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EFFECT OF SELECTED RETAIL PACKAGING MATERIALS, STORAGE TEMPERATURE AND TIME ON THE QUALITY OF DRIED MOPANE WORM (*Imbrasia belina*)

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ABSTRACT

This study assessed the effects of selected retail packaging materials, storage temperature and duration on the quality and shelf life of traditionally processed and sun-dried mopane worms (*Imbrasia belina*). Changes in the quality of dried mopane worms (MW) were evaluated in a 2 x 2 x 5 factorial experiment comprising packaging materials (low-density polyethylene (LDPE) and high-density polyethylene (HDPE)), storage temperature (ambient and accelerated), and storage time (0, 30, 60, 90 and 120 days) with three replications. Dried MW samples were analysed for changes in physicochemical (ash, moisture, fat, protein content and colour, microbiological (yeast, mould and coliform count), and sensory (colour, taste, texture and overall acceptability) qualities. The results of the experiment were subjected to ANOVA, and the means were separated using the post *hoc* Tukey test at 5% level of significance. Packaging material did not significantly ($p > 0.05$) affect ash, moisture, fat, protein content, yeast and coliform count, and sensory qualities of dried MW. However, the mould count and colour parameters of dried MW were significantly ($p < 0.05$) affected by packaging material. Storage time significantly affected ($p < 0.05$) moisture, fat, protein content, colour parameters and sensory qualities of dried MW. The ash content was not significantly ($p > 0.05$) affected by storage time, but the storage temperature significantly affected ($p < 0.05$) ash, moisture content and colour parameters of dried MW. The three-way interaction between packaging material, storage temperature and time was not significant ($p > 0.05$) for all proximate composition and microbial quality parameters, indicating that it is safe to consume dried MW over a period of 120 days post-processing. This study recommended that a further study for storage periods greater than 120 days be done to determine the shelf life of traditionally processed dried MW packaged in retail-sized HDPE and LDPE. The HDPE performed better than LDPE in preserving the quality of dried MW, as evidenced by the better-quality parameters recorded under this packaging material.

Key words: Mopane worm, retail packaging, shelf life, food quality, storage, temperature, time

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INTRODUCTION

Mopane worm (*Imbrasia belina*) is an edible insect found in Southern Africa and the Democratic Republic of Congo [1]. It falls in the moth family Saturniidae known as Saturniids or emperor moths [2]. According to Kwiri *et al.* [3], mopane worm is an essential source of nutrition and income for Southern Africa and the Democratic Republic of Congo. Mopane worm is rich in protein with levels comparable to fish and other meats [4]. Past studies have estimated that the dried MW contains 60.70% crude protein, 16.70% crude fat, and 10.72% minerals [5]. Furthermore, MW has high levels of amino acids and can be stored for many months without undergoing significant nutritional quality deterioration [1, 6]. Drying degutted mopane worm prolongs its shelf life, therefore, maintaining a steady supply of protein in the diet of the people in the area. However, insufficient drying can lead to deteriorative changes of stored MW, leading to spoilage due to microbial, chemical or physical actions. The deteriorative changes due to inadequate drying result in decreased MW nutritional quality, discolouring, texture changes and lower edibility.

Concerns have been raised over handling and processing practices, hygiene and overall food safety of dried MW [3]. Garniner [7] reported that MW's packaging, processing and storage are basic and poor, leading to its spoilage by pests and microorganisms. Furthermore, Mujuru *et al.* [8] recommended that MW harvesters and processors observe hygienic harvesting and primary processing practices and follow protocols that avoid contamination and recontamination of dried MW. Packaging is vital in ensuring hygienic handling, protection and marketing of a product. Product packaging can be for bulk or retail purposes.

Retail packaging, also known as packaging ready for shelving, prepares products for delivery to retailers in commercialized units ready for sale [9]. Some of the typical retail packaging materials include low-density polyethylene (LDPE), high-density polyethylene (HDPE), polypropylene (PP), Polytetrafluoroethylene (PTFE), and Nylon (Polyamide) [10]. Wholesalers trading in MW usually use smaller sealed and labelled retail packages for sale in LDPE and HDPE [3]. Packaging materials affect the rate at which deteriorative changes in packaged products occur and thus determine the product's shelf-life [11]. Therefore, packaging materials affect packaged foods' nutritional and sensory quality attributes over time for given storage conditions [12].

Factors contributing to losses in the nutritional quality of packaged food products include temperature, packaging material and storage time [13]. Temperature affects the rate of chemical reactions of packaged food products leading to quality

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deterioration and thus shortens the shelf life of a packaged food product. Kwiri *et al.* [3] indicated that increasing the surrounding temperature under which a food is stored increases the rate of its chemical reaction, thus increasing its quality deterioration rate and shortening the shelf life. Additionally, higher temperatures influence product moisture loss; therefore, products packaged in non-airtight packages result in toughened or brittle products. Furthermore, according to Heitschmidt [14], moisture loss from food leads to detrimental changes in its organoleptic characteristics. Sloan *et al.* [15] reported rapid deterioration in nutritional quality and sensory attributes of dehydrated Taro slices stored under elevated temperatures compared to pieces stored under ambient storage temperature.

Studies by Agrawal [16], Mahalingaiah *et al*. [17], and Siah and Modd Tahir [18], have reported that packaging materials, storage conditions and time singly or in combination affect stored food products' quality and storage stability. Therefore, the choice of retail packaging materials is essential. Some of the typical retail packaging materials are low-density polyethylene (LDPE), high-density polyethylene (HDPE), polypropylene (PP), polytetrafluoroethylene (PTFE) and nylon (polyamide) [19]. Currently, traditionally processed sun-dried MW is packaged for retail using LPDE and HDPE under ambient conditions. This study evaluated the effect of selected retail packaging materials (LPDE and HDPE), storage temperature (ambient and accelerated temperature: (accelerated temperature in this study is a higher temperature which was used to monitor deterioration of nutritional content of dried mopane worm comparing it to a normal storage condition ambient temperature) and time (0, 30, 60, 90 and 120 days) on the quality of MW by assessing the changes in the microbiological, physicochemical and sensory characteristics of traditionally processed sun-dried MW.

MATERIALS AND METHODS

Packaging, storage and sampling of dried mopane worm

The dried mopane worm (*Imbrasia. belina*) samples were subdivided into small portions of 1 kg each. The 1 kg portions were randomly filled into HDPE and LDPE. The open ends of all the packages containing the samples were twisted and fastened tightly to make them airtight. There were four packages, two of each type of packaging material. The two packages (LDPE and HDPE) were then stored under ambient temperature (T1) and the other two packages (LDPE and HDPE) under accelerated temperature (33 ˚C) for 120 days. The accelerated storage (T2) was done using an oven temperature set at 33 °C for a period of 120 days.

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Ambient temperature storage was done by placing the dried MW samples in a typical kitchen cupboard for a period of 120 days (0, 30, 60, 90 and 120).

The initial sampling was done on day zero and at 30-day intervals until day 120. The packages were opened to obtain samples for analysis, and approximately 100 g of dried MW was picked from the two storage (ambient and accelerated temperature) environments. The samples were analysed for the different quality parameters following the method described by Kamau *et al.* [10].

Experimental design and data analysis

A three-factor full-factorial design comprising (packaging materials, storage temperature and storage time) was used. The factors studied were packaging materials (LDPE and HDPE), storage temperature (ambient and accelerated) and storage time (0, 30, 60, 90 and 120 days) with three replications. All data were obtained in triplicates, and the mean and standard deviation were calculated. The microbial data were transformed to $\log_{10}$ to meet the requirements of equal variance and normal distribution as described by Kung *et al.* [20]. The effects of packaging materials, storage temperature and duration, and their interaction on the quality attributes of dried MW were analysed using a three-way analysis of variance (ANOVA) using Minitab 19 (Minitab, Coventry, UK). Significant differences were established at ($p < 0.05$) using the Tukey test.

Analysis of the physicochemical properties of dried mopane worm

Protein content determination

Protein content was determined following the Kjeldahl method AOAC [21]; 1 g of dried MW was digested for 90 minutes at 400 °C in sulphuric acid with Kjeldahl tablet (Merck, South Africa) as the catalyst. The digest containing ammonium sulphate and carbon dioxide was diluted with 40 ml distilled water before neutralising with 35% sodium hydroxide (NaOH) through a distillation unit (UDK 129, Italy) for 4 min. The digest was distilled into 50 ml of a boric acid solution containing methyl red indicator (Merck, South Africa). Finally, the pinkish boric acid solution was titrated against 0.1 M hydrochloric acid until a permanent clear colour was observed. The amount of crude protein was then calculated by multiplying the percentage of nitrogen in the digest by 6.25 AOAC [21] using Equation 1 and Equation 2.

$$\%\ \text{Nitrogen} = \frac{(\text{volume of acid x Molarity of standard acid})\ \text{x}\ 0.014}{\text{weight of the original sample}}\ \text{x}\ 100 \qquad (1)$$

$$\%\ \text{crude protein content} = \text{nitrogen content x}\ 6.25 \qquad (2)$$

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Fat content determination

Fat content was determined using the Soxhlet extraction method using a Buchi 810 Soxhlet fat extractor AOAC [21]. Three 250 ml beakers were thoroughly washed, heated, and cooled in desiccators. Four extraction thimbles were selected, and the corresponding weights were recorded as W1. Two grams (2 g) of dried MW were weighed and placed into the Soxhlet extraction thimble (W2). The extraction thimble was plugged with cotton wool and placed in the Soxhlet extractor. One hundred and fifty millilitres of petroleum ether was added, and extraction was done for 16 hours in the Soxhlet apparatus. Subsequently, the flask was transferred to a steam bath in a hood for 3 hours to evaporate the petroleum ether. This was followed by 1 hour of further drying in a hot air oven at 100 °C, then cooled in a desiccator and the final weight, W3, recorded. The fat content was calculated as:

$$\%\ \text{Fat} = \frac{\text{Weight of fat}}{\text{Weight of the original sample}}\ \text{x}\ 100 \qquad (3)$$

Moisture content determination

To determine the moisture content, the weight of the empty crucibles (W_1) and the weight of crucibles containing 2 g dried MW sample (W_2) were determined using a standard laboratory weighing scale. The crucibles were then placed in a preheated oven maintained at 105 °C for 3 hours. Subsequently, the crucibles were transferred to a desiccator and allowed to cool, and then weighed again (W_3) AOAC [21]. The moisture content difference was corrected by dividing the weight of wet samples by weight of dried samples. Moisture content was calculated using Equation 4.

$$\%\ \text{Moisture content} = \frac{(\text{W2}-\text{W1})-(\text{W3})}{\text{W2}-\text{W1}}\ \text{x}\ 100 \qquad (4)$$

where, W1 = weight of empty crucible (gram), W2 = weight of crucible with the sample (gram), and W3 = weight after drying (gram).

Ash content determination

To determine total ash content, two grams of dried MW were weighed W2 and placed in a clean dry pre-weighed crucible W1. The crucible with its content was ignited in a muffle furnace at about 550 °C for 6 hours until light grey ash was obtained. The crucible was removed from the furnace to a desiccator to cool and then weighed. The crucible was reignited in the furnace and allowed to cool until a constant weight was obtained W3 AOAC [21]. Total ash content was calculated using Equation 5.

$$\%\ \text{Total ash content} = \frac{W2 - W1}{W3} \times 100 \qquad (5)$$

where, W1= weight of empty crucible (gram), W2= weight of crucible with ash (gram), W3= weight of the sample (gram).

Determination of the 3-dimensional colour values of dried MW

A colorimeter was used to measure colour parameters of dried mopane worm samples (Colourflex EZ, HunterLab, USA) that expresses the colour values as L* (darkness or lightness), a* (reddish or greenish), b* (yellowish or blueness) at each time, respectively as described by Pathare *et al.* [22]. Before using the instrument, its black glass was placed against the measuring port to set the colorimeter reading to zero, when finished, it was calibrated using the white tile. The MW was poured into a dried sample cup. The values of L*, a* and b* were recorded in triplicates and used to calculate total colour difference (∆E*) Equation 6.

$$\Delta \mathbf{E}* = \sqrt{\Delta \mathbf{L}^{*2} + \Delta \mathbf{a}^{*2} + \Delta \mathbf{b}^{*2}} \qquad (6)$$

Analysis of the microbiological load of stored dried mopane worm

Microbial analysis was done to determine the microbial stability of dried MW for 120 days. The solution was prepared by dissolving 20 g of Buffered Peptone Water (BPW) into 1000 ml distilled water. A weight of 0.5 g of the dried MW powder was aseptically taken from each of the 8 packages and homogenised into 45 ml of sterile BPW solution. The sample homogenates were serially diluted from 10^1 to 10^3 by taking 1 ml from the first dilution and transferred into 9 ml tubes of BPW. Thereafter 1 ml aliquots from the resultant dilutions were inoculated in triplicate plates using the pour plate and spread plate techniques.

Yeast and mould determination

Potato Dextrose Agar (PDA) was used to determine the yeast and mould count of dried MW AOAC [23]. The plates were incubated in the dark at 25 °C for 5 days and after that mould and yeast colonies were counted following the general methods for enumeration of yeast and moulds AOAC [23].

Coliform determination

Violet Red Bile Agar (VRBA) method was used to enumerate the coliform count of dried MW. The plates were allowed to cool and kept in an inverted position to avoid condensation of moisture in the plate and then incubated. The plates were incubated for 45 – 48 hours at 37 °C. Visible colonies were counted after

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incubation and the results were reported as $\log_{10}$ cfu/g as explained by Mujuru *et al.* [8].

Sensory evaluation of stored dried mopane worm

Sensory analysis was done to determine the consumer acceptability of dried MW over time using 101 participants. The consent of the participants was obtained before they participated in the sensory evaluation exercise. The participants evaluated the dried mopane worm for taste, colour, texture and overall acceptability on a 9-point hedonic scale wherein 1 represented extreme dislike and 9 represented extreme like. The sensory evaluation was conducted on days 0, 60 and 90, according to Mahalingaiah *et al.* [17]. Necessary precautions were taken to prevent the carry-over of flavour during the tasting by ensuring that the participants rinsed their mouths with distilled water after each stage of the sensory evaluation activity.

RESULTS AND DISCUSSION

Proximate composition

A summary of the proximate composition of dried MW is presented in Table 1. There was no significant ($p > 0.05$) change in the ash content of dried MW with time for the two packaging materials and temperature conditions over time. The average ash content for LDPET1, HDPET1, LDPET2 and HDPET2 were 9.81 ± 0.92 %, 9.99 ± 1.46 %, 9.26 ± 0.68 %, and 8.59 ± 0.59 %, respectively. In a study by Madibela *et al.* [6], the reported ash content of MW was in the range 4.5 – 5.5 % for MW harvested from Maunatlala, Moreomabele and Sefophe in Botswana. The higher value of ash content in dried MW in this study was attributed to the possible excessive addition of salt during the traditional processing and the site effects as reported by Madibela *et al.* [6]. Past studies have reported that there is no standard quantity of salt added to the MW during its processing [24]. The increasing ash content over time observed in this study could be attributed to continuous loss of water from the dried MW muscles and the decreasing level of the organic matter in dried MW with time [24].

The water in food, its location and availability, is the most important factor influencing microbial growth and enzymatic activity [25, 26]. The average moisture content of dried MW on day 0, 30, 60, 90 and 120 were 6.01 ± 0.75 %, 4.31 ± 1.03 %, 3.90 ± 1.30 %, 4.85 ± 1.70 % and 4.47 ± 1.18 %, respectively. The moisture content decreased with time in all treatments. Decreasing moisture content of dried food products with time is common and has been proven in other studies by Madibela *et al.* [6] and Heitschmidt [14]. The moisture content was generally higher under T1 storage conditions than under T2. The higher moisture content under T1 could lead to increased water activity resulting in favourable conditions for microbial growth, which could decrease the shelf life of the dried MW stored under T1.

The level of fat content was significantly ($p < 0.05$) affected by storage time. The average fat content on day 0, 30, 60, 90 and 120 were 12.72 ± 0.80 %, 12.22 ± 0.75 %, 12.68 ± 0.52 %, 12.15 ± 0.75 % and 11.31 ± 0.56 %, respectively. The fat content decreased with increasing storage time. Decreasing fat content in food products stored under ambient conditions has also been reported by Farid *et al.* [27] on shoal fish treated with salt and salt-turmeric, Adenike [28] on smoked catfish treated with sodium citrate and black pepper, and Makawa *et al.* [29] on Tilapia. The fat content of dried MW was higher under T1 than under T2 for the study period. The lower levels of fat content under T2 were attributed to greater deteriorative changes in the composition in dried MW due to accelerated temperature storage condition maintained throughout the study duration relative to T1. Rihayat *et al.* [30] reported similar findings for tuna fish floss stored under ambient and accelerated temperatures. The decreasing fat content of dried MW indicates that oxidation of poly-unsaturated fatty acids occurred in the dried MW. The oxidation of lipids gives the dried MW a rancid flavour and may explain the decline in consumer acceptability of the dried MW over time, as reported by Jongberg *et al.* [31].

Storage time significantly ($p < 0.05$) affected the protein content of dried MW. The protein content of dried MW for LDPE T1, and LDPE T2 ranged from 63.08 to 67.66 %, and 62.60 to 67.64 %, respectively. Protein content in this study decreased with increasing storage time. The reported decreasing protein content of dried MW with time agree with the results of Folorunsho *et al.* [32], that reported decreasing protein content in a study on smoked fish stored in three different packaging materials for six months and Ribah *et al.* [33] who reported decreasing protein content in a study on Balangu ready-to-eat meat product. The protein content of dried MW for HDPET1, and HDPET2 ranged from 60.93 to 71.69 % and 57.92 to 69.41 %. The protein content was higher under the T1 storage condition than under T2. The higher protein content under T1 indicates dried MW should be stored at temperatures lower than T2 to safeguard against a faster decreasing rate of protein.

The 3 - dimensional colour indices

Colour is an important quality measure of food products, and its measurement is critical following food processing activities such as drying, where colour changes often occur, Teon [34]. A summary of the 3–D colour of dried MW over time is presented in Table 2. The packaging materials, storage temperature and time significantly ($p < 0.05$) affected the L*, a*, b* and ∆E* of dried MW. A study by Kamau *et al.* [10] reported similar findings on a semi-processed adult house cricket meal. The average L* on day 0, 30, 60, 90 and 120 were 29.92 ± 4.12, 31.02 ± 3.12, 26.24 ± 1.87, 26.28 ± 3.70 and 26.67 ± 0.78, respectively; indicating decreasing trend over time. The reported decreasing lightness (L*) of dried MW with time agrees with the results of Akonor *et al.* [35] in a study on shrimp meat.

The a* index and b* index levels were higher in HDPE than LDPE under T1 and T2. The average a* index level for LDPET1, LDPET2, HDPET1 and HDPET2 were 3.40 ± 0.47, 4.20 ± 0.68, 3.64 ± 0.70 and 4.04 ± 0.83, whereas the average b* index level for LDPET1, LDPET2, HDPET1 and HDPET2 were 8.72 ± 1.28, 9.99 ± 2.21, 9.23 ± 1.84 and 10.19 ± 2.18, respectively. Over time, the a* index and b* index decreased for all treatments. The reported decreasing a* and b* index agrees with the results of Ferreira *et al.* [36], who reported decreasing a* and b* index with time in a study on dried salted pork meat treated with different levels of sodium chloride.

The level of ∆E* generally decreased with time. The average ∆E* level on day 0, 30, 60, 90 and 120 were 0.00 ± 0.00, 6.35 ± 3.73, 5.37 ± 2.66, 7.02 ± 3.10 and 5.70 ± 1.49, respectively. The reported decreasing ∆E* of dried MW with time agrees with the findings of Kamau *et al.* [10], who reported decreasing total colour change in a study on semi-processed adult house cricket meal with increasing time. These findings indicate that HDPE maintained the colour of dried MW better than the LDPE.

Microbiological count

Microorganisms such as mould and yeast can grow in food products resulting in spoilage and poisoning USDA [37]. A summary of the microbiological count of dried MW is presented in Table 3. The average mould count for LDPET1, LDPET2, HDPET1 and HDPET2 were 0.03 ± 0.06 log10cfu/g, 0.16 ± 0.13 log10cfu/g, 0.32 ± 0.22 log10cfu/g and 0.17 ± 0.06 log10cfu/g. The mould count was identified in the dried MW. A study by Mujuru *et al.* [8] reported the presence of mould in a study that investigated the microbiological quality of MW processed using different traditional processing methods in Gwanda, Zimbabwe. The average yeast count on day 0, 30, 60, 90 and 120 were 0.19 ± 0.04 $\log_{10}$cfu/g, 0.71 ± 0.16 $\log_{10}$cfu/g, 0.57

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± 0.30 log_{10}cfu/g, 0.95 ± 0.49 log_{10}cfu/g and 0.27 ± 0.07 log_{10}cfu/g, respectively. The decreasing yeast count from day 90 to day 120 with increasing time can be attributed to the decreasing moisture content of the dried MW. The highest count for the dried MW in this study was 10^3cfu/g, which is lower than the allowed upper limit of 10^5 cfu/g PHLS [38], thus indicating that the dried MW is safe from microbial contamination for the study period under the experimental treatments.

Another food safety concern of the consumers of MW is coliform, a bacterium with different strains capable of causing health concerns and, in severe cases, death. In this study, coliform was only detected in dried MW on day 90 in the HDPE package at T2. The presence of coliform under T2 indicates that storing the dried MW at elevated temperatures in HDPE in humid environments should be done for less than 90 days.

Sensory evaluation

Traditionally, sensory evaluation tests are conducted to evaluate the liking of a product by consumers [24, 39]. Results of the sensory evaluation of dried MW is presented in Table 4. Time significantly ($p < 0.05$) affected the sensory quality of stored dried MW for all treatments. Similar findings were reported by Siah *et al.* [18] for a study on tilapia fillets. The average sensory colour on day 0, 60 and 90, were 6.48 ± 0.15, 6.13 ± 0.24 and 6.11 ± 0.29, respectively. The decreasing sensory colour liking score is similar to the findings by Agrawal [16] on a study on the shelf life of khoa.

The average overall acceptability values for LDPET1, LDPET2, HDPET1 and HDPET2 were 6.48 ± 0.01, 6.43 ± 0.27, 6.49 ± 0.14 and 6.29 ± 0.56. These acceptability scores for dried MW above 6.0 on the 9-point hedonic scale imply that the dried MW was “liked moderately.” The LDPET1 and LDPET2 indicate that the packaging influences overall acceptability and that LDPE is a better medium for packing the dried MW than HDPE. The overall acceptability ratings for most foods fall between 5.5 and 7.5, with a score above 7 is considered good, 7.5 is considered very good, and 8 and above considered above [40].

CONCLUSION

From this study, HDPE performed better in maintaining the quality of traditionally processed dried MW. Notably, the use of LDPE and HDPE as packaging materials confers an acceptable degree of storage stability and protection against the loss of nutritional quality while satisfactorily protecting the dried MW from microbial contamination. The temperature and the packaging materials are critical factors

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affecting the dried MW's stability. Therefore, there is a need for carefully selecting the packing materials while ensuring some degree of control over the storage temperature of above 33 ˚C to ensure that the quality of the stored dried MW does not deteriorate post-processing rapidly. Overall sensory acceptability liking scores was higher for ambient than accelerating temperature storage condition. Although the HDPE performed better than LDPE material in preserving the nutritional, microbial and sensory qualities of MW, the LDPE had better consumer sensory acceptability. The 120 days of post-processing was not adequate to arrive at the shelf life of dried MW. Consequently, further research for a period of more than 120 post-processing is recommended to enable the determination of the shelf life of dried MW packed in these commonly used materials.

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Table 1: Effect of packaging materials, temperature and time on proximate composition of dried traditionally processed mopane worm

Temperature °C	Packaging materials	Proximate composition	Time (days)				
			0	30	60	90	120
T1	LDPE	Ash %	9.01^{a} ± 0.41	9.55^{a} ± 1.54	10.17^{a} ± 0.51	8.89^{a} ± 0.64	11.41^{a} ± 3.80
T2	LDPE		8.85^{a} ± 0.10	9.91^{a} ± 0.95	8.80^{a} ± 0.15	10.22^{a} ± 0.09	8.50^{a} ± 0.36
T1	HDPE		9.41^{a} ± 0.10	7.40^{a} ± 1.03	11.08^{a} ± 1.99	11.25^{a} ± 2.11	10.87^{a} ± 2.83
T2	HDPE		8.99^{a} ± 0.10	8.80^{a} ± 0.73	9.22^{a} ± 0.25	7.55^{a} ± 0.26	8.40^{a} ± 0.04
T1	LDPE	Moisture %	5.38^{abcdef} ± 0.64	5.32^{abcdef} ± 0.71	5.08^{abcdef} ± 0.16	6.93^{ab} ± 0.78	5.75^{abcd} ± 2.95
T2	LDPE		5.57^{abcde} ± 0.99	2.69^{fg} ± 0.37	2.07^{g} ± 0.04	3.50^{cdefg} ± 0.11	3.43^{cdefg} ± 0.04
T1	HDPE		7.28^{a} ± 0.40	5.07^{abcdef} ± 0.68	5.18^{abcdef} ± 0.04	6.08^{abc} ± 0.15	5.55^{abcde} ± 1.05
T2	HDPE		5.79^{abcd} ± 1.70	4.17^{bcdefg} ± 0.63	3.26^{defg} ± 0.18	2.88^{efg} ± 0.16	3.16^{defg} ± 0.11
T1	LDPE	Fat %	14.03^{a} ± 3.28	11.26^{a} ± 0.39	12.40^{a} ± 0.46	12.04^{a} ± 0.88	10.75^{a} ± 1.39
T2	LDPE		12.31^{a} ± 0.55	11.72^{a} ± 1.08	13.52^{a} ± 0.15	11.48^{a} ± 0.33	11.58^{a} ± 0.37
T1	HDPE		12.63^{a} ± 0.89	12.86^{a} ± 0.92	12.13^{a} ± 0.63	13.37^{a} ± 1.92	12.10^{a} ± 0.65
T2	HDPE		11.90^{a} ± 0.19	13.04^{a} ± 0.67	12.68^{a} ± 0.32	11.72^{a} ± 0.61	10.81^{a} ± 0.84
T1	LDPE	Protein %	63.08^{a} ± 5.55	67.66^{a} ± 2.92	65.74^{a} ± 2.61	64.19^{a} ± 6.00	63.45^{a} ± 1.42
T2	LDPE		67.64^{a} ± 4.71	62.00^{a} ± 3.48	64.32^{a} ± 5.82	64.39^{a} ± 3.28	65.01^{a} ± 4.42
T1	HDPE		67.57^{a} ± 5.11	71.69^{a} ± 3.96	68.30^{a} ± 3.74	68.12^{a} ± 6.74	60.93^{a} ± 2.61
T2	HDPE		65.50^{a} ± 6.23	69.41^{a} ± 3.14	62.83^{a} ± 3.01	65.74^{a} ±6.71	57.92^{a} ± 3.19

Treatment and Interactions	Significance level (p-value)			
	Ash %	Moisture %	Fat %	Protein %
PM	0.517	0.258	0.434	0.369
T(°C)	0.009	0.001	0.311	0.176
D	0.376	0.001	0.017	0.043
PM x T	0.237	0.576	0.265	0.219
PM x D	0.325	0.120	0.059	0.088
T x D	0.034	0.015	0.097	0.614
PM x T x D	0.075	0.209	0.493	0.711

The values are given as mean of triplicates and standard deviation. Same letters in rows indicate the values are not significantly different ($p > 0.05$). PM packaging material, T temperature in degree Celsius and D time in days

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Table 2: Effect of packaging materials, temperature and time on 3 – dimensional colour parameters of dried traditionally processed MW

Temperature °C	Packaging materials	Colour parameters	Time (days)				
			0	30	60	90	120
T1	LDPE	L*	34.01^{b} ± 0.05	26.99^{k} ± 0.02	27.59^{h} ± 0.04	23.37^{p} ± 0.04	27.27^{j} ± 0.02
T2	LDPE		31.30^{e} ± 0.03	33.67^{c} ± 0.01	28.33^{g} ± 0.01	23.15^{q} ± 0.05	25.41^{n} ± 0.03
T1	HDPE		23.04^{r} ± 0.01	34.43^{a} ± 0.03	25.45^{n} ± 0.02	26.29^{m} ± 0.03	26.64^{l} ± 0.06
T2	HDPE		31.31^{e} ± 0.02	28.99^{f} ± 0.02	23.57^{o} ± 0.03	32.31^{d} ± 0.04	27.37^{i} ± 0.02
T1	LDPE	a*	3.47^{f} ± 0.04	3.26^{fgh} ± 0.06	4.20^{d} ± 0.05	2.73^{i} ± 0.10	3.32^{fgh} ± 0.03
T2	LDPE		4.32^{d} ± 0.03	4.72^{c} ± 0.06	5.11^{ab} ± 0.04	3.49^{f} ± 0.12	3.35^{fg} ± 0.05
T1	HDPE		3.21^{gh} ± 0.16	3.09^{h} ± 0.09	3.12^{gh} ± 0.01	4.91^{bc} ± 0.08	3.87^{e} ± 0.02
T2	HDPE		4.32^{d} ± 0.05	2.68^{i} ± 0.04	3.83^{e} ± 0.10	5.26^{a} ± 0.04	4.13^{d} ± 0.12
T1	LDPE	b*	7.55^{gh} ± 0.16	9.22^{e} ± 0.01	10.76^{d} ± 0.17	7.18^{gh} ± 0.25	8.89^{e} ± 0.10
T2	LDPE		11.42^{c} ± 0.05	12.29^{b} ± 0.03	11.61^{c} ± 0.12	7.55^{gh} ± 0.20	7.06^{h} ± 0.06
T1	HDPE		7.34^{gh} ± 0.45	11.27^{c} ± 0.07	7.57^{g} ± 0.12	11.62^{c} ± 0.27	8.36^{f} ± 0.10
T2	HDPE		11.46^{c} ± 0.02	9.33^{e} ± 0.08	7.50^{gh} ± 0.16	13.74^{a} ± 0.04	8.92^{e} ± 0.15
T1	LDPE	∆E*		7.23^{de} ± 0.08	7.23^{de} ± 0.18	10.69^{b} ± 0.07	6.88^{e} ± 0.08
T2	LDPE			2.55^{j} ± 0.02	3.08^{i} ± 0.01	9.06^{c} ± 0.17	7.40^{d} ± 0.10
T1	HDPE			12.06^{a} ± 0.10	2.46^{j} ± 0.04	5.66^{f} ± 0.46	3.81^{h} ± 0.11
T2	HDPE			3.54^{h} ± 0.02	8.71^{c} ± 0.04	2.67^{j} ± 0.01	4.71^{g} ± 0.08

	Significance Levels (p-value)			
Treatments and Interactions	L*	a*	b*	∆E*
PM	0.001	0.003	0.001	0.001
T (°C)	0.001	0.001	0.001	0.001
D	0.001	0.001	0.001	0.001
PM x T	0.001	0.001	0.001	0.001
PM x D	0.001	0.001	0.001	0.001
T x D	0.001	0.001	0.001	0.001
PM x T x D	0.001	0.001	0.001	0.001

The values are given as mean of triplicates and standard deviation. Same letters in rows indicate the values are not significantly different ($p > 0.05$). PM packaging material, T temperature in degree Celsius and D time in days

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Table 3: Effect of packaging materials, temperature and time on the microbiological quality of dried traditionally processed MW

Temperature °C	Packaging materials	Microbiological count	Time (days)				
			0	30	60	90	120
T1	LDPE	Mould (log_{10}cfu/g)	$0.16^{a} \pm 0.28$	$0.00^{a} \pm 0.00$	$0.00^{a} \pm 0.00$	$0.00^{a} \pm 0.00$	$0.00^{a} \pm 0.00$
T2	LDPE		$0.10^{a} \pm 0.17$	$0.26^{a} \pm 0.24$	$0.00^{a} \pm 0.00$	$0.36^{a} \pm 0.32$	$0.10^{a} \pm 0.17$
T1	HDPE		$0.36^{a} \pm 0.39$	$0.10^{a} \pm 0.17$	$0.20^{a} \pm 0.35$	$0.73^{a} \pm 0.38$	$0.20^{a} \pm 0.35$
T2	HDPE		$0.26^{a} \pm 0.24$	$0.10^{a} \pm 0.17$	$0.10^{a} \pm 0.17$	$0.20^{a} \pm 0.17$	$0.20^{a} \pm 0.35$
T1	LDPE	Yeast (log_{10}cfu/g)	$0.16^{b} \pm 0.28$	$0.75^{ab} \pm 0.78$	$1.08^{ab} \pm 0.54$	$0.57^{ab} \pm 0.47$	$0.33^{ab} \pm 0.58$
T2	LDPE		$0.16^{b} \pm 0.28$	$0.89^{ab} \pm 0.42$	$0.58^{ab} \pm 0.53$	$0.44^{ab} \pm 0.43$	$0.33^{ab} \pm 0.58$
T1	HDPE		$0.26^{b} \pm 0.24$	$0.75^{ab} \pm 0.71$	$0.32^{ab} \pm 0.55$	$1.08^{ab} \pm 0.18$	$0.20^{b} \pm 0.35$
T2	HDPE		$0.16^{b} \pm 0.28$	$0.46^{ab} \pm 0.56$	$0.39^{ab} \pm 0.36$	$1.69^{a} \pm 0.09$	$0.20^{b} \pm 0.35$
T1	LDPE	Coliform (log_{10}cfu/g)	$0.00^{b} \pm 0.00$	$0.00^{b} \pm 0.00$	$0.00^{b} \pm 0.00$	$0.00^{b} \pm 0.00$	$0.00^{b} \pm 0.00$
T2	LDPE		$0.00^{b} \pm 0.00$	$0.00^{b} \pm 0.00$	$0.00^{b} \pm 0.00$	$0.00^{b} \pm 0.00$	$0.00^{b} \pm 0.00$
T1	HDPE		$0.00^{b} \pm 0.00$	$0.00^{b} \pm 0.00$	$0.00^{b} \pm 0.00$	$0.00^{b} \pm 0\ 00$	$0.00^{b} \pm 0.00$
T2	HDPE		$0.00^{b} \pm 0.00$	$0.00^{b} \pm 0.00$	$0.00^{b} \pm 0.00$	$1.09^{a} \pm 0.10$	$0.00^{b} \pm 0.00$

Treatments and Interactions	Significance levels (p-value		
	Mould	Yeast	Coliform
PM	0.023	0.317	0.646
T (°C)	0.257	0.181	0.646
D	0.902	0.692	0.733
PM x T	0.342	0.331	0.092
PM x D	0.113	0.299	0.327
T x D	0.759	0.831	0.327
PM x T x D	0.246	0.795	0.733

The values are given as mean of triplicates and standard deviation. Same letters in rows indicate the values are not significantly different ($p > 0.05$). PM packaging material, T temperature in degree Celsius and D time in days

Table 4: Effect of packaging materials, temperature and time on sensory attributes of dried traditionally processed mopane worm

Temperature °C	Packaging materials	Sensory parameters	Time (days)		
			0	60	90
T1	LDPE	Colour	6.52^{ab} ± 2.12	6.16^{ab} ± 2.04	6.14^{ab} ± 2.21
T2	LDPE		6.28^{ab} ± 2.22	5.84^{ab} ± 2.14	6.36^{ab} ± 2.15
T1	HDPE		6.44^{ab} ± 2.12	6.50^{ab} ± 1.68	6.31^{ab} ± 2.06
T2	HDPE		6.69^{a} ± 2.06	6.02^{ab} ± 2.15	5.63^{b} ± 2.32
T1	LDPE	Taste	6.43^{ab} ± 2.13	6.20^{ab} ± 2.15	6.09^{ab} ± 2.21
T2	LDPE		6.56^{a} ± 2.22	6.02^{ab} ± 2.28	6.33^{ab} ± 2.01
T1	HDPE		6.33^{ab} ± 2.11	6.29^{ab} ± 1.96	6.36^{ab} ± 2.18
T2	HDPE		6.72^{a} ± 2.08	5.84^{ab} ± 2.34	5.50^{b} ± 2.33
T1	LDPE	Texture	6.22^{ab} ± 2.32	6.16^{ab} ± 2.07	5.78^{ab} ± 2.13
T2	LDPE		6.15^{ab} ± 2.20	5.50^{ab} ± 2.47	6.23^{ab} ± 2.02
T1	HDPE		6.18^{ab} ± 2.10	5.93^{ab} ± 2.11	6.07^{ab} ± 2.15
T2	HDPE		6.58^{a} ± 1.90	5.69^{ab} ± 2.39	5.40^{b} ± 2.45
T1	LDPE	Overall acceptability	6.47^{ab} ± 2.16	6.47^{ab} ± 1.90	6.49^{ab} ± 1.97
T2	LDPE		6.77^{a} ± 1.99	6.11^{ab} ± 1.95	6.42^{ab} ± 1.92
T1	HDPE		6.67^{a} ± 2.05	6.46^{ab} ± 1.90	6.34^{ab} ± 2.09
T2	HDPE		7.03^{a} ± 1.70	6.19^{ab} ± 2.31	5.66^{b} ± 2.38

Treatment and Interactions	Significance Level (p-value)			
	Colour	Taste	Texture	Overall acceptability
PM	0.693	0.435	0.804	0.601
T (°C)	0.089	0.347	0.302	0.316
D	0.018	0.005	0.005	0.001
PM x T	0.455	0.142	0.764	0.507
PM x D	0.159	0.577	0.315	0.049
T x D	0.400	0.093	0.140	0.025
PM x T x D	0.064	0.085	0.014	0.397

The values are given as mean of triplicates and standard deviation. The same letters in rows are not significantly different ($p > 0.05$). PM packaging material, T temperature in degree Celsius and D time in days

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