which can lead to oxidation and spoilage. Proper packaging also includes clear labelling for traceability, nutritional information, and usage instructions (Packaging Science Association, 2024).

The objective of the study was to determine the effects of drying methods (sun, solar and oven) and packaging materials (glass bottle, corn-starch, plastic and polyethylene) on the protein and carbohydrate content of mango chips before and after storage.

II. MATERIALS AND METHODS

Fresh mature-green mango fruits were harvested from Sebore farms in the Mayo Belwa local government area of Adamawa State, Nigeria. It is situated within the north eastern part of Nigeria, which is characterized by diverse topography and a rich agricultural landscape. Sebore Farms lie between latitudes 9°10'00" N and 9°15'00" N and longitudes 12°25'00" E and 12°30'00" E. This designation places it within the Sudan Savanna ecological zone, which is known for its semi-arid climate and grassland vegetation. The orchard of Modibbo Adama University is situated between latitudes 90 20' 00" and 90 21' 30" N and longitudes 120 29' 00"E and 120 30, 30"E. It has a tropical climate with distinct dry and wet seasons. The precipitation in the region begins in April and ends in October, indicating the wet season, whereas the dry season starts in November and ends in March. The area experiences a minimum average temperature of 20.5°C and can reach a maximum temperature of up to 40°C (Adebayo & Zemba, 2020). The harvested mangoes were brought to the Department of Crop Production of Modibbo Adama University Yola, for processing and drying where drying was conducted. The drying was considered complete once constant weights were obtained, indicating that the moisture content had reached a stable level and that further drying did not significantly reduce the weight of the samples.

➢ *Data Analysis*

Results of the data recorded were analyzed using analysis of variance (ANOVA) with Genstat Discovery Edition Software, and the means were separated by least significant difference (LSD) at the 5% level of probability.

➢ *Proximate Analysis*

Proximate analysis of protein and carbohydrate content was carried out in accordance with the AOAC standards (2016)

- *Determination of the Crude Protein*

The micro Kjeldahl method described by AOAC (2016) was used. Two grams of each sample were mixed with 10ml of concentrated H_2SO_4 in a heating tube. One tablet of the selenium catalyst was added to the tube, and the mixture was heated inside a fume cabinet. The digest was diluted with distilled water in a 100ml standard flask. 10ml portion of the digest was mixed with an equal volume of 45 % NaOH solution and then poured into a Kjeldahl distillation apparatus. The mixture was distilled, and the distillate was collected into a 4% boric acid solution

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containing 3 drops of methyl red. A total of 50ml distillate was collected and titrated. The sample was analyzed in triplicate, and the average value was obtained. Nitrogen contents were calculated and multiplied by 6.25 to obtain crude protein contents.

$$\% \, Nitrogen = \frac{(100 \times N \times 14 \times VF)T}{100 \times V_a} \quad (1)$$

Where:

N = Normality of the titrate (0.1N)
VF = Total volume of the digest = 100ml
T = Titer value
V_a = Aliquot volume distilled

- *Determination Of Carbohydrate Content*

The nitrogen-free method described by AOAC (2016) was used. Carbohydrate content was calculated as weight by the difference between 100 and the summation of other proximate parameters as nitrogen-free extract (NFE).

$$\% \, Carbohydrate \, (NFE) = 100 - (M + P + F_1 + A + F_2) \quad (2)$$

Where:

M = Moisture content
P = Crude protein
F_1 = Fat content
A = Ash content
F_2 = crude fiber

- *Sensory Evaluation*

Sensory evaluation was conducted using twenty (20) panelist selected randomly from the staff and some members of the Modibbo Adama University community.

Chips production occurred at the laboratories of the Department of Crop Production and Horticulture at the university.

Pre-cooling, washing, and hot-water blanching precede chips production. A kitchen knife was used for slicing the fruit to make the chips. The samples were weighed using sensitive balance where two (2) kilograms of each sample were dried. Some samples were sun dried for 8 days at an average ambient temperature of 31.69^{0}C and RH 58.41%, some were dried using a solar cabinet dryer constructed from locally sourced materials for 7 days at an average collector temperature of 32.65^{0}C and RH 56.19%, and others were oven dried for 60 hours at a constant temperature of 70^{0}C.

For sensory evaluation, the selected panelists were requested to make their choices and indicate their preferences in terms of taste, chewiness, color (appearance), and overall acceptability. They showed clear preference for the sun-dried samples that were brighter, attractive, and enticing in terms of color as opposed to the dark color of the oven-dried samples that were sweeter in terms of taste.

III. RESULTS

- *Effects of Drying Methods on the Proximate Compositions of Dried Mango Chips at the Time of Storage*

The mean performance of the effects of drying methods on the crude protein content of dried mango chips at the commencement of storage is presented in Table 1. With respect to drying methods, there were highly significant differences (P≤0.01) among the drying methods at commencement of storage in 2022, but in 2023, there were no significant differences (P≥0.01) observed among the drying methods on the crude protein content. In 2022, the sun drying method significantly differed in crude protein content (1.37%) compared with oven and solar drying methods (2.41% and 2.23%, respectively. These two values were not statistically different from one another. No significant differences (P≥0.01) were observed in 2023 among the drying methods (Table 2). Protein content remained consistent across all drying methods.

Table 1 Effects of Drying Methods on Protein Contents of Mango Fruit at the Time of Storage

	Protein Content (%)	
Treatment	2022	2023
Drying Methods		
Sun	1.37	2.58
Solar	2.23	2.78
Oven	2.41	2.79
P<F	0.001	0.107
LSD	0.052	0.225

- *Protein Content of Dried Mango Chips During Storage*

The mean performance of the effects of drying methods and packaging material on the protein content of dried mango fruit stored at different sampling periods for 2022 and 2023 is presented in Table 2. For the drying methods, there were significant differences (P≤0.01) among the effects of the various drying methods on protein percentage in the first and fourth months of storage, but no significant differences (P≥0.01) were observed in the second and third months of storage. In the first month, the oven drying method recorded the highest percentage (2.34%), followed by the solar drying method with 2.27%, while the sun drying method with 2.16% recorded the lowest value. No significant differences (P≥0.01) were observed in the second and third months of storage. In the fourth month, there was a significant difference (P≤0.01) between the

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effects of the oven drying method (1.73%), which was the highest in the month, and the solar drying method's effect (1.52%), which was the lowest. The sun drying method also resulted in 1.68%

In 2023, highly significant differences (P≤0.01) were observed among the different drying methods in their effects on the protein content of dried mango chips stored. The difference was only in the first and third months of the storage period. No significant differences (P≥0.01) were observed in the second and fourth months. In the first month of storage in 2023, 2.70% recorded by the effect of the oven drying method on the protein content of dried mango fruit was higher than the 2.33% recorded by that of the solar cabinet dryer. The sun drying method with 2.29% of the samples was the lowest value recorded, and it differed significantly (P≤0.01) from the highest value. No significant differences (P≥0.01) were observed in the second month. In the third month, the lowest value of 2.42% recorded by the oven drying method differed significantly from the highest values of 2.74% and 2.73% recorded by the effects of the solar cabinet and sun drying methods, respectively. These two values were not statistically different from each other. There were no significant difference (P≥0.01) in the effects of the different drying methods on the percentage of protein in dried mango chips in the fourth month of storage.

The effect of the various packaging materials on the percentage of protein in dried mango fruit in storage were highly significantly different (P≤0.01) from one another throughout the storage period in 2022. The first month of storage in 2022 contained polyethylene packaging material with 1.89% protein percentage, which was the lowest recorded value in the month and significantly lower and different (P≤0.01) from the highest value of 2.80% recorded for plastic packaging material, which was followed by Glass bottle packaging material with 2.35%. In the second month, polyethylene packaging material had a value of 2.69%, followed by plastic packaging, which had the highest value of 2.71%. These values differed from the lower value of 2.15% recorded for corn starch packaging. Again, in the third month of the storage period, polyethylene packaging material had the highest protein content at 2.63%, followed by glass bottle packaging material at 2.52%. The lowest value of 2.06% in month was recorded for the effect of corn starch packaging material on the protein content of dried mango chips.

The fourth month was observed to have corn starch packaging material with a content of 2.03%, which differed significantly (P≤0.01) from the other packaging materials. The lowest value of 1.20% was recorded for the glass bottle packaging material. Plastic packaging material: 1.99% In 2023, packaging materials were observed to have had significant differences (P≤0.01) in their various effects on the protein content of dried mango chips stored. In the first month of storage, polyethylene packaging material accounted for 2.16%, which was lower than the highest value of 2.95% recorded for plastic packaging material. Corn starch and glass bottle packaging materials also recorded 2.34 and 2.32%, respectively. In the second month, corn starch packaging material recorded the highest value of 2.95%, followed by 2.87% recorded by that of plastic packaging material, while the second was brought by the effect of Glass bottle packaging material, with 2.35%. In the third month, polyethylene packaging material had the highest value of 2.82%, followed by corn starch packaging material with 2.72%, and the lowest value of 2.48% was recorded by the effect of Glass bottle packaging material. Significant differences (P≤0.01) observed in the fourth month of the storage period showed that corn starch packaging material with 1.78% was the highest value recorded in the month; it followed by polyethylene packaging material with 1.63%, while plastic packaging materials recorded the lowest value of 1.56%.

Table 2 Effects of Drying Methods and Packaging Materials on the Crude Protein Content of Dried Mango Chips During Storage

	Year 2022					**Year 2023**			
Treatments	**1st Month**	**2nd Month**	**3rd Month**	**4th Month**		**1st Month**	**2nd Month**	**3rd Month**	**4th Month**
Drying Methods									
Sun	2.16	2.51	2.53	1.68		2.29	2.88	2.73	1.70
Solar	2.27	2.39	2.48	1.52		2.33	2.72	2.74	1.63
Oven	2.34	2.55	2.19	1.73		2.70	2.67	2.42	1.59
P<F	0.029	0.53	0.058	0.05		≤0.001	0.31	≤0.001	0.45
LSD	0.131	0.32	0.297	0.172		0.123	0.31	0.075	0.19
Packaging Methods									
Glass bottle	2.35	2.38	2.52	1.20		2.32	2.35	2.48	1.60
Corn starch	2.00	2.15	2.06	2.03		2.31	2.95	2.72	1.78
Plastic	2.80	2.71	2.39	1.99		2.95	2.87	2.50	1.56
Polyethylene	1.89	2.69	2.63	1.36		2.16	2.86	2.82	1.63
P<F	≤0.001	≤0.001	≤0.001	≤0.001		≤0.001	0.002	≤0.001	0.019
LSD	0.193	0.285	0.202	0.172		0.113	0.313	0.130	0.141

The mean performance of the effects of variety and drying method on the percentage carbohydrate content of dried mango chips at the commencement of storage is presented in Table 3. With regard to drying methods, highly significant differences (P≤0.01) both in 2022 and 2023 were observed among drying methods regarding percentage

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carbohydrate content. In 2022, the sun drying method differed significantly lower in carbohydrate content (74.95%) compared to oven drying and solar cabinet drying methods (89.57% and 78.94%, respectively. Also in 2023, the sun drying method differed significantly lower in percentage carbohydrate content with 78.49% compared to oven drying and solar cabinet drying methods percentage carbohydrate content (78.49% versus 82.95% and 81.00%, respectively. These drying methods were statistically the same; no significant difference existed among them (Table 3). Therefore, the choice of drying method may not have a significant impact on the carbohydrate content of the final product.

Table 3 Effects of Drying Methods on Carbohydrate Contents of Mango Fruit at the Start of Storage

	Carbohydrate Content (%)	
Treatment	2022	2023
Drying Methods		
Sun	78.94	78.49
Solar	74.95	81.00
Oven	89.57	82.95
P<F	≤0.001	≤0.001
LSD	0.570	2.013

➢ *Carbohydrate Content of Dried Mango Chips Stored*

The mean performance of the effects of drying methods, and packaging materials on the carbohydrate percentage of stored dried mango chips at different sampling periods is presented in Table 4. Regarding drying methods, in 2022, there were highly significant differences (P≤0.01) all through the storage period among the drying methods on the carbohydrate percentage of dried mango chips. In the first month in the store, the oven drying method recorded the highest carbohydrate percentage (77.51%). Th1s value differed significantly from those of the other drying methods, where the sun drying method with 74.87% carbohydrate content did not differ significantly from the solar cabinet drying method with 74.05%. Similar trends were observed in the second, third, and fourth month of the storage period.

In the second month of storage, drying method recorded the highest carbohydrate percentage of 75.84%, which differed significantly (P≤0.01) from the lower value of 72.82% recorded by the solar cabinet drying method. Sun drying method recorded 73.92% carbohydrate in the same month. In the third month of storage, the table indicates that the solar cabinet drying method with 68.35% carbohydrate content was the lowest value recorded, and it differed significantly (P≤0.01) from the highest value of 73.64% carbohydrate content recorded by the oven drying method. Sun drying method recorded a carbohydrate percentage of 70.52% in the same month. In the fourth month of storage in 2022, the solar cabinet drying method with 72.00% carbohydrate was the lowest carbohydrate percentage recorded in the month, and it differed significantly (P≤0.01) from the highest value of 74.22% recorded by the oven drying method, which was not statistically different from the 74.00 recorded by the sun drying method.

In 2023, there were significant differences (P≤0.01) amongst the drying methods in their effects on the carbohydrate content of dried mango chips throughout the months of storage, except in the fourth month, which recorded no significant difference (P≥0.01). In the first month, the solar cabinet drying method recorded a carbohydrate percentage of 76.94%. This value differed significantly (P≤0.05) from the highest values of 77.81% and 77.12% recorded by the sun drying and oven drying methods, respectively. However, these two values were not statistically different from one another. In the second month, oven drying method produced a carbohydrate percentage effect of 75.51%. This value differed significantly (P≤0.05) from the lowest values of 74.37 and 74.64% recorded by the solar cabinet and sun drying methods, respectively. However, these two values were not statistically different from one another. In the third month of storage, sun drying method with 73.13% carbohydrate content differed significantly (P≤0.01) from the lowest value of 70.20% recorded by solar cabinet drying method, while oven drying method also in the same month recorded a 71.76% carbohydrate content effect on the dried mango chips stored.

Regarding packaging materials, highly significant differences (P≤0.01) existed among the various packaging materials throughout the four months of storage in 2022 in terms of carbohydrate content's effects on the stored dried mango chips. In the first month of storage, glass bottles had the highest percentage carbohydrate effect (78.34%) followed closely by polyethylene packaging material (77.59%). These values differed significantly higher (P≤0.01) from the 72.23% value recorded by corn starch packaging material. A similar trend was observed in the second and third months of storage. In the second month of storage, corn starch packaging material had the lowest value of 70.01% carbohydrate effect, which differed significantly from the highest value of 80.64% recorded for the glass bottle packaging material. Polyethylene packaging material contained 74.41% carbohydrate in the same month. In the third month of the storage period, polyethylene packaging material exhibited a carbohydrate percentage effect of 71.14%, which followed the highest value of 76.44% recorded for the effect of Glass bottle packaging material. These values differed significantly from the lowest value of 66.30% recorded for the corn starch packaging material. However, in the fourth month, polyethylene packaging material recorded the highest value of 76.19% carbohydrate percentage, followed by Glass bottle packaging material

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with 74.75%, whereas plastic packaging material differed significantly (P≤0.01) lower with 70.44% of the carbohydrate content of dried mango chips during storage.

In 2023 too, just as in 2022, there were highly significant differences (P≤0.01) amongst the packaging materials with regard to the carbohydrate content effect of dried mango chips stored throughout the four-month period. In the first month of 2023, polyethylene packaging materials had the highest carbohydrate content of 78.81%, followed by Glass bottle packaging material, which recorded 78.39%, whereas corn starch packaging material had a significantly lower (P≤0.01) value of 75.28%. In the second month of 2023, polyethylene packaging material accounted for 75.85% carbohydrate, following the highest percentage of 79.50% recorded for glass bottle packaging material. These values were higher and significantly differed (P≤0.01) from the lowest value of 70.24% recorded for corn starch packaging material.

In the third month, the 75.35% carbohydrate percentage effect recorded by the packaging material of glass bottles differed significantly higher (P≤0.01) from the lowest percentage value of 66.34% recorded by corn starch packaging material. Plastic packaging material had 73.27% in the same month. The fourth month of the storage period in 2023 showed that 69.82% of carbohydrate was packaged in polyethylene followed by the highest percentage of 73.04% recorded in glass bottle packaging material. These values were higher and significantly different (P≤0.01) from the lowest percentage of 62.95% recorded by corn starch packaging material in the same month.

Table 4 Effects of Drying Methods and Packaging Materials on the Carbohydrate Content of Dried Mango Chips During Storage

Treatments	Year 2022					Year 2023			
	1st Month	2nd Month	3rd Month	4th Month		1st Month	2nd Month	3rd Month	4th Month
Drying Methods									
Sun	74.87	73.92	70.52	74.00		77.81	74.64	73.13	67.97
Solar	74.05	72.82	68.35	72.00		76.94	74.37	70.20	69.37
Oven	77.51	75.84	73.64	74.22		77.12	75.51	71.76	66.17
P<F	≤0.001	≤0.001	≤0.001	0.013		0.006	0.002	0.046	0.081
LSD	0.620	0.518	0.523	1.42		0.466	0.505	2.224	2.80
Packaging Methods									
Glass bottle	78.34	80.64	76.44	74.75		78.39	79.50	75.35	73.04
Corn starch	72.23	70.01	66.30	72.25		75.28	70.24	66.34	65.52
Plastic	73.74	71.70	69.45	70.44		76.67	73.77	73.27	62.95
Polyethylene	77.59	74.41	71.14	76.19		78.81	75.85	71.83	69.82
P<F	≤0.001	≤0.001	≤0.001	≤0.001		≤0.001	≤0.001	≤0.001	≤0.001
LSD	0.612	0.816	0.643	1.25		0.660	0.503	2.149	2.53

IV. DISCUSSION

Significant difference (p≤0.01) existed among the drying methods, with oven drying method having a higher protein percentage than the solar cabinet and sun drying methods. It was observed that after drying, the protein content of the dried mango chips increased and was higher than the values obtained for the fresh samples. This increase may be due to the removal of water from the fresh sample, which led to an increase in the density and concentration of protein in the dried samples. A similar observation was made by Onwuchekwa et al., (2019), who reported that pulp drying significantly concentrated chemical nutrients in the protein content, ranging from 1.90 to 5.08%. The values obtained in this study for dried mango chips across the three drying methods agreed and fell within the large values obtained by Onwuchekwa et al., (2019)

After packaging and storage, there were significant differences among the drying methods in the percentage of mango chips protein in some months of the storage period, and the drying process increased the concentration of protein in the dried samples, due to the removal of moisture content. Similar findings were reported by Akther et al. (2020), who reported that crude protein, crude fiber fat, and ash contents increased in mango powder due to the elimination of moisture content i.e increasing concentration of nutrients. The range of protein percentage values in this study was lower than the range of values obtained by Akther *et al.,* (2020)

For the effects of packaging materials on the protein content of dried mango chips (Keith and Julie varieties), in this study, there was a significant difference (P≤0.01) among the packaging materials, with corn starch packaging material having the highest protein content, and glass bottle packaging material had the lowest protein content after the storage period. The high protein content in the corn starch packaging material may be due to its porous nature, which allowed moisture and air (gasses)to penetrate it. Thus, stored dried mango chips were made to re-absorb moisture that increased their volume. Glass bottles had the lowest percentage of protein content, probably due to their non-porous nature, which prevented the penetration of moisture and air (gases). This lack of exposure to external elements ensured that the contents remained intact without any adulteration. This observation aligns with a report by Cary Company (2018), which emphasizes the importance of the non-porous nature of glass in ensuring that the product

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remains as pure as possible by preventing contamination from external factors.

For dried mango chips, after drying but before commencement of storage, there was highly significant difference (p≤0.01) among drying methods (sun, solar cabinet and oven) for the Keith and Julie verities of mango chips. The carbohydrate content of dried mango fruits after drying was significantly higher than that in fresh mango samples. Oven drying method had the highest carbohydrate content in both 2022 and 2023. This could be attributed to the higher and controlled temperature (70^0c) obtained in the oven drying method that removed more moisture from the fresh sample, leaving a higher concentration of carbohydrate in the dried mango chips. The lowest carbohydrate content was obtained using the solar cabinet drying method (2022) and sun drying method (2023). These two drying methods had lower drying temperatures than the oven drying method. This result agrees with the findings of Tunde-Akintunde and Afolabi (2007), who observed that oven-dried samples consistently had higher carbohydrate contents due to the more efficient and uniform removal of moisture at controlled temperatures. There was a significant difference (p≤0.01) among drying methods in terms of their effects on the carbohydrate content of dried mango fruit chips.

Also, oven drying method had the highest carbohydrate percentage among the drying methods throughout the storage period in both years of study. This could be the result of the higher and controlled temperature used in the oven drying method, which removed more moisture than the solar cabinet and sun drying methods; which left high concentrations of carbohydrate in the dried mango fruit chips stored. This observation was similar to that reported by Mwithiga and Olwal (2005), who found that oven drying resulted in a higher carbohydrate content in dried fruits due to efficient moisture removal at controlled temperatures, which prevented enzymatic activity and nutrient degradation.

The values obtained in this study for the percentage of carbohydrates in dried mango chips stored were higher than those obtained by Mohammed *et al.*, (2020) for open sun drying (OSD), conventional solar dry (CSD), and improved solar cabinet dryers (ISD); The result of this study were below the ones obtained by Mahamat *et al.*, (2024) for the Doba, Bebedjia, Koumra, Moundou, and Bongor varieties of dried mango chips. However, the results of this study fall within the range obtained by Onwuchekwa *et al.*, (2019) , for the 21 mango accessions and also the result of Akther *et al.*, 2020) for rotary oven dried (ROD) mango chips.

Significant differences (p≤0.01) existed among the various packaging materials used in this study (Glass bottle, corn starch, plastic and polyethylene). Of these, glass bottle had the highest carbohydrate content. This can be attributed to the non-porous nature and impermeability of glass to moisture and air (gases). This result agrees with the report of Jaime *et al.* (2003) that glass packaging has good barrier properties against external agents, especially moisture and oxygen. Although plastic packaging materials had the lowest value at the end of 2023 of the sampling period, on average, corn starch packaging material was observed to have had the lowest percentage of carbohydrate retention. This could be due to the porous nature of corn starch to moisture and air (gases) that caused changes in the volume of the stored mango chips, resulting in their reduction.

V. CONCLUSION

There were significant differences among the different drying methods and among the packaging materials in their effects on both the protein and carbohydrate content of the dried mango chips. These differences were observed both before and after storage. Therefore, when choosing drying methods and packaging materials for food products, it is necessary to pay attention and careful consideration to factors that are detrimental to the maintenance of quality and integrity of food materials during storage, especially moisture and air (gasses). After the storage period of 4 months, oven-dried samples had higher concentrations of retained nutrients than the solar cabinet and sun-dried samples,. In terms of packaging materials, glass bottles had the highest percentage of retained nutrients compared to corn starch, plastic, and polyethylene packaging materials due to their non-porous nature and impermeability to moisture and air (glass), whereas corn starch retained the least nutrients due to its porous nature and permeability to air (gases) and moisture.

Drying increased the concentrations of both proteins and carbohydrates; similarly, the permeability to moisture and air increased or decreased with increased storage time due to the packaging materials. This impacts the quality and shelf life of stored products. Based on the findings in this study (in the effects on protein and carbohydrate), oven-dried samples should be packaged in glass bottles for optimal quality retention and longer shelf-life of dried mango chips.

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