EFFECT OF CONVENTIONAL BULK AND SOME RETAIL PACKAGING MATERIALS ON QUALITY OF DRIED MOPANE WORM (*Imbrasia belina*)

By

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ABSTRACT

In this study, the effect of conventional bulk and selected retail packaging materials, and duration of storage was investigated on physicochemical, microbial stability and sensory quality of traditionally processed dried mopane worm under two storage conditions. The samples were analysed for changes in physicochemical (ash, moisture, fat, protein, and colour), microbiological (yeast, and mould and coliform count), and sensory colour, taste, texture and overall acceptability) qualities every 30 days for 120 days. The changes in the quality of traditionally processed and sun-dried mopane worm (MW) were evaluated using a 2 x 2 x 5 factorial experimental design comprising packaging materials, storage temperature and storage time with three replications. Results obtained from the experiment were subjected to ANOVA. Where significant ANOVA results were obtained mean separation was done using Tukey test at 5 % level significance. The first part of this study assessed the effects of conventional bulk packaging materials, storage temperature and time on the quality and shelf life of dried mopane worm. The two-way and three-way interactions among treatments significantly affected L*, a*, b* and ∆E* qualities of dried MW throughout the experimental period. The levels of L*, a*, b* decreased HST_2. Whereas the values of a*, and b* increased in all treatments. The three-way interactions between packaging material, storage temperature and time significantly ($p < 0.05$) affected fat content, fat content decreased in PPT_1, PPT_2 and HST_1, but increased in HST_2 with increasing storage time. The three-way interaction did not significantly ($p > 0.05$) affect moisture, ash, protein content; microbial count; and sensory colour, taste, texture and overall acceptability qualities. Moisture content decreased among treatments with increasing storage time. The decreasing moisture content resulted in a decreased yeast and mould count in HST_2 during storage. The two-way interaction between storage temperature and time significantly ($p < 0.05$) affected moisture, fat content, sensory colour, taste, texture and overall acceptability qualities during storage. The liking scores for colour, taste, texture and overall acceptability decreased in HST_1 and HST_2. However, the two-way interaction between packaging material and time insignificantly ($p > 0.05$) affected moisture, protein content, microbial count and sensory colour, taste texture and overall acceptability qualities. The protein content of dried MW increased among treatments during storage. The second part of this study assessed the effects of selected retail packaging materials, storage temperature and time on the quality and shelf life of traditionally processed and sun-dried mopane worm. The two-way and. three-way interactions among treatments significantly ($p < 0.05$) affected L*, a*, b*, ∆E* qualities of dried MW. The levels of L*, a*, b* and ∆E* decreased in all treatments with increasing storage time. The three-way interaction significantly ($p < 0.05$) affected sensory texture qualities of dried MW during storage, but did not significantly ($p > 0.05$) affect ash, moisture, fat, protein content, microbial yeast, and mould, and sensory colour, taste, texture and overall acceptability. The liking scores for colour, taste, texture and overall acceptability were higher in $HDPET_1$ than in $HDPET_2$. The two-way interaction between storage temperature and time significantly ($p < 0.05$) affected ash content, moisture content and overall sensory acceptability. The moisture content decreased among the treatments with increasing storage time. Higher moisture content was reported in both $LDPET_1$ and $HDPET_1$ of dried MW samples during storage period. However, the two-way interaction between storage temperature and time did not significantly ($p > 0.05$) affect fat and, protein content; yeast, mould and coliform count; as well as sensory colour, taste and texture qualities. The yeast and mould count decreased in $LDPET_2$, $HDPET_1$ and $HDPET_2$ with increasing storage time. The two-way interaction between packaging material and time, and packaging material and storage temperature had no significant ($p > 0.05$) effect on ash count, moisture content, fat content, protein content, yeast count, mould count, coliform count, sensory colour, taste, texture and overall acceptability of dried MW. Ash content increased among treatment with increasing storage time. Only the two-way interaction between packaging material and time significantly ($p < 0.05$) affected and overall acceptability. Therefore, it was concluded that for conventional bulk packaging the PP was better than HS packaging material while for retail packaging HDPE was better than LDPE in preserving the nutritional and sensory quality of traditionally processed dried MW .

DECLARATION ON PLAGIARISM

I, Dikeledi Shirit Monyetsware, Student Number 11572738, hereby declare that this dissertation for a Master of Science degree in Agriculture in Agricultural Mechanization at the University of Venda hereby submitted by me, has not previously been submitted for a degree at this or any other university; and that it is my work in design and execution, and that all work sourced from other persons has been referenced.

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LIST OF ABBREVIATIONS AND SYMBOLS

AOAC	Association of Official Agricultural Chemists
D	Days
FAO	Food and Agriculture Organisation of the United Nations
HDPE	High-density polyethylene
$HDPET_1$	High-density polyethylene at ambient temperature
$HDPET_2$	High-density polyethylene at accelerated temperature
HS	Hessian sack
HST_1	Hessian sack at ambient temperature
HST_2	Hessian sack at accelerated temperature
LAB	Lactic acid bacteria
LAF	Laminated aluminium foil
LDPE	Low-density polyethylene
$LDPET_1$	Low-density polyethylene at ambient temperature
$LDPET_2$	Low-density polyethylene at accelerated temperature
MPA	Modified atmosphere packaging
MW	Mopane worm
NRF	National research fund
PM	Packaging material
PE	Polyethylene
PP	Polypropylene woven sack
PPT_1	Polypropylene woven sack at ambient temperature
PPT_2	Polypropylene woven sack at accelerated temperature
RH	Relative humidity
SANS	South African National Standard
T	Temperature
T_1	Ambient temperature
T_2	Accelerated temperature
VP	Vacuum packaging
W	Weight
WPO	World Packaging Organisation

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CHAPTER ONE
INTRODUCTION

1.1 Background

Mopane worm (*Imbrasia belin*) is an edible insect that is found in Southern Africa and the Democratic Republic of Congo. It falls in the moth family *Saturniidae* known as *Saturniids* or *emperor moths* (Klok & Chown, 1999). Mopane worm has two outbreaks a year, normally from December to January and from April to May (Stack et al., 2003; Ghazoul, 2006). Outbreaks and abundance vary annually, as determined by the availability of rainfall and the presence of host tree leaves (*Colophospermum mopane*) (Moreki et al., 2012). The larva of mopane worm in its final stage is an important source of nutrition and income for poor people in Southern Africa and the Democratic Republic of Congo (Marais, 1996).

According to Ross and Van Huis (2017), mopane worm can be viewed as animal source food like fish and meat. Moreover, mopane worm like other animal origins food contain moisture, protein, fats, carbohydrate, minerals and other organic substances (Rahman, 2007). Headings and Rahnema (2002), estimated that the processed mopane worm (dried and ready for consumption) contains 60 - 70 % crude protein, 16.70 % crude fat, and 10.72 % minerals, on a dry matter basis. Furthermore, the worm contains high levels of amino acids and three-time the protein content of beef by unit weight and has the advantage that it can be stored for many months (Dube and Dube, 2010).

Traditionally, mopane worms of all sizes are collected, prepared and consumed by rural communities within the range of the mopane woodlands. The bulk of the harvesting and processing of the worms is principally done by women and children. A survey in Botswana indicated that 95 % of harvesters are poor, rural women and of these, 73 % live within 50 kilometers of the harvesting areas (Dube and Dube, 2010). Soon after harvesting, the mopane worm can be kept in live storage for a maximum of 3 days (FAO, 2010). According to Kwiri et al. (2014) mopane worms are harvested, degutted, washed and usually cooked using water and salt for 30 minutes and sun-dried. Defoliart (1995) estimated that sun-drying of mopane worm can take approximately 43 hours to completely dry to a safe storage level. Allotey and Mpuchane (2003) pointed out that the larvae can be preserved by either sun drying or smoking. Drying degutted mopane worm prolongs their shelf life to almost a year therefore maintaining a steady supply of protein in the diet of the people in the area. However, it should be noted that insufficient drying can lead to poor medium-term preservation, with the development of mould. Dried foods such as mopane worm undergo spoilage due to microbial, chemical or physical actions. Nutritional values, color, texture and edibility are susceptible to spoilage (Rahman, 2007).

The global consumer demands for safe and healthier foods have raised concerns over insect handling and processing practices, hygiene and overall food safety (Kwiri et al., 2014). Gardiner (2005) reported that packaging, processing and storage of mopane worms are basic and poor leading to spoilage by pests and microorganisms. Additionally, Aremu (2015) stated that packaging plays a vital role in terms of protection, storage and hygienic handling of a product and a key role in marketing the product. According to Stannard (1997), yeast and moulds are a common cause of food spoilage, particularly foods of reduced water activity (aw) such as dried MW. Yeasts have not been implicated in food poisoning whilst molds and some of its strains can produce mycotoxins which can cause serious chronic illness if consumed (Mpuchane et al., 2000). Mujuru et al. (2014) recommended that harvesters and processors of MW must observe good harvesting and manufacturing practices and follow protocols that do not result in the re-contamination of produce.

Packaging materials used for the storage of mopane worm include polypropylene woven bags, whereas for retail and selling, thin transparent sachets are used. These packaging materials offer little protection to the packed products and are prone to contamination and spoilage of the mopane worms from deteriorating sources such as pests and microorganisms. Styles and Skinner (1996) stated that the MW is packed in sacks or large tins for sale to traders in the markets. Traders re-sell MW in small packets, such as 100 g packs, buy and repack it in small plastic bags. Traders who cannot afford plastic bags use used newspapers to pack MW for customers (Styles and Skinner, 1996). Klunder et al. (2012) pointed out that, edible insects like many meat products, rich in nutrients and moisture, provide a favourable environment for microbial survival and growth. However, microbial growth and survival are also influenced by processing and storage conditions along the value chain (Belluco et al., 2013). For the bulk packaging, the effect could be worsened because of the length of time in which the MW is held under such unfavourable conditions. The packaging type and storage conditions applied to affect the quality, shelf life and safety of food products through their influences on moisture content, water activity and nutrient compositions of the food product (Opara and Mditshwa, 2013). The major quality attributes of foods are texture, flavor, color, appearance, and nutritive value, and these attributes can all undergo undesirable changes during processing and storage (Robertson, 2010).

Ssepuuya et al. (2016) pointed out that vacuum packaging had a positive impact on the overall acceptability of *R. nitidula* stored at room temperature but not on *R. nitidula* stored at chilled and frozen temperature. Furthermore, different authors (FAO, 2012; Raheem, 2012; Adebola and Nusa Halima, 2014) have also reported that polyethylene packages have a higher permeability to gases and water vapor than plastic polypropylene packages. According to Kamau et al (2018), the yeast and mould of the adult house cricket were higher in ambient than under refrigeration storage condition. According to Olayemi et al (2015) the use of packaging materials improved the storability of smoked dried fish by increasing the shelf life from about one month to between four and six months. Several studies (Womeni et al., 2012; Opara and Mditshwa, 2013; Olayemi et al., 2015) have reported the effects of packaging and storage conditions on the quality and shelf life of a wide range of whole and minimally processed food products such as meat, other edible insect and fish. However, there is limited knowledge on the potential impact of packaging and storage conditions on quality attributes of dried mopane worm.

This study proposed to determine the effect of the currently used packaging materials, for retail and bulk packaging, storage temperature and time on the quality of dried mopane worm using standard methods. The quality parameters to be studied were physicochemical, microbiological and sensory attributes for 120 days. The study hypothesized that conventional traditional bulk and selected retail packaging materials show variations in the quality attributes. To realise the hypotheses the study sought to investigate the effect of conventional traditional bulk and selected retail packaging materials, storage temperature and time on physicochemical, microbiological and sensory qualities of dried mopane worm *(I. belin).*

1.2. Research questions

The research questions for this study were:

i. What is the effect of storage conditions and time on the quality of traditionally processed dried mopane worm?

ii. What is the effect of bulk and retail packaging materials on quality parameters of traditionally processed dried mopane worm?

1.3. Objectives

The specific objectives of this study were to:

i. Investigate the effect of conventional bulk packaging material, storage conditions and duration on physicochemical, microbiological and sensory qualities of dried mopane worm (*I. belin*) at ambient and accelerated temperature.

ii. Investigate the effect of selected retail packaging materials, storage conditions and duration on physicochemical, microbiological and sensory qualities of dried mopane worm (*I. belin*) at ambient and accelerated temperature.

1.4. Outline of dissertation structure

This dissertation is organised into five chapters.

Chapter 1 Provides a general overview of the study detailing its justification, research questions and objectives.

Chapter 2 This chapter reviews the mopane worm geographic location and cycle, and packaging of agricultural products. It details different packaging materials used for agricultural products and discusses their respective advantages and disadvantages. The chapter further details shelf life and shelf-life testing methods and food quality. It also focuses on the food quality analysis methods employed on dried products.

Chapter 3 Investigates the effects of conventional bulk packaging material, storage conditions and duration on physicochemical, microbiological and sensory quality of dried mopane worm (*I. belin*) at ambient and accelerated temperature.

Chapter 4 Investigates the effect of some retail packaging materials, storage condition and duration physicochemical, microbiological and sensory quality of dried mopane worm (*I. belin*) at ambient and accelerated temperature.

Chapter 5 This is the conclusion and recommendation chapter of this study. It highlights the major findings of this work and makes recommendations arising from the study.

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CHAPTER TWO
LITERATURE REVIEW

2.1 Mopane worm overview

2.1.1 Mopane worm habitant

The Mopane woodlands are found in Botswana, Namibia, Zimbabwe, and northern parts of South Africa as shown in Figure 2.2. It is in this vast habitat that the Mopane caterpillar thrives. Local knowledge of insect ecology and biology in some rural communities is extensive (Mbata et al., 2002). Its distribution is largely correlated to that of its principal host, the Mopane tree (*Colophospermum mopane*). The Mopane caterpillar is bivoltine in most areas; that is, two generations are produced each year the first between November and January, its major outbreak, and the second between March and May Stack et al. (2003); Ghazoul, (2006).

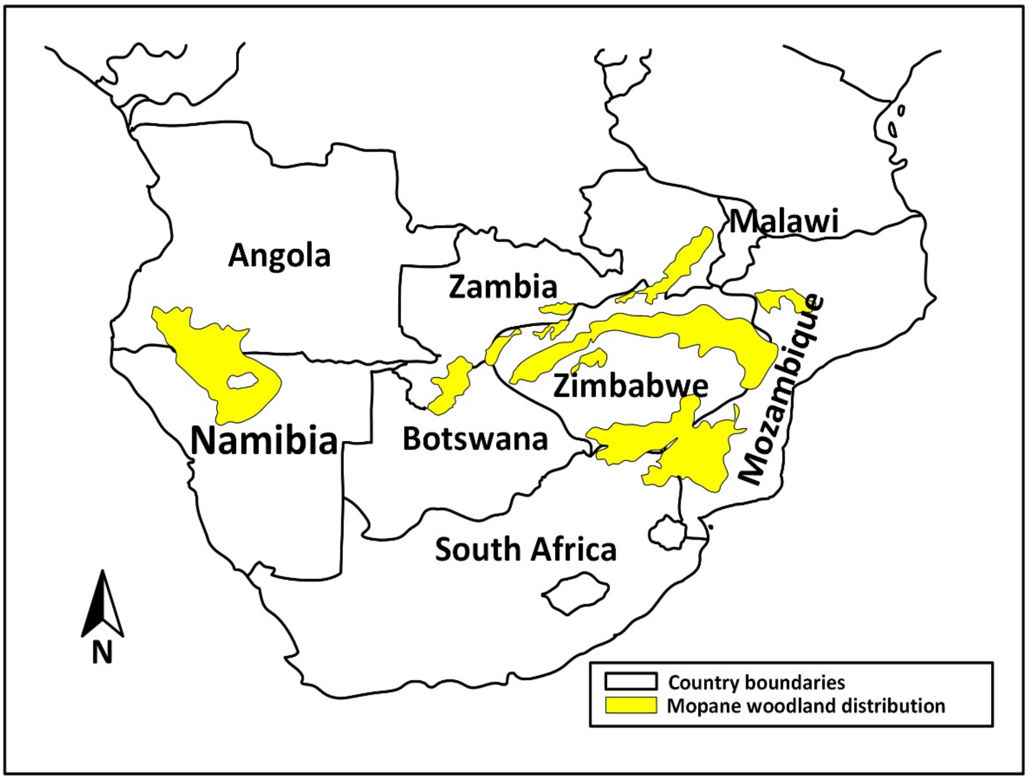

Figure 2.1 The distribution of mopane woodlands in southern Africa. (Source: Makhado et al. (2016))

2.1.2 Mopane worm harvesting, processing and drying

After harvesting, the Mopane caterpillars are subjected to traditional processing methods, such as boiling, roasting and sun-drying as shown in Figure 2.3 (Glew et al., 1999). These are done to improve the taste, storability and palatability of the Mopane caterpillars with an implied assumption of ensuring the production of safe food products (Van Huis, 2012).

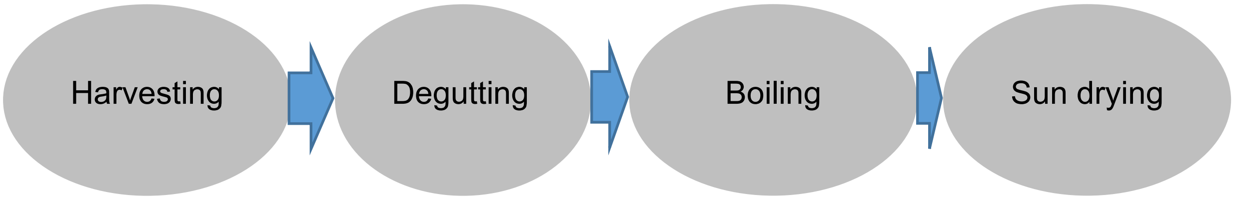

Figure 2.2. Summary of the steps involved in the traditional processing of mopane worm (MW).

2.1.3 Importance of MW on human nutrition

This caterpillar is an important source of nutrition in lean times; and are a regular part of the diet of many rural households in Southern Africa (Stack et al., 2003). Dried Mopane caterpillars last for several months and are a valuable source of nutrition in times of stress. Nutritionally, the protein content of the Mopane caterpillar is in the range of 48 - 61 percent and fat content is 16-20 percent, of which 40 percent is essential fatty acids. Also, MW is a good source of calcium, zinc and iron (Glew et al., 1999; Headings and Rahnema, 2002). Owing to these attributes, MW is very important in the lives of the rural poor in southern Africa in the areas in which it is found.

2.1.4 Importance of MW on the economy of the rural communities

The most popular and profitable caterpillar on the African continent is undoubtedly the Mopane caterpillar*, I. belin*. Harvesting and trading the caterpillars also provide important income for many rural families; and this is often the prime incentive for harvesting MW (Stack et al., 2003). The income generated from dealing in MW is comparable with and often higher than that generated by selling the produce from conventional crops (Munthali and Mughogho, 1992; Chidumayo and Mbata, 2002). The income generated by the Mopane caterpillar harvest provides many families with funds to purchase household items such as clothing, school materials and basic utensils (Stack et al., 2003).

2.1.5 Trade value and importance of MW

MW sales greatly contribute to commercial enterprise apart from sales within rural communities and subsistence consumption (Makhado et al., 2012). In southern Zimbabwe, MW is sold in rural and urban markets, and several market players are involved (Styles and Skinner, 1996). Owing to economic misfortunes faced by rural communities, the MW has become a vital trading commodity in southern Africa. Unemployed males close to urban areas are becoming increasingly involved in the collection of the worms and most cases, are contracted by local traders (Styles and Skinner, 1996). The women are generally engaged in the sale (including barter) of the commodity in small volumes while men tend to be engaged mainly in the more lucrative long-distance and large volume trade which could sometimes be of cross-border nature (Styles and Skinner, 1996). The dried MW is sold with the measures (containers) ranging from a litre tin to a 90 kg bag. Moreover, increasing levels of poverty in urban areas have created a demand for low-cost protein such as the MW for relish (Stack et al., 2003). Over the years, supermarkets have become the main retail outlets for pre-packed and labelled MW supplied by wholesales food packaging companies such as Quality Foods and Jasbro in Zimbabwe (Styles and Skinner, 1996).

Research indicates that in South Africa, about 16000 tonnes of Mopane worms were traded on the commercial market in 1982, some of which were traded as animal feed (Dube and Dube, 2010). A sizable amount of trade occurs at bus terminals, roadside markets, and beer halls where the worm is sold as a snack. Styles and Skinner (1996) reported that MW had an annual trade value of about $3.3 million and $1.6 million in Botswana and South Africa.

There is little doubt that the trade in Mopane caterpillars provides a valuable source of income for many poor rural subsistence farmers, which although modest in terms of monetary value, can nonetheless form a significant proportion of their annual income. Mopane worm trade is the largest indigenous product commercial activity in Botswana and may be the second only to agriculture as the source of livelihood for the rural communities in the Mopane woodland. Mopane worm sales are an important commercial enterprise, over and above subsistence consumption and sale within rural villages. It is estimated that in South Africa 16000 metric tonnes are traded on the commercial market, some of which is used as animal feed (Makhado et al., 2012).

2.2 Food packaging

Food is packaged for storage, preservation and protection traditionally for a long time. These three are the basic functions of food packaging that are still required today for better maintenance of quality and handling of foods (Mathew and Jaganathan, 2017). Food packaging is an integral part of the processing and preservation of foods and can minimize many of the potential spoilage changes, imparting improved keeping quality and increased shelf life to the processed and packaged food (McMillin, 2017). According to Hur et al (2013) packaging of food is essential in the preservation of quality attributes of the product and important in establishing shelf life. Food packaging has a functionality of containment, protection, convenience, and brand communication (Hur et al., 2013; McMillin, 2017).

A primary package is one that is indirect contact with the contained product. It provides the initial, and usually the major, protective barrier. Examples of primary packages include metal cans, paperboard cartons, glass bottles, and plastic pouches shown in Figure 2.1. Frequently, consumers purchase only the primary package at retail outlets. A secondary package contains some primary packages, for example, a corrugated case. The secondary package is the physical distribution carrier and was designed to be used in retail outlets for the display of primary packages. A tertiary package is made up of some secondary packages, generally a metal container up to 40 m in length that can hold many pallets (Robertson, 2010).

Aside from their essential role in production and distribution, food packaging and food contact materials also help to preserve essential food characteristics, such as form, shape or texture of a food product. Packaging and contact materials also help to prolong or preserve the freshness of a product, thereby extending its shelf life. In addition, packaging and contact materials provide a barrier to pests and contaminants (Raheem, 2012).

Figure 2.3. Primary packaging: **A**. Plastic pouches, **B**. Papers cartons, **C**. Metal cans and **D**. Glass bottles (Spinner, 2014; Skujins, 2015; Kleinsasser, 2017; Phuah, 2018).

Food packaging and food contact materials come in a variety of forms. Packaging can include bottles, cans, jars, cartons and bags, as well as wrapping materials (Raheem, 2012). Packaging and contact materials can be made of paper, plastic, petroleum-based substances, engineered products and recycled materials. Packaging materials based on agricultural ingredients like plant fibres, sugars and starches are increasingly available, and are popular with food producers and consumers alike since they are environmentally preferable to conventional packaging materials and use less energy to manufacture (FAO, 2012).

2.3. Packaging materials

2.3.1 Plastics

Plastics are a wide range of polymers made from simple organic chemicals (Opara and Mditshwa, 2013). Each polymer has specific characteristics, these characteristics range from strength and toughness to temperature tolerances or permeability to gases and water (Opara and Mditshwa, 2013). Using plastic as packaging material also offers a marketing advantage. Unlike metal and aluminium packaging materials, harnessing the transparency of film packaging for product visibility is now widely practiced, enabling consumers to assess the visual quality of the product before purchase (Wyrwa and Barska, 2017). However, the variable permeability to light, gases and vapours of plastics is a major drawback. The various kinds of plastic films include low-density polyethylene (LDPE), laminated aluminium foil (LAF), high-density polyethylene (HDPE), polypropylene (PP), polyethylene (PE) (Sangroniz et al., 2019).

2.3.2 Paper

Paper and cardboard are made from cellulose fibres derived from wood and plant fibres using sulphate and sulphite (Robertson, 2011). Paper and paperboards have poor barrier properties to oxygen, carbon dioxide and water vapour (Raheem, 2012). The poor barrier properties of plain paper make it unsuitable for long time storage. Protective properties of paper are usually improved by coating, laminating or filled with waxes and resins (Deshwal et al., 2019). Paper and cardboard are widely used in corrugated boxes, milk cartons, sacks, and paper plates. Packaging material based on paper has an advantage due to its high recyclability at relatively low cost (Ojha et al., 2015).

2.3.3 Metal

The good physical protection and recyclability of metal are widely preferred in many food applications. Aluminium and steel are two metals predominately used in packaging (Marsh, 2007). Aluminium is commonly in use making cans, foil, and laminated paper. Aluminium as a packaging material widely packages for carbonated beverages and seafood. The high cost of aluminium compared to other metals is the main disadvantage of using it in food packaging. Steel packaging material makes cans for drinks and processed foods such as beans and peas. The high mechanical strength and low weight of steel make it relatively easy to store and ship food (Marsh, 2007). Steel can be recycled many times without quality loss and its cost is significantly lower than aluminium hence it is commonly used in packaging of foods. (Deshwal and Panjagari, 2020).

2.3.4 Glass

Glass is another common packaging material, which dates to 3000 BC (Marsh, 2007). Glass packages processed foods especially where moisture and oxygen barrier are important. Carbonated beverage drinks contain dissolved carbon dioxide creating pressure within the package, and glass is often the suitable packaging capable of withstanding carbon dioxide pressure. Moreover, the odourless and static chemical property of glass that ensures unimpaired taste and flavour of the contents makes it advantageous for food packaging (Marsh, 2007). The reusability and recyclability of glass-based packaging material contribute to less negative impacts on the environment. However, the heavyweight of glass adds to the transportation costs of food products (Ramos et al., 2015).

2.4. Packaging materials currently used for mopane worm

Packaging materials were developed over the years to prevent the deterioration of foods by microbes resulting from exposure to air, moisture, or pH changes associated with the food or its surrounding atmosphere (Brennan, 2006). The packaging materials currently used for mopane worm at bulk storage are (polypropylene woven sack (PP), and hessian sack (HS)) and for retail display are (low-density polyethylene (LDPE) and high-density polyethylene (HDPE) (Fellows, 2000).

2.4.1 Bulk packaging

The main function of storage in the economy is to even out fluctuations in market supply, both from one season to the next and from one year to the next, by taking produce off the market in surplus seasons, and releasing it back onto the market in lean seasons (Berger and Welt, 2005). Storing foodstuffs in bulk or in sacks is a usual method for controlling pests without application of chemical methods. These sacks are made of different materials such as sheeted polymers, biomaterial such as jute/hessian sacks used for packaging agricultural products to prevent the entrance of pests and contaminations (Marsh and Bugusu, 2007). Bulk packaging made of polymers provides a solution for commodities weighing 10-50kg during handling, storage and transportation, while smaller packaging for food products range from 50 ml to 5 kg. Polymeric packaging fulfils the diverse role from protecting products, preventing spoilage, contamination, extending shelf life, ensuring safe storage thereby helping to make them readily available to consumers in our day-to-day life (Risch, 2009).

Polypropylene is a clear glossy film with a high tensile strength and puncture resistance. Polypropylene has a moderate barrier to moisture, gases and odours, which is not affected by changes in humidity. Furthermore, it is widely used to pack snack foods and dried foods. The packaging of products is the last line of defence for processors against insect infestation of their finished products (Marsh and Bugusu, 2007).

Hessian fibre is 100 % biodegradable and recyclable and thus environmentally friendly (Sen and Das, 2016). The material is the cheapest vegetable fibre procured from the best or skin of the plant’s stem. The second most important vegetable fibre after cotton, in terms of usage, global consumption, production, and availability (Coles, 2003). Hessian has high tensile strength, low extensibility, and ensures better breath ability of fabrics. Therefore, hessian is very suitable in agricultural commodity bulk packaging. It is one of the most versatile natural fibres that have been used in raw materials for packaging, textiles, no- textile, construction, and agricultural sectors (Sen and Das, 2016).

Advantages of hessian include good insulating and antistatic properties, as well as having low thermal conductivity and moderate moisture regain. Other advantages of hessian include acoustic insulating properties and manufacture with no skin irritations (Sen and Das, 2016).

Disadvantage of hessian include poor drapability and crease resistance, brittleness, fibre shedding, and yellowing in sunlight. Hessian has a decreased strength when wet, and also becomes subject to microbial attack in humid climates (Sen and Das, 2016).

2.4.2. Retail packaging

Retail packaging, also known as packaging ready for shelving, is the preparation of products for delivery to retailers in commercialised units ready for sale (FAO, 2014; Uboldi et al., 2015). Its function is containment of a measured quantity of a product in easy-to-purchase quantities or sizes (Brody and Marsh, 1997). The product is to be protected against infestation, contamination, entry of oxygen and moisture. Retail packaging material should have good impact strength and good tensile strength and good puncture resistance as some products have sharp edges (Brody et al, 2008).

Polyethylene is the most simple, versatile and inexpensive plastic synthesized by polymerization reaction of ethylene (Risch, 2009). Polyethylene was one of the first plastics used widely for food packaging. There are several types of polyethylene in use today including low-density (LDPE), high density (HDPE), linear low density (LLDPE) and very low density (VLDPE) (Risch, 2009). In food packaging LDPE and HDPE are the most commonly used of polyolefin.

Low-density polyethylene (LDPE): is flexible, easy to seal, strong, tough and resistant to moisture, but relatively high gas permeability and sensitivity to oils and poor odour resistance (Majid, et al, 2018). LDPE is relatively transparent and is used in application where heat sealing is necessary. LDPE is less expensive than most films and is therefore widely used for bags, for coating papers and as a component in laminates. This material is the easiest of the polyethylene family to process. Some applications include shrink film, stretch film and commodity packaging bags (Coles, 2003).

High density polyethylene (HDPE): is stronger, thicker, less flexible and more brittle than LDPE and a better barrier to gases and moisture (Risch, 2009). Sacks made from HDPE have high tear and puncture resistance and have good seal strength. They are waterproof and chemically resistant. HDPE is a stronger plastic and has a higher melting point than LDPE (Coles, 2003).

2.5 Shelf life

2.5.1 Shelf life of food products.

Shelf life according to IFST 1993 is the period under defined conditions of storage, after manufacture or packing, for which a food product will remain safe and be fit for use. During the period of storage, the food product should retain its desired sensory, chemical, physical, functional or microbiological characteristics (IFST, 1993). To determine shelf life two methods can be used direct and indirect. Direct methods may take longer but will be more accurate. Indirect methods are quicker but less accurate, which means adjustment is needed once product is in the market. Indirect methods include accelerated shelf-life tests where the food is stored at a higher-than-expected temperature (Okonkwo et al., 1992). Because of globalisation of food trade as well as intensification of national and international competition in the food market, the need for more rapid determination of shelf life has generally become greater. The most common form of accelerated shelf-life determination relies on storing food at an elevated temperature. The assumption is that by storing food at a higher temperature, any adverse effect on its storage behaviour and hence shelf life may become apparent in a shorter time. The shelf life under normal storage conditions can be estimated by extrapolation using the data obtained from the accelerated determination (Labuza and Schimdl, 1985).

2.5.2 Effect of packaging materials on quality and shelf life of food products.

Packaging as preservation has to protect products from external influence that could cause quality deterioration from moisture, oxygen, light, other flavour, odour and chemical (Wijayanti et al., 2016). Different packaging is expected to affect the nutritional changes in food products during storage (Wijayanti et al., 2016).

The study conducted by Chukwu and Imodiboh (2009) concluded that processing beef into *kilishi* does not lead to a significant reduction in the available mineral contents of the raw product (fresh beef) and that most of the microbiological counts detected during the analysis of the *kilishi* samples may be due to some of the condiments used in the production process. The use of potassium sorbate in the storage of *kilishi* proved to be effective against microbiological spoilage and maintained the organoleptic properties (though not conducted) of the product under storage conditions. Also, the use of polythene bags and the traditional brown paper as packaging materials confers certain degree of storage stability and protection against mould and bacteria activity on the shelf life of *kilishi* (Chukwu and Imodiboh, 2009).

The study by Omelagu (2012) concluded that *unam inungu* packed with co-extruded LDPE/PP was highly acceptable to the panellists and has good physiochemical properties showing acceptable total viable counts, thiobarbituric acid reactive substances and free fatty acid at 6 months of storage. Being a popular meat product indigenous to the south-south geographical zone of Nigeria, the product has a great market potential. However, the study has revealed that *unam inungu* cannot be stored in a clay pot as practiced traditionally for a period exceeding 5 months under ambient conditions. The above notwithstanding, with increasing urbanisation, there is no guarantee that this product would not be held by distributors beyond 4 months in marketing channels or even at homes. On this realisation/possibility is best to use the PP/LDPE co-extruded plastic film for its packaging (Omelagu, 2012).

The study conducted by Olaoye et al. (2018) noted that the use of different packaging materials in the storage of *tsire* (roasted boneless meat of animal) may impact the production of organic acids in the product, and hence affect its shelf life and storage stability. It was further concluded that the possibility of spoilage being associated with the *tsire* during storage is very high, probably due to the spontaneous reactions of the miscellaneous microflora in the meat product. It is recommended that the use of biological agents, especially lactic acid bacteria (LAB) be adopted as bio preservatives during storage. This could promote the secretion of organic substances, especially organic acids, capable of limiting spoilage through their action on spoilage organisms (Olaoye et al., 2018).

2.6 Packaging methods

Packaging has become an indispensable element in the food manufacturing process to meet the huge demand of the food industry, there has been a remarkable growth in the development of food packaging in the past decades (Stasiewicz et al., 2014). Among the packaging technologies developed by and for the food industry, active packaging, intelligent packaging, modified atmosphere packaging (MAP), and vacuum packaging and has led to the evolution of fresh and minimally processed food preservation (Siah and Tahir, 2011).

2.6.1 Active packaging

Active packaging is a system in which the product, package and package environment interact to provide a positive characteristic of the food. Often this is accomplished by incorporating active compounds into the packaging materials to absorb substances from the food or environment or to release agents from the packaging into the environment or food. The protection or shelf life of the product in response to interactions of the product, package and environment are often the functions of active packaging technologies, but other functions may also be employed (Yam et al., 2005).

Active packaging may have chemo or bio active components. The functions of active packaging include control of carbon dioxide, moisture, odours and oxygen and their diffusion into packages, diffusion of ethylene from packages, scavenging or absorbing of oxygen, generation of oxygen or carbon dioxide, and the enhancement of flavours, antimicrobial agents, and microwave susceptors; in addition to indications of specific compounds (Berenzon & Saguy, 1998; De Kruift et al., 2002; Brody, 2005). The active packaging system associates the preservative role of antimicrobials and other components with the pre-existing packaging concepts to the most industry (Scannel et al., 2000).

Active packaging releases substances into the food or the environment surrounding the food or it absorbs food-derived chemicals from the food or the environment with the packaging surrounding the food (Ahmed et al., 2017). The interior environment of the packaging can be altered by the incorporation of active substances into the package via pad, tablet or sachet and permitting mechanisms such as evaporation and absorption processes to hinder the microbial proliferation and other degradation processes (Lee, 2010). The quality attributes of the active packaged food products at the time of consumption is far better than the same food preserved conventionally (Lee, 2010).

2.6.2 Intelligent packaging

Intelligent packaging usually refers to packaging systems that incorporate sensors or indicators that signal a needed change or initiate a needed change in the package environment or package (De Kruift et al., 2002; McMillin, 2017). A more generally accepted characterization is a packaging system that can accomplish intelligent functions to enhance decisions concerning shelf life, safety, quality, and information about the food (Yam et al., 2005). The traceability, tracking, and recordkeeping of products through logistical chains could be improved through the collection and integration of data obtained from identification and sensing devices such as barcode labels, radio frequency identification tags, time-temperature indicators, gas indicators and biosensors (Yam et al., 2005; Malik and Sharma, 2014). The headspace of food packages changes their composition over time. Devices capable of identifying, quantifying, and or reporting changes in the atmosphere within the package, the temperatures during transfer and storage and the microbiological quality of food are the basis of intelligent packaging.

The indicators should be easily activated and exhibit a change or show an indication that is easily measurable and irreversible time and temperature-dependent changes must be reproducible and ideally matched or readily correlated with the food quality, and also provide information regarding the status of the package (Yam et al., 2005). The traceability, tracking, and recordkeeping of products through logistical chains could be improved through the collection and integration of data obtained from identification and sensing devices such as barcode labels, radio frequency identification tags, time-temperature indicators, gas indicators, and biosensors (Yam, et al., 2005).

The intelligent packaging is used to monitor exposure to temperature during transport and storage; and is an indication of quality for the producer because they ensure that the product reaches the consumer in optimal condition (Welt et al., 2003). Each relies on different scientific and technological principles, giving information defined by the specific application (Fang et al., 2017). The application of thermochromics materials like photonic crystals, nanomaterials, and other new materials would solve problems in safety, accuracy, and cost to ensure safe and reliable food (Wang et al., 2015). The use of a consistent temperature and continual monitoring of temperature and O_2 in packages with built-in sensors can extend the shelf life of fresh pork longer than 56 days (Petrak, 2016).

2.6.3 Modified atmospheric control

Modified atmosphere packaging (MAP) is defined as the enclosure of a packaged food with an optimal gas composition that is specifically designed to extend its shelf life and is different from the atmospheric gas composition (Church and Parsons, 1995; Shin and Selke, 2014). MAP may be used for bulk or retail-ready products (Mathew and Jaganathan, 2017). MAP has led to the evolution of fresh and minimally processed food preservation. MAP refers to a condition initially produced at the time of packaging. The gases within the package are allowed to change as the physical and biological conditions dictate. Rather than preserving food through the extremes of heat (sterilization) or cold (freezing), MAP utilizes minimal processing to preserve food with the absolute least amount of damage to quality, texture, taste and nutrition (Fernandez et al., 2009). Modified atmospheric packaging (MAP) has gained considerable popularity over the last decades as a modern non-thermal method of food preservation.

The proper combination of gases (carbon dioxide, nitrogen and oxygen) in the headspace of food packs results in suppression of the microbial flora of perishable foods developed under aerobic conditions and retention of their sensorial attributes. Other than proper gases combination in the headspace of packages, the shelf life of products in MAP also very much depends on the quality of raw material, storage temperature and packaging materials used (Farber, 1991; Sivertsvik, 2007; Rotabakk et al., 2008; Fernandez et al., 2010).

2.6.4 Vacuum packaging

According to Mathew and Jaganathan (2017) vacuum packaging is defined as the packaging of a product in a high barrier package from which air is removed to prevent the growth of aerobic spoilage organisms, shrinkage, oxidation and colour deterioration. Vacuum Packaging (VP) is accomplished by evacuating all the air within a package and hermetically sealing. This means that storing and preserving the food in an airless environment, therefore this packaging technology is widely applied in the food industry due to its effectiveness in reducing oxidative reaction in the product at a relatively low cost (Brody, 1989; Davies, 1995; Patil et al., 2020). This increases storage or shelf life by inhibiting the growth of microorganisms and improves hygiene by reducing the danger of cross-contamination (Meena et al., 2017). Vacuum packaging also preserves flavour and protects against dehydration and weight loss, (Hintlain & Hotchkiss, 1986; Brody, 1989; Gorris & Peppelenbos, 1992; Varoquaux and Nguyen, 1994; McMillin, 2008). The use of vacuum packaging inhibits the growth of aerobic spoilage bacteria, offers positive control of the moisture content of the food product and lengthens shelf life for food products (Martens, 1995; Meena et al., 2017). The concentration of carbon dioxide (about 20 %) prevents growth of gram-negative spoilage bacteria. However, the growth of facultative anaerobic, CO_2 tolerant bacteria mainly lactic acid bacteria can still occur in vacuum packaging.

2.7 Discussion of reviewed literature

Mopane worms are consumed in large quantities in Africa particularly in Southern African regions. Though mopane worms are high in protein and other valuable minerals to human health, they are susceptible to contamination and therefore loss of quality and shelf life.

Several factors contribute to the loss of quality and affect the shelf life of mopane worm, key among them are poor handling and storage conditions, packaging materials and hygiene during processing. These factors promote infestation of fungus if not controlled. The fungus once they attack any food product, they cause loss of desirable quality attributes, loss of quality attributes and lead to the shortening of the shelf life of MW.

It is important to understand the interaction between mopane worm and its packaging materials, as well as storage conditions. Currently, there is no literature on the effect of currently used packaging materials on the quality and shelf life of dried mopane worm. Therefore, there is a need to establish how the packaging materials and storage environment influence quality and shelf life of mopane worm. This information will be crucial in developing suitable packaging materials that will preserve the quality and extend shelf life of MW under conditions that limit the infestation of disease-causing microbe that can be detrimental the health of its consumers.

The packaging materials that are being used both for traditional bulk and commercial retail should be investigated to find out whether they are serving the packaging primary mandate thus protecting the MW. Traditional bulk packaging materials should store the mopane worm for a long period safely. On the other hand, retail packaging materials should protect the MW while at retail outlets, thus preserving the quality of MW being offered to the consumer.

The lack of documentation on the effect of both traditional bulk and the commonly used retail packaging materials on the quality and shelf life of dried mopane worm *(I. belin)* is overdue. Many previous studies have reported that traditionally processed dried MW is stored in bulk and retail packaging materials whose efficacy in protecting the MW is unknown. Accordingly, this study is intended to fill the knowledge gap by subjecting traditionally processed mopane worm to physicochemical and microbiological analysis when stored under currently used packaging materials for bulk and retail as well as to conduct a sensory analysis to determine consumer overall acceptability. The information obtained from this study will be helpful to harvesters, traders and consumers to make informed decisions on bulk and retail storage of traditionally processed dried MW. The findings of the study also intend to provide useful information to MW consumers.

2.8 Conclusion

Mopane worm is an important relish food in most parts of southern Africa. MW contains comparatively high levels of protein, fat, carbohydrate valuable minerals in comparison to beef and chicken, the common source of these nutrient in southern Africa. The worm is harvested from the ground and the leaves of the trees. Traditionally, after harvesting, MW is degutted, boiled and dried in the sun, after which they can be stored. Literature reveals that mopane worm packaging, storage and processing practices are poor and unhygienic. According to literature mopane worm are stored in polythene bags, sold in thin plastic bags and traditionally stored in polypropylene woven bags and plastic buckets. The currently, used packaging materials lead to infestation by the pests, microorganisms that accelerate fast deterioration and rewetting. Once the MW exposed to possible contaminations, its safety for consumption is unguaranteed. The literature review shows that there is information on the nutritive composition of mopane worm, the contribution of mopane worm to food security and other focuses on mopane worm; however, there is no evidence of the study that focuses on the storage and packaging of mopane worm. Therefore, it is necessary to undertake a study on the effect of packaging, storage and time on the quality and shelf life of MW.

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CHAPTER THREE

EFFECT OF CONVENTIONAL BULK PACKAGING MATERIALS, STORAGE TEMPERATURE AND DURATION ON QUALITY OF DRIED MOPANE WORM

Abstract

This study assessed the effects of conventional bulk packaging materials, storage temperature and duration on quality and shelf life of traditionally processed sun-dried mopane worm *(I. belin)*. Changes in the quality of mopane worm was evaluated in a 2 x 2 x 5 factorial experiment comprising packaging materials (polypropylene woven sack and hessian sack), storage temperature (ambient and accelerated), and storage duration (0, 30, 60, 90 and 120 days) with three replications. Dried MW samples were analysed for changes in physicochemical (ash, fat, moisture, protein and colour (L*, a*, b* and ∆E*)) 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 separated using Tukey test at 5 % significance level. Packaging material significantly ($p < 0.05$) affected protein content during storage. Ash, moisture and fat content were not significantly ($p > 0.05$) affected by packaging material. Storage time and temperature significantly ($p < 0.05$) affected moisture, fat and protein content. The interaction between packaging material, temperature and storage time significantly ($p < 0.05$) affected colour parameters. Coliform, mould and yeast count of dried MW were not significantly ($p > 0.05$) affected by packaging material, storage temperature and duration of storage. Microbial qualities were not significantly ($p > 0.05$) affected by the interaction between packaging material, temperature and storage time. Packaging material and temperature did not significantly ($p > 0.05$) affect the sensory qualities throughout the experimental period. However, temperature significantly ($p < 0.05$) affected the overall acceptability of dried MW. Overall, the quality of dried MW was lower in hessian sack than in polypropylene sack; hence, a polypropylene sack is a better bulk storage and packaging material for traditionally processed dried MW .

Keywords: mopane worm, bulk packaging, quality, temperature, time.

3.1. Introduction

Bulk packaging systems are primary style of packaging used for farm in warehouses before they are distributed in smaller quantities and packages. An ideal bulk packaging system for dried MW should be inert, leak-proof, impermeable to air and moisture, opaque, resistant to mechanical abrasion and puncture and inexpensive. (Antony et al., 1988). Besides, it should be insect-proof and should withstand heat and ultra-violet rays. A proper bulk packaging material should ideally inhibit undesirable enzyme activities, but not interfere with, or inhibit, beneficial activities (Scetar et al., 2010). Packaging has become very significant because it protects the food product from contamination by micro and macro-organisms and their filth, prevention from loss or gain of moisture, and to facilitates its safe and hygienic handling (Antony et al., 1988; Chowdhury et al., 2011).

Factors such as packaging material, storage temperature and time influence the retention of nutrients in stored dehydrated foods (Villota et al., 1980). Also, storage time and temperature are major factors affecting the rate of loss of quality and shelf life of dried mopane worm (MW) (Uzzaman et al., 2018). Storage time contributes to losses of nutritional quality of dried MW. Product deterioration can be evaluated by assessing quality attributes and how they change or deteriorate over time to conclude failure. Deterioration evaluation should always be, directly or indirectly, related to a sensory assessment (Huis in't Veld, 1996). Thus, the quality of a product can result in economic losses due to consumer rejection (Gray et al., 1996; Scetar et al., 2010).

Storage temperature affects the rate of food deterioration, which includes chemical reactions in particular oxidation and colour changes at elevated levels of temperature, thus greatly contribute to flavour deterioration (Sanchez-Escalante et al., 2001; Gram et al., 2002; Allen, 2010; Amaral et al., 2014). Increasing temperature contributes to increases moisture loss from a product (Okonkwo et al., 1992). Sensory attributes can have a much more rapid change at higher storage temperatures than during ambient storage (Heitschmidt, 2012). The effect of temperature on the quality of stored products is therefore important.

Studies have established that packaging material, storage conditions and time either singly or in combination have effect on the quality and storage stability of food products (Amaral et al., 2014). The aim of this study was, therefore, to evaluate the combined effect of conventional bulk packaging materials (polypropylene woven sack and hessian sack), storage temperature (ambient and accelerated) and storage duration on the microbiological, physicochemical and sensory characteristics of traditionally processed dried mopane worm.

3.2. Materials and Methods

3.2.1. Packaging, storage and sampling of dried mopane worm

The mopane worm *(I. belin)* dried samples were subdivided into small portions of 1 kg each. The 1 kg portions were then randomly filled into polypropylene (PP) and a hessian sack (HS) Figure 3.1. The open ends of all the packages containing the samples were thereafter twisted and fastened tightly to make them airtight. There were four (4) packages, two (2) of each type of package. The two packages were then stored under ambient temperature and the other two at accelerated temperature for 120 days see Figure 3.2. The accelerated storage was done using an oven with a temperature set at 33 °C. Whereas in ambient storage a kitchen cupboard was used to store sample bags.

(a) Polypropylene woven sack

(b) Hessian sack

Figure 3.1. Conventional bulk Packaging materials used for dried MW storage. (a) Polypropylene woven sack and (b) Hessian sack.

Sampling was done on day zero and thereafter at 30-day intervals. To obtain samples for analysis at the different intervals, the packages were opened and approximately 100 g of dried MW was picked from the two storage environments and the samples analysed for the different quality parameters following the method described by Kamau et al. (2018).

3.2.2. Experimental design and data analysis

A three-factor full-factorial design comprising of (packaging materials, storage temperature and storage time) was used. The factors studied were packaging materials (Polypropylene woven sack and Hessian sack), storage temperature (ambient and accelerated) and storage time (0, 30, 60, 90 and 120 days) with three replications. The structure of the experimental design and treatments are presented in Figure 3.2.

All data were obtained in triplicates and reported as mean. The microbial data was transformed to $\log_{10}$ to meet the requirements of equal variance and normal distribution (Kung et al., 2017). The effects of packaging materials, storage temperature and duration as well as 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 Tukey test.

3.3 Analysis of the physicochemical of dried mopane worm

3.3.1 Protein content determination

Protein content was determined following the Kjeldahl method (AOAC, 2006); 1 g of dried MW were 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 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 reported. Equation 3.1 and Equation 3.2 were used to calculate the crude protein content.

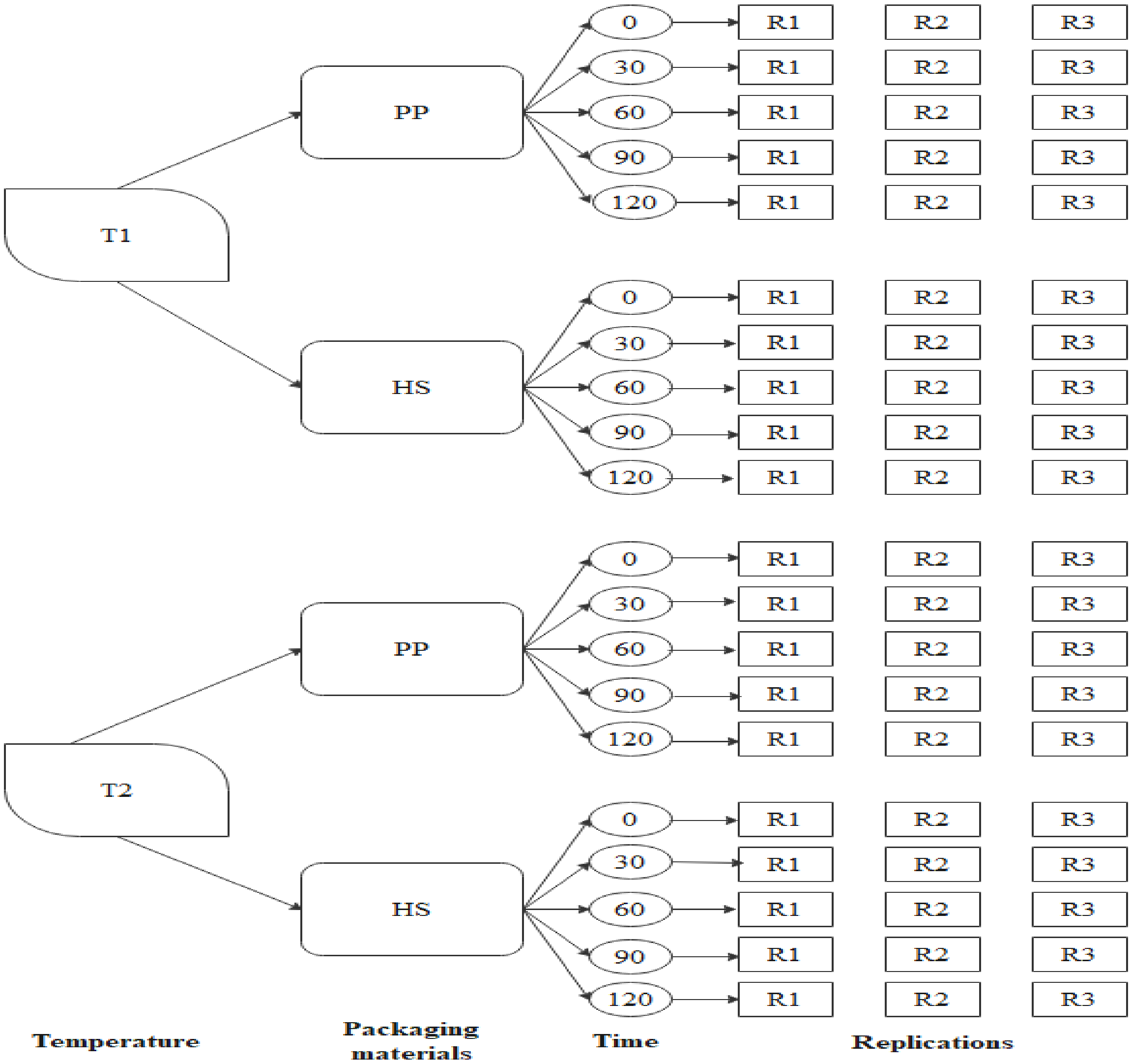

Figure 3.2. Schematic presentation of the experimental treatment structure with three factors (Temperature, Packaging materials, Time and three replications)

$$\%\,Nitrogen = \frac{(volume\ of\ acid\ x\ Molarity\ of\ standard\ acid)\ x\ 0.014}{weight\ of\ the\ original\ sample}\ x\ 100 \quad (3.1)$$

$$\%\,crude\ protein\ content = nitrogen\ content\ x\ 6.25 \quad (3.2)$$

3.3.2 Fat content determination

Fat content was determined through the Soxhlet extraction method (AOAC, 2006) using Buchi 810 Soxhlet fat extractor. 2 g of dried MW was weighed and placed into the Soxhlet extraction thimble. The extraction thimble was plugged with cotton wool and placed in the Soxhlet extractor. 150 ml of petroleum ether was added and extraction was done for 16 hours in the Soxhlet apparatus. The flask was thereafter 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 recorded. The fat content was calculated using Equation 3.3.

$$\% \, Fat = \frac{Weight\ of\ fat}{Weight\ of\ the\ original\ sample}\ x\ 100 \tag{3.3}$$

3.3.3 Moisture content determination

To determine moisture content of dried mopane worm. Two grams of dried MW sample was weighed in a clean dry and pre-weighed crucible and then placed in an oven at 105 °C for 3 hours. The crucibles were transferred to a desiccator and allowed to cool and then weighed. Further placement in the oven was carried out until a constant weight was obtained (W3) (AOAC, 2006). Moisture content was calculated using Equation 3.4.

$$\% \, Moisture\ content = \frac{(W2-W1)-(W3)}{W2-W1}\ x\ 100 \tag{3.4}$$

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

3.3.4. Ash content determination

To determine total ash content, two grams of dried MW was weighed and placed in a clean dry pre-weighed crucible. 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

(W2) (AOAC, 2006). Total ash content was calculated using Equation 3.5.

$$\% \, Total \; ash \; content = \frac{W2 - W1}{W3} \, x \, 100 \qquad (3.5)$$

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

3.3.5 Determination of the 3-dimensional colour values of dried MW

The 3-dimensional colour of dried mopane worm was measured using a calorimeter *(Colourflex EZ, HunterLab, USA)*, based on the CIE colour specifications. 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. MW colour changes were determined by calorimetric evaluation of the CIE parameters, lightness (L*), green-redness (a*) and blue-yellowness (b*) values were recorded in triplicates. The mean of the measurement per treatment was calculated. Total colour difference (ΔE*), which indicates the magnitude of change in colour parameters between the initial and final colour values during storage was calculated using Equation 3.6 (Pathare et al., 2013).

$$\Delta \boldsymbol{E} * = \sqrt{\Delta \boldsymbol{L}^{*2} + \Delta \boldsymbol{a}^{*2} + \Delta \boldsymbol{b}^{*2}} \qquad (3.6)$$

Where, L* lightness, a* red/ green, b* yellow/blue and ΔE* total colour difference

3.4. 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 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.

3.4.1. Yeast and mould determination

Potato Dextrose Agar (PDA) was used to count yeast and mould of dried MW (AOAC., 2014). The plates were incubated in the dark at 25 °C for 5 days and thereafter colonies were counted, all following AOAC. (2014) general methods for enumeration of yeast and moulds.

3.4.2. Coliform determination

Violet Red Bile Agar (VRBA) was used to enumerate the coliform count of dried MW. The plates were, allowed to cool, kept at 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 incubation and the results were reported as $\log_{10}$ cfu/ g (Mujuru et al., 2014).

3.5. Sensory evaluation of stored dried mopane worm

Sensory analysis was done to determine the consumer acceptability of MW over time. The consumer acceptability was conducted using 101 participants. The participants were given a consent form to complete, a questionnaire and the evaluation forms before participating in this sensory evaluation exercise. The participants evaluated the dried mopane worm for taste, colour, texture and overall acceptability on a 9 hedonic scale in which 1 represented extremely disliked and 9 represented extremely liked. The sensory evaluations were conducted on day 0, 60, and 90. (Mahalingaiah et al, 2014). Necessary precautions were taken to prevent carry-over of flavour during the tasting by ensuring that the participants rinsed their mouth with water after each stage of sensory evaluation.

3.4. Results

3.4.1 Proximate composition

A summary of the proximate composition of dried MW is presented in Table 3.1. Packaging materials did not significantly; ($p > 0.05$) affect the moisture and fat content of dried MW. However, the ash and protein content was significantly ($p < 0.05$)

affected by packaging materials. Storage time significantly ($p < 0.05$) affected ash, moisture and fat content of dried MW during storage. However, storage time insignificantly ($p > 0.05$) affected protein content. Storage temperature significantly ($p < 0.05$) affected moisture, fat and protein content of dried MW. However, storage temperature insignificantly ($p > 0.05$) affected ash content of dried MW.

The interaction between packaging material and the storage, and packaging material and time significantly ($p < 0.05$) affected ash content of dried MW. Only the interaction between storage temperature and time insignificantly ($p > 0.05$) affected ash content of dried MW. The three-way interaction between packaging material, storage temperature, and time, had no significant ($p > 0.05$) effect on the ash content of dried MW (Table 3.1). The mean levels of ash content of dried MW stored in two bulk packaging materials (PP and HS) under T_1 and T_2 storage conditions from day 0 to day 120 is shown in (Figure 3.3 (a)).

The level of ash content in PPT_1 and PPT_2 increased with increasing storage time. The ash content of dried MW in PPT_2 was lower when compared to ash content in PPT_1. The ash content of dried MW for PPT_1, and PPT_2, ranged from 9.44 to 13.85 %, and 9.02 to 10.02%. The levels of ash content in HST_1 packaging material increased, whereas the ash content in HST_2 insignificant decreased with increasing storage time (Figure 3.3 (a)). The ash content in HST_2 was lower when compared to ash content in HST_1. The ash content of dried MW for HST_1 and HST_2 ranged from 8.07 to 9.49 % and 8.17 to 9.09 %.

The interaction between packaging material and temperature, and packaging material and time had no significant ($p > 0.05$) effect on moisture content of dried MW. Only the interaction between temperature and time significantly ($p < 0.05$) affected the moisture content of dried MW. The three-way interaction between packaging material, temperature and time, had no significant ($p > 0.05$) effect on moisture content of dried MW (Table 3.1). The mean levels of the moisture content of dried MW stored in the two bulk packaging materials (PP and HS) under T_1 and T_2 storage conditions from day 0 to day 120 is shown in (Figure 3.3 (b)).

The level of moisture content in PPT_1 and PPT_2 (Figure 3.3 (b)) increased on day 90 with increasing storage time. The levels of moisture content in PPT_2 were lower when compared to the moisture level in PPT_1. The moisture content of dried MW for PPT_1 and PPT_2 ranged from 5.19 to 7.44 % and 1.75 to 5.04 %. The levels of moisture content in HST_1 and HST_2 (Figure 3.3 (b)) generally decreased with increasing storage time. The moisture levels in HST_2 were lower when compared to moisture levels in HST_1. The moisture content of dried MW for HST_1 and HST_2 ranged from 5.27 to 6.23 % and 1.11 to 6.40 %.

The interaction between packaging material and time, and temperature and time significantly ($p < 0.05$) affected fat content of dried MW. Only the interaction between packaging material and temperature had no significant ($p > 0.05$) effect on fat content of dried MW. The three-way interaction between packaging material, temperature and time significantly ($p < 0.05$) affected the fat content of dried MW (Table 3.1). The mean levels of fat content of dried MW stored in two bulk packaging materials (PP and HS) under T_1 and T_2 storage conditions from day 0 to day 120 is shown in (Figure 3.3 (c)).

The levels of fat content in PPT_1 and PPT_2 see (Figure 3.3 (c)) decreased with increasing storage time. The levels of fat content in PPT_2 were lower when compared to the fat content in PPT_1. The fat content of dried MW for PPT_1 and PPT_2 ranged from 11.39 to 12.56 % and 9.99 to 12.49 %. The levels of fat content in HST_1 increased, whereas the fat content in HST_2 decreased with increasing storage time see (Figure 3.3 (c)). The levels of fat content in HST_2 was lower when compared to HST_1. The fat content of dried MW for HST_1 and HST_2 ranged from 10.65 to 13.18 % and 8.78 to 13.07 %.

The interaction between packaging material and time, and temperature and time had no significant ($p > 0.05$) on the protein content of dried MW. Only the interaction between packaging material and temperature significantly ($p < 0.05$) affected the protein content of dried MW. The three-way interaction between packaging material, temperature and time, had no significant ($p > 0.05$) effect on the protein content of dried MW (Table 3.1). The mean levels of the protein content of dried MW stored in the two bulk packaging materials (PP and HS) under T_1 and T_2 storage conditions from day 0 to day 120 is shown in (Figure 3.3 (d)).

Table 3.1. Effect of packaging materials, temperature and time on proximate composition of dried traditionally processed MW.

Temperature °C	Packaging materials	Proximate composition	Time (Days)				
			0	30	60	90	120
T_1	PP	Ash (%)	9.72^{b} ± 1.25	9.44^{b} ± 1.37	9.77^{b} ± 0.36	13.85^{a} ± 2.90	9.75^{b} ± 1.54
T_2	PP		9.02^{b} ± 0.12	8.28^{b} ± 0.47	8.36^{b} ± 0.03	10.02^{b} ± 1.87	9.43^{b} ± 0.35
T_1	HS		8.07$_{b}$ ± 1.01	9.49^{b} ± 2.33	9.00^{b} ± 1.13	9.15^{b} ± 0.92	8.78^{b} ± 0.17
T_2	HS		9.09^{b} ± 0.20	8.80^{b} ± 0.26	8.17^{b} ± 1.02	8.54^{b} ± 0.69	8.56^{b} ± 0.13
T_1	PP	Moisture (%)	6.02^{a} ± 0.28	6.13^{a} ± 0.18	5.19^{abcd} ± 0.15	7.44^{a} ± 0.34	5.23^{abcd} ± 0.53
T_2	PP		5.04^{abcde} ± 1.46	2.42^{ef} ± 0.13	1.75^{f} ± 0.02	2.88^{cdef} ± 0.20	3.09^{bcdef} ± 0.06
T_1	HS		6.06^{a} ± 0.21	5.55^{ab} ± 0.69	5.40^{abc} ± 0.04	6.23^{a} ± 0.06	5.27^{abcd} ± 2.15
T_2	HS		6.40^{a} ± 1.67	1.11^{f} ± 0.66	1.80^{ef} ± 0.04	3.01^{bcdef} ± 0.05	2.72^{def} ± 0.03
T_1	PP	Fat (%)	12.56^{a} ± 0.76	12.44^{ab} ± 0.59	12.26^{ab} ± 0.44	11.39^{abc} ± 0.62	12.15^{ab} ± 0.67
T_2	PP		12.49^{a} ± 0.33	12.34^{ab} ± 0.90	12.34^{ab} ± 0.76	11.71^{abc} ± 0.60	9.99^{cde} ± 0.06
T_1	HS		12.57^{a} ± 0.22	11.86^{ab} ± 0.59	12.92^{a} ± 0.29	10.65^{bcd} ± 0.78	13.18^{a} ± 0.62
T_2	HS		12.55^{a} ± 0.51	12.63^{a} ±. 0.30	13.07^{a} ± 0.30	9.39d^{e} ± 0.54	8.78^{e} ± 1.01
T_1	PP	Protein (%)	57.25^{c} ± 6.24	59.59^{bc} ± 3.74	63.27^{abc} ± 1.77	63.22^{abc} ± 2.21	63.25^{abc} ± 2.36
T_2	PP		72.24^{ab} ± 6.05	71.65^{abc} ± 2.38	76.00^{a} ± 1.54	69.03^{abc} ± 4.88	74.98^{a} ± 3.16
T_1	HS		72.47^{ab} ± 4.72	73.79^{ab} ± 2.55	72.60^{ab} ± 2.14	72.74^{ab} ± 2.65	74.35^{ab} ± 2.75
T_2	HS		66.85^{abc} ± 11.15	69.50^{abc} ± 9.03	62.23^{abc} ± 3.89	70.22^{abc} ± 6.02	68.54^{abc} ± 4.32

Treatment and interactions	Significance Level (p value)			
	Ash content %	Moisture content %	Fat content %	Protein content %
PM	0.002	0.464	0.186	0.012
T (°C)	0.007	0.001	0.001	0.027
D	0.016	0.001	0.001	0.656
PM x T	0.054	0.545	0.073	0.001
PM x D	0.018	0.184	0.001	0.232
T x D	0.157	0.001	0.001	0.891
PM x T x D	0.498	0.419	0.013	0.416

The values are given as mean of triplicates and standard deviation. Same letters in rows are not significantly different ($p > 0.05$).

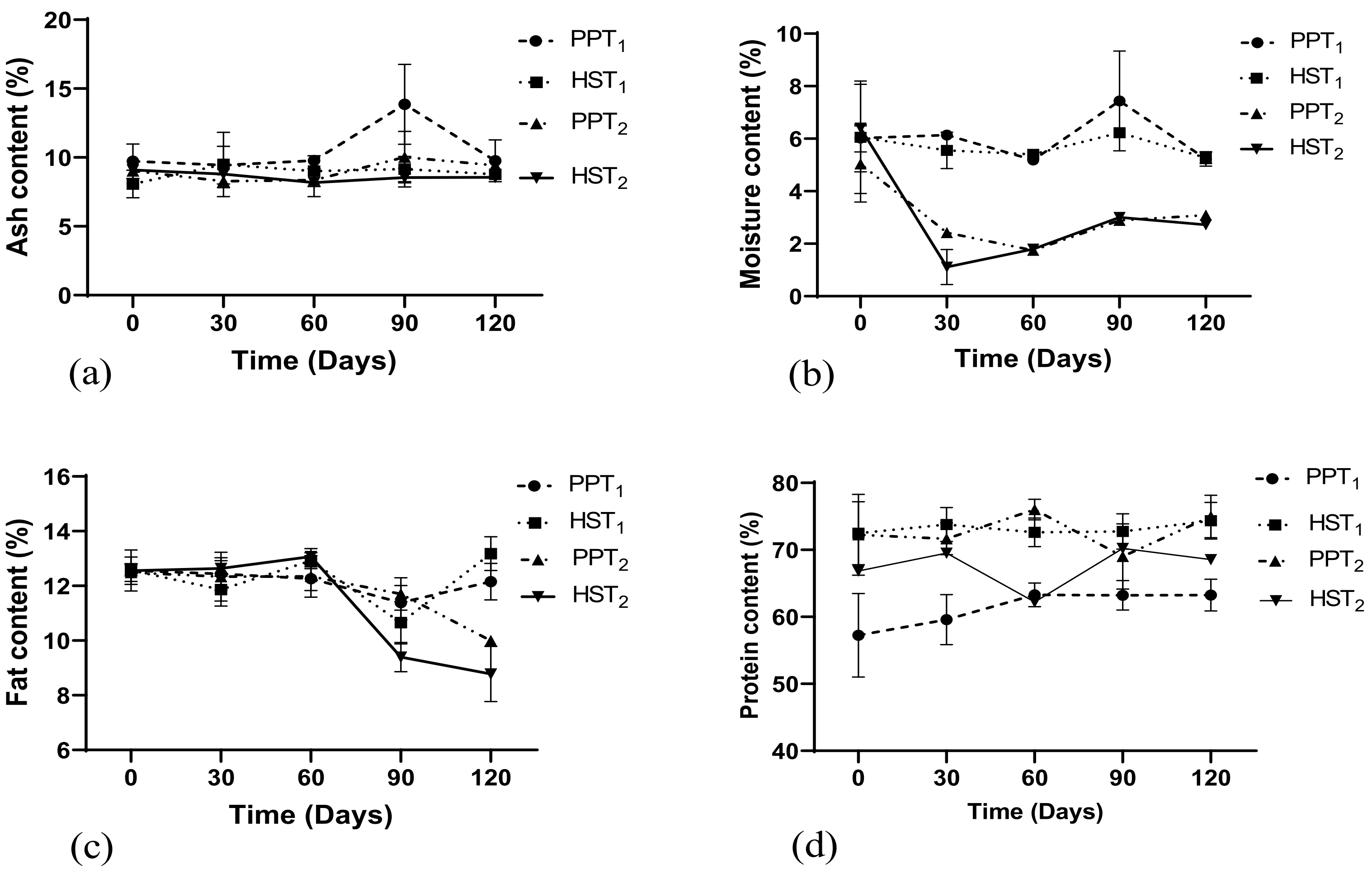

Figure 3.3. Variation of the mean levels of (a) ash content, (b) moisture content, (c) fat content and (d) protein content of dried MW packaged in bulk packaging materials PP and HS stored under ambient (T_1) and accelerated (T_2) temperature conditions

The level of protein content in PPT_1 and PPT_2 see (Figure 3.3 (d)) increased with increasing storage time. The levels of protein content were lower in PPT_1 when compared to the protein content in PPT_2. The protein content of dried MW for PPT_1 and PPT_2 ranged from 57.25 to 63.27 % and 69.03 to 76.00 %. The level of protein content in HST_1 and HST_2 see (Figure 3.3 (d)) increased with increasing storage time. The protein content in HST_2 was lower when compared to protein content in HST_1. The protein content of dried MW for HST_1 and HST_2 ranged from 72.47 to 74.35 % and 62.23 to 70.22 %.

3.4.2 The 3-dimensional colour

A summary of the results on the 3-dimensional colour of dried MW is presented in Table 3.2. Packaging material significantly, ($p < 0.05$) affected lightness (L*), redness (a*), yellowness (b*) and total colour difference (ΔE*) of dried MW. Storage times significantly ($p < 0.05$) affected lightness (L*), redness (a*), yellowness (b*) and total colour difference (ΔE*) of dried MW samples. Temperature significantly ($p < 0.05$) affected lightness (L*), redness (a*), yellowness (b*) and total colour difference (ΔE*) of dried MW samples.

All the two-way and three-way interactions among the treatments significantly ($p < 0.05$) affected lightness index of dried MW (Table 3.2). The levels of L* in PPT_1 and PPT_2 see (Figure 3.4 (a)) decreased with an increasing storage time. The levels of L* were lower in PPT_2 when compared to the L* in PPT_1. The L* index of dried MW for PPT_1 and PPT_2 ranged from 26.81 to 31.57 and 23.54 to 33.64. The level of L* in HST_1 and HST_2 see (Figure 3.4 (a)) decreased with an increasing storage time. The L* in HST_2 was lower than L* in HST_1. The L* index of dried MW for HST_1 and HST_2 ranged from 23.88 to 30.40 and 20.46 to 31.53.

All the two-way and three-way interactions among the treatments significantly ($p < 0.05$) affected the redness/greenness index of dried MW (Table 3.2). The levels of a* in PPT_1 decreased and in PPT_2 the levels of a* increased with storage time see (Figure 3.4 (b)). The levels of a* were lower in PPT_1 when compared to levels of a* in PPT_2. The a* index of dried MW for PPT_1 and PPT_2 ranged from 2.18 to 4.33 and 3.25 to 4.66. The levels of a* increased in HST_1 and decreased in HST_2 with an increasing storage time see (Figure 3.4 (b)). The levels of a* in HST_2 were lower than the levels of a* in HST_1. The a* index of dried MW for HST_1 and HST_2 ranged from 2.30 to 4.86 and 2.74 to 4.44.

All the two-way and three-way interactions among the treatments significantly ($p < 0.05$) affected the yellowness-blueness index of dried MW (Table 3.2). The levels of b* in PPT_1 and PPT_2 see (Figure 3.4 (c)) decreased with increasing storage time. The levels of b* were higher during storage in PPT_1 when compared to levels of b* in PPT_2. The b* index of dried MW for PPT_1 and PPT_2 ranged from 8.87 to 11.44 and 8.30 to 11.47. The levels of b* increased in HST_1 and decreased in HST_2 with an increasing storage time see (Figure 3.4 (c)). The levels of b* in HST_2 were higher when compared to HST_1 throughout the storage time except on day 120. The b* index of dried MW for HST_1 and HST_2 ranged from 5.94 to 11.15 and 6.72 to 11.40.

All the two-way and three-way interactions among the treatments significantly ($p < 0.05$) affected total colour difference index of dried MW (Table 3.2). The levels of ΔE^* in PPT_1 and PPT_2 see (Figure 3.4 (d)) increased with increasing storage time. The levels of ΔE^* were higher during storage PPT_2 when compared to levels of ΔE^* in PPT_1. The ΔE^* of dried MW for PPT_1 and PPT_2 ranged from 0.00 to 4.07 and 0.00 to 8.53. The levels of ΔE^* decreased in HST_1 and increased in HST_2 with an increasing storage time see (Figure 3.4 (d)). The levels of ΔE^* in HST_2 were higher when compared to HST_1 during storage time. The ΔE^* of dried MW for HST_1 and HST_2 ranged from 0.00 to 8.43 and 0.00 to 12.09.

3.4.3 Microbiological qualities

The results on the microbiological quality of dried MW are presented in Table 3.3. Packaging material had no significant ($p > 0.05$) effect on yeast and mould of dried MW. The coliform count was not-detected (ND) in both packaging materials during storage. Storage time did not significantly ($P > 0.05$) affect the yeast and mould count of dried MW. Storage temperature insignificantly ($p > 0.05$) affected yeast and mould of dried MW Coliform count was not-detected in both storage conditions during storage.

All the two-way and three-way interactions among the treatments did not significantly ($p > 0.05$) affect the mould and yeast count of dried MW (Table 3.3). The mean levels of the yeast count of dried MW stored in the two bulk packaging materials (PP and HS) under T_1 and T_2 storage conditions from day 0 to day 120 are shown in (Figure 3.5 (a)).

Table 3.2. 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
T_1	PP	L*	30.64^{c} ± 0.02	31.57^{b} ± 0.01	30.41^{c} ± 0.03	26.81^{g} ± 0.02	28.46^{e} ± 0.02
T_2	PP		31.46^{b} ± 0.04	33.64^{a} ± 0.04	26.12^{h} ± 0.02	23.54^{i} ± 0.02	28.52^{e} ± 0.02
T_1	HS		30.40^{c} ± 0.84	27.81^{f} ± 0.04	23.88^{i} ± 0.05	26.40^{gh} ± 0.03	29.63^{d} ± 0.01
T_2	HS		31.48^{b} ± 0.02	26.56^{gh} ± 0.03	20.46^{j} ± 0.14	31.53^{b} ± 0.02	26.93^{g} ± 0.04
T_1	PP	a*	4.33^{cd} ± 0.01	2.18^{j} ± 0.06	3.50^{fgh} ± 0.05	3.60^{f} ± 0.11	4.13^{de} ± 0.09
T_2	PP		4.36^{cd} ± 0.04	3.52^{fg} ± 0.02	3.25^{gh} ± 0.10	4.12^{de} ± 0.17	4.66^{ab} ± 0.08
T_1	HS		3.94^{e} ± 0.16	2.91^{i} ± 0.14	2.30^{j} ± 0.19	4.49^{bc} ± 0.02	4.86^{a} ± 0.04
T_2	HS		4.44^{bc} ± 0.07	4.13^{de} ± 0.12	2.74^{i} ± 0.04	3.90^{e} ± 0.05	3.21^{h} ± 0.05
T_1	PP	b*	11.35^{ab} ± 0.12	8.87^{h} ± 0.03	11.44^{a} ± 0.08	10.19^{f} ± 0.14	9.75^{g} ± 0.06
T_2	PP		11.47^{a} ± 0.05	10.67^{de} ± 0.17	8.69^{hi} ± 0.09	8.30^{j} ± 0.19	10.47^{ef} ± 0.12
T_1	HS		11.02^{bcd} ± 0.23	8.55^{hij} ± 0.15	5.94^{l} ± 0.04	10.70^{de} ± 0.12	11.15^{abc} ± 0.06
T_2	HS		11.40^{a} ± 0.12	9.80^{g} ± 0.15	6.72^{k} ± 0.06	10.95^{cd} ± 0.27	8.32^{ij} ± 0.17
T_1	PP	ΔE*	-	3.41^{de} ± 0.11	0.87^{fg} ± 0.05	4.07^{d} ± 0.04	2.71^{e} ± 0.10
T_2	PP		-	2.48^{e} ± 0.10	6.12^{c} ± 0.06	8.53^{b} ± 0.10	3.11^{de} ± 0.02
T_1	HS		-	3.75^{d} ± 0.71	8.43^{b} ± 0.78	4.05^{d} ± 0.83	1.38^{f} ± 0.21
T_2	HS		-	5.18^{c} ± 0.03	12.09^{a} ± 0.10	0.82^{fg} ± 0.13	5.63^{c} ± 0.13

Treatment and Interaction	Significance Level (p value)			
	L*	a*	b*	ΔE*
PM	0.001	0.006	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 are not significantly different ($p > 0.05$).

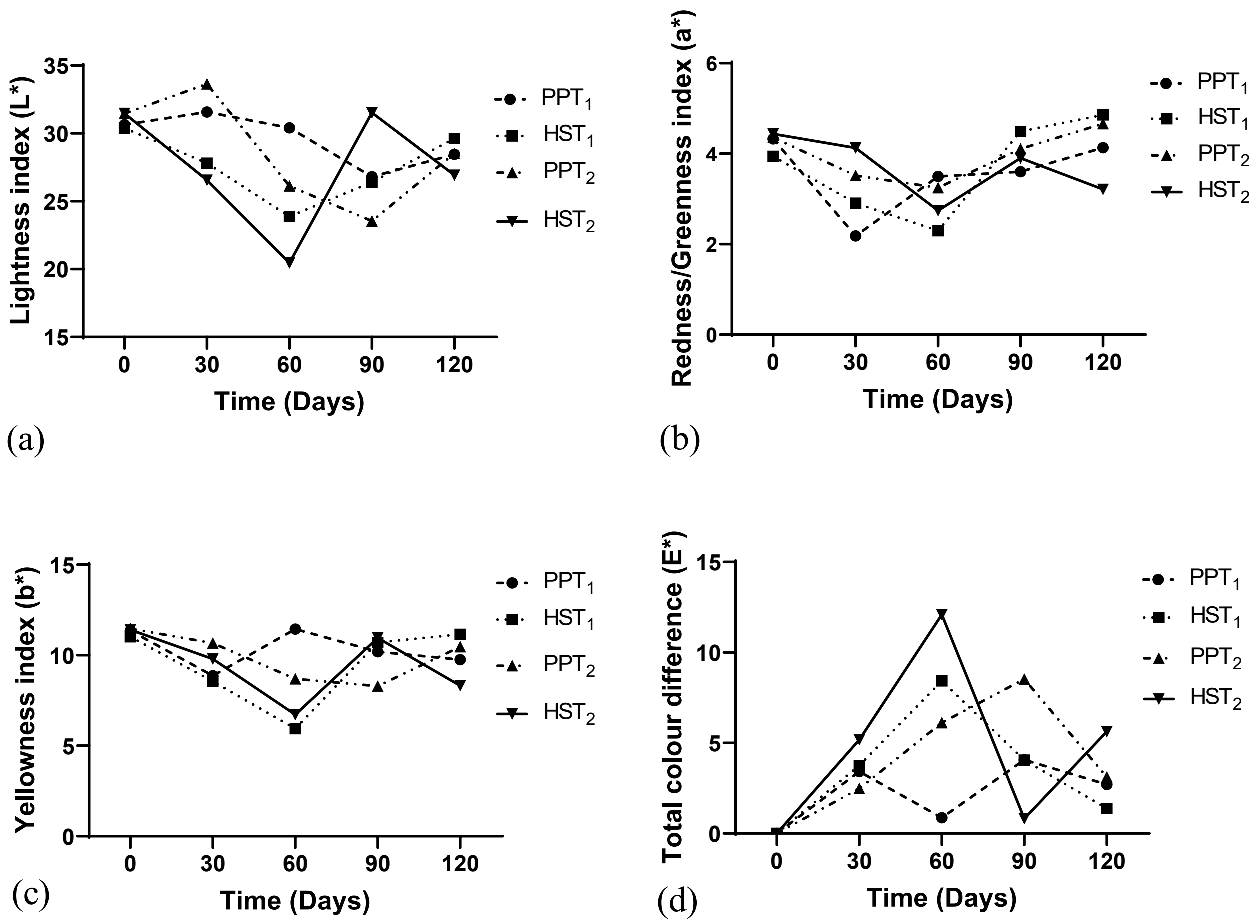

Figure 3.4. Variation of the mean levels of (a) lightness index (L*), (b) redness/greenness index (a*), (c) yellowness index (b*) and (d) total colour difference (ΔE*) of MW packaged in bulk packaging materials PP and HS stored under ambient (T_1) and accelerated (T_2) temperature conditions

The yeast count in PPT_1 and PPT_2 increased with increasing storage time see of 120 days (Figure 3.5 (a)). The levels of yeast count in PPT_2 were higher when compared to yeast count in PPT_1. The yeast count of dried MW for PPT_1 and PPT_2 ranged from 0.16 to 0.42 log_{10} cfu/g and 0.16 to 0.68 log_{10} cfu/g. The levels of yeast count in HST_1 increased and in HST_2 yeast count decreased with increasing storage time of 120 days see (Figure 3.5 (a)). The levels of yeast count in HST_2 we higher when compared to yeast count in HST_1. The yeast count of dried MW for HST_1 and HST_2 ranged from 0.10 to 0.51 log_{10}cfu/g and 0.20 to 0.77 log_{10}cfu/g.

All the two-way and three-way interactions among the treatments insignificantly ($p > 0.05$) affected mould count of dried MW see (Table 3.3). The mean levels of mould count of dried MW stored in the two bulk packaging materials (PP and HS) under T_1 and T_2 storage conditions from day 0 to day 120 is shown in (Figure 3.5 (b)).

The mould count in PPT_1 increased, whereas the levels of mould count in PPT_2 decreased with increasing storage time see (Figure 3.5 (b)). The levels of mould count in PPT_1 were higher when compared to mould count in PPT_2. The mould count of dried MW for PPT_1 and PPT_2 ranged from 0.00 to 0.52 log_{10}cfu/g and 0.00 to 0.38 log_{10}cfu/g. The levels of mould count in HST_1 increased and in HST_2 mould count decreased with increasing storage time see (Figure 3.5 (b)). The levels of mould count in HST_2 we higher when compared to mould count in HST_1. The mould count of dried MW for HST_1 and HST_2 ranged from 0.20 to 0.46 log_{10}cfu/g and 0.10 to 0.52 log_{10}cfu/g.

3.4.4 Sensory evaluation attributes

A summary of the sensory attributes of dried MW is presented in Table 3.4. Packaging material had no significant ($p > 0.05$) effect on sensory colour, taste, texture and overall acceptability of dried MW samples during storage. Storage time significantly ($p < 0.05$) affected sensory colour, taste. Texture and overall acceptability of dried MW throughout the storage time. Storage temperature significantly ($p < 0.05$) affected sensory overall acceptability of dried MW samples. However, storage temperature had no significant ($p > 0.05$); effect on sensory colour, taste and texture of dried MW sample.

Table 3.3. Effect of packaging materials, temperature and time on microbiological quality of dried traditionally processed MW.

Temperature °C	Packaging materials	Microbiological Count	Time (Days)				
			0	30	60	90	120
T_1	PP	Mould (log_{10} cfu/g)	0.43[a] ± 0.23	0.26[a] ± 0.24	0.00[a] ± 0.00	0.52[a] ± 1.38	0.28[a] ± 0.49
T_2	PP		0.23[a] ± 0.40	0.10[a] ± 0.17	0.00[a] ± 0.00	0.38[a] ± 0.43	0.28[a] ± 0.49
T_1	HS		0.20[a] ± 0.35	0.20[a] ± 0.17	0.30[a] ± 0.30	0.36[a] ± 0.10	0.46[a] ± 0.45
T_2	HS		0.52[a] ± 0.24	0.10[a] ± 0.17	0.20[a] ± 0.17	0.49[a] ± 0.50	0.50[a] ± 0.46
T_1	PP	Yeast (log_{10} cfu/g)	0.16[a] ± 0.28	0.42[a] ± 0.73	0.20[a] ± 0.17	0.39[a] ± 0.36	0.41[a] ± 0.71
T_2	PP		0.16[a] ± 0.28	0.68[a] ± 0.67	0.59[a] ± 0.53	0.47[a] ± 0.57	0.41[a] ± 0.71
T_1	HS		0.26[a] ± 0.24	0.51[a] ± 0.64	0.10[a] ± 0.17	0.48[a] ± 0.48	0.30[a] ± 0.30
T_2	HS		0.30[a] ± 0.30	0.49[a] ± 0.84	0.57[a] ± 0.99	0.77[a] ± 0.73	0.20[a] ± 0.17
T_1	PP	Coliform (log_{10} cfu/g)	ND	ND	ND	ND	ND
T_2	PP		ND	ND	ND	ND	ND
T_1	HS		ND	ND	ND	ND	ND
T_2	HS		ND	ND	ND	ND	ND

Treatments and interactions	Significance Levels (p value)	
	Yeast log_{10} cfu/g	Mould log_{10} cfu/g
PM	0.957	0.319
T (°C)	0.327	0.808
D	0.602	0.083
PM x T	0.972	0.347
PM x D	0.934	0.738
T x D	0.848	0.960
PM x T x D	0.985	0.790

The values are given as mean of triplicates and standard deviation. Same letters in rows are not significantly different ($p > 0.05$). ND = None Detected

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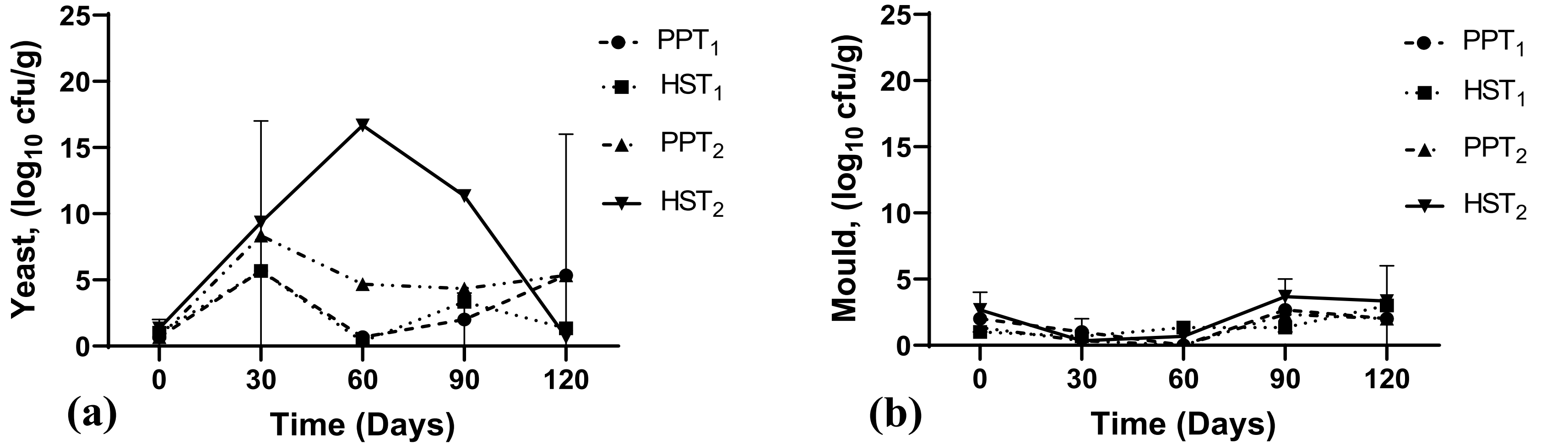

Figure 3.5. Variation of the mean levels of (a) yeast count and (b) mould count of MW packaged in bulk packaging materials PP and HS stored under ambient (T_1) and accelerated (T_2) temperature conditions

The interaction between packaging material and storage temperature, and packaging material and time had no significant ($p > 0.05$) effect on sensory colour liking scores. Only the interaction between storage temperature and time significantly ($p < 0.05$) affected the sensory colour liking scores of dried MW. The three-way interaction between packaging material, storage temperature and time had no significant ($p > 0.05$) effect on the sensory colour of dried MW. The mean levels of participants' liking scores for sensory colour of MW stored in the two bulk packaging materials (PP and HS) under T_1 and T_2 storage conditions from day 0 to day 90 is shown in (Figure 3.6 (a)).

The level of participants' liking scores in PPT_1 increased and the levels of participants' liking scores decreased in PPT_2 with increasing storage time see (Figure 3.6 (a)). The participants' liking scores in PPT_1 were higher than participants' liking scores in PPT_2 during 90 days. The sensory colour of dried MW for PPT_1 and PPT_2 ranged from 6.25 to 6.49 and 5.95 to 6.77. The participants' liking scores for sensory colour of dried MW decreased in both in HST_1 and HST_2 with increasing storage time. The participants' liking scores in HST_1 were higher than participants' liking scores in HST_2 during 90 days. The sensory colour of dried MW for HST_1 and HST_2 ranged from 6.14 to 6.31 and 5.72 to 6.53.

The interaction between packaging material and storage temperature, and packaging material and time had no significant ($p > 0.05$) effect on liking scores of sensory taste. Only the interaction between storage temperature and time significantly ($p < 0.05$) affected the taste of dried MW. The three-way interaction between packaging material, storage temperature and time, had no significant ($p > 0.05$) effect on the liking scores of sensory taste of dried MW (Table 3.4).

The level of liking scores for sensory taste of dried MW decreased in both PPT_1 and PPT_2 with increasing storage time (Figure 3.6 (b)). The liking scores for sensory taste in PPT_1 was higher than liking scores of sensory taste in PPT_2. The sensory taste of dried MW for PPT_1 and PPT_2 ranged from 6.11 to 6.66 and 5.50 to 6.54. The liking scores for sensory taste decreased in both HST_1 and HST_2 with increasing storage time. The liking scores for sensory taste was higher in HST_1 than liking scores for sensory taste in HST_2. The sensory taste of dried MW for HST_1 and HST_2 ranged from 6.19 to 6.44 and 5.55 to 6.52.

The interaction between packaging material and storage temperature, and packaging material and time had no significant ($p > 0.05$) effect on liking scores for sensory texture. Only the interaction between storage temperature and time significantly ($p < 0.05$) affected the liking scores for sensory texture of dried MW. The three-way interaction between packaging material, storage temperature and time, had no significant ($p > 0.05$) effect on the liking scores for sensory texture of dried MW (Table 3.4).

The level of liking scores for sensory texture of dried MW increased in both PPT_1 and PPT_2 with increasing storage time (Figure 3.6 (c)). The liking scores for sensory texture in PPT_1 was higher when compared to liking scores for sensory texture in PPT_2 during 90 days of storage. The sensory texture of dried MW for PPT_1 and PPT_2 ranged from 6.00 to 6.23 and 5.40 to 6.36. The liking score for sensory texture decreased in both HST_1 and HST_2 with increasing storage time. The liking scores for sensory texture was higher in HST_1 than liking scores for sensory texture in HST_2. The sensory texture of dried MW for HST_1 and HST_2 ranged from 5.94 to 6.27 and 5.21 to 6.37.

The interaction between packaging material and storage temperature, and packaging material and time had no significant ($p > 0.05$) effect on the liking scores for sensory overall acceptability. Only the interaction between storage temperature and time significantly ($p < 0.05$) affected the liking scores for sensory overall acceptability of dried MW. The three-way interaction between packaging material, storage temperature and time, had no significant ($p > 0.05$) effect on the liking scores for sensory overall acceptability of dried MW (Table 3.4).

The levels of participants' overall acceptability liking scores of dried MW decreased in both PPT_1 and PPT_2 with increasing storage time (Figure 3.6 (d)). The participants' overall acceptability liking scores were higher in PPT_1 than in PPT_2 during storage. The sensory overall acceptability of dried MW for PPT_1 and PPT_2 ranged from 6.46 to 6.76 and 5.85 to 6.67. The levels of participants' overall acceptability liking scores of dried MW decreased in both HST_1 and HST_2 with increasing storage time. The participants' overall acceptability liking scores were higher in HST_1 than participants' overall acceptability liking scores HST_2 during storage time. The sensory overall acceptability of dried MW for HST_1 and HST_2 ranged from 6.32 to 6.79 and 5.65 to 6.67.

Table 3.4. Effect of packaging materials, temperature and time on sensory attributes of dried traditionally processed MW

Temperature °C	**Packaging materials**	**Sensory parameters**	**Time (Days)**		
			0	**60**	**90**
T_1	PP	Colour	$6.25^{ab} \pm 2.13$	$6.49^{ab} \pm 1.99$	$6.30^{ab} \pm 2.12$
T_2	PP		$6.77^{a} \pm 1.94$	$5.97^{ab} \pm 2.14$	$5.95^{ab} \pm 2.21$
T_1	HS		$6.31^{ab} \pm 2.03$	$6.28^{ab} \pm 1.99$	$6.14^{ab} \pm 1.84$
T_2	HS		$6.53^{ab} \pm 2.15$	$5.72^{b} \pm 2.40$	$5.84^{ab} \pm 2.27$
T_1	PP	Taste	$6.66^{a} \pm 2.04$	$6.11^{abc} \pm 2.25$	$6.29^{abc} \pm 2.36$
T_2	PP		$6.54^{ab} \pm 2.09$	$5.50^{c} \pm 2.38$	$6.41^{abc} \pm 1.79$
T_1	HS		$6.27^{abc} \pm 2.22$	$6.44^{abc} \pm 2.10$	$6.19^{abc} \pm 2.03$
T_2	HS		$6.52^{ab} \pm 2.33$	$5.55^{bc} \pm 2.58$	$6.14^{abc} \pm 2.06$
T_1	PP	Texture	$6.14^{ab} \pm 2.21$	$6.00^{ab} \pm 2.11$	$6.23^{a} \pm 2.13$
T_2	PP		$6.21^{a} \pm 2.18$	$5.40^{ab} \pm 2.26$	$6.36^{a} \pm 1.96$
T_1	HS		$6.27^{a} \pm 2.14$	$6.15^{ab} \pm 1.82$	$5.94^{ab} \pm 2.10$
T_2	HS		$6.37^{a} \pm 2.01$	$5.21^{b} \pm 2.42$	$5.95^{ab} \pm 1.96$
T_1	PP	Overall acceptability	$6.76^{ab} \pm 1.90$	$6.46^{abc} \pm 1.99$	$6.49^{abc} \pm 2.03$
T_2	PP		$6.67^{ab} \pm 2.12$	$5.85^{bc} \pm 2.28$	$6.62^{ab} \pm 1.85$
T_1	HS		$6.51^{abc} \pm 2.16$	$6.79^{a} \pm 1.83$	$6.32^{abc} \pm 1.85$
T_2	HS		$6.67^{ab} \pm 2.04$	$5.65^{c} \pm 2.36$	$6.10^{abc} \pm 2.05$

Treatment and Interactions	**Significance Level (p value)**			
	Colour	**Taste**	**Texture**	**Overall acceptability**
PM	0.215	0.591	0.541	0.255
T (°C)	0.186	0.091	0.090	0.013
D	0.012	0.001	0.000	0.005
PM x T	0.693	0.927	0.559	0.361
PM x D	0.892	0.356	0.245	0.351
T x D	0.006	0.012	0.004	0.002
PM x T x D	0.832	0.526	0.825	0.362

The values are given as mean of triplicates and standard deviation. Same letters in rows are not significantly different ($p > 0.05$).

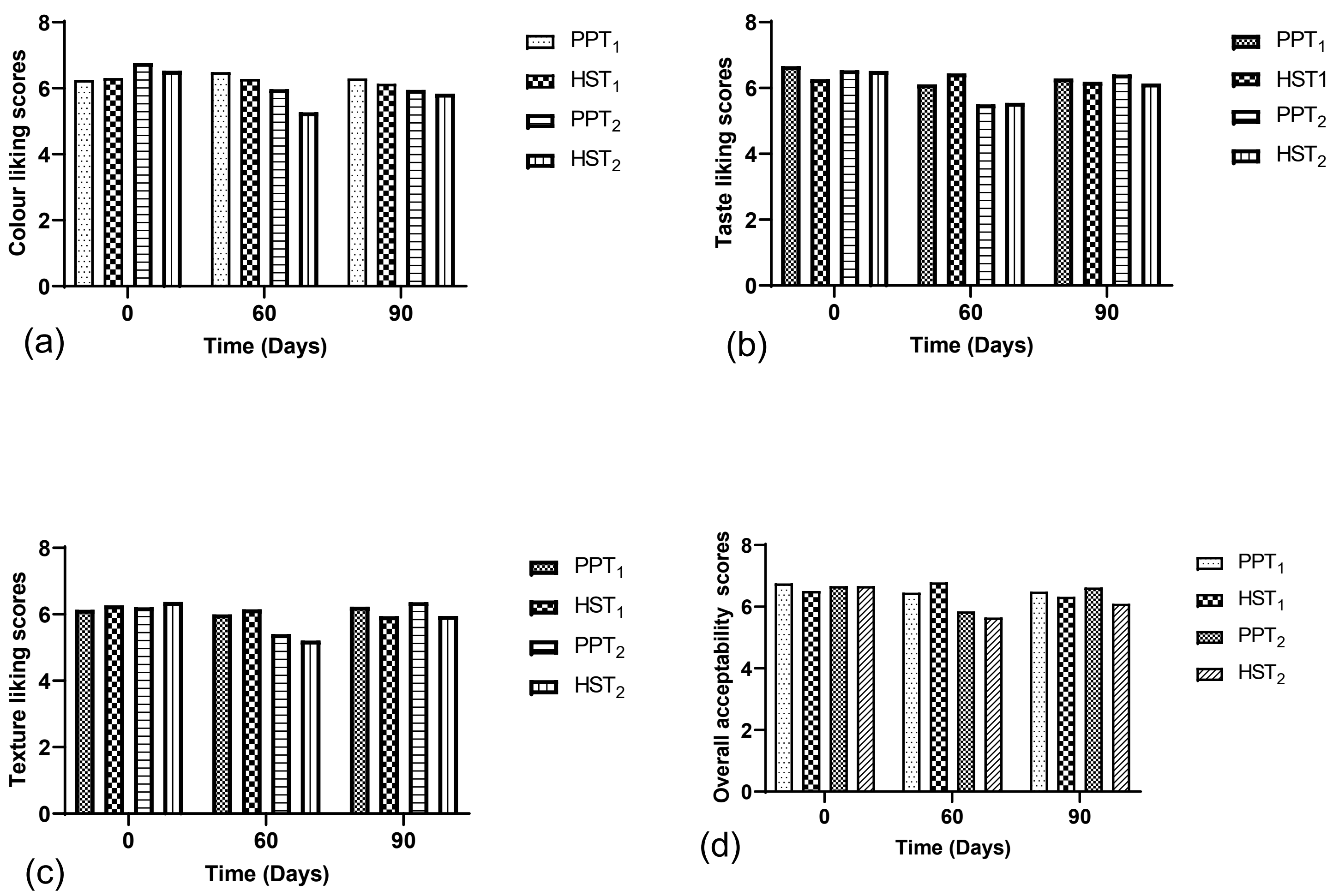

Figure 3.6. Variation of the mean levels of sensory parameters of MW packaged in bulk packaging materials PP and HS stored under ambient (T_1) and accelerated (T_2) temperature conditions

3.5 Discussion

Factors such as packaging materials, storage temperature and time have influence on the overall quality of stored foods (Villota et al., 1980; Uzzaman et al., 2018). The changes in quality of stored food are generally assessed by measuring and monitoring the changes in selected physicochemical and microbiological qualities (Chowdhury et al., 2011; Amaral et al., 2014), and the sensory attributes (Seydim et al., 2006; Yilmaz and Demirci, 2010). Commonly used physicochemical parameters to quantify the quality of foods include ash, moisture, protein, fat contents and CIE colour measurements (Siah and Tahir, 2011; Shakouri et al., 2015). The microbial quality of foods is traditionally determined using (yeast, mould and coliform count) (Okonkwo et al., 1992; Pereira et al., 2015). Lastly, organoleptic parameters such as texture, visual/sensory colour, texture and overall acceptance are used to assess the sensory attributes of food products (Linssen and Roozen, 1994; Lavieri and Williams, 2014; Padehban et al., 2018). The combination of the organoleptic and sensory attributes is used to arrive at overall acceptability of a food product (Koral et al., 2010) with a high score on the Liking scale indicating good overall liking of a food (Amaral et al., 2014; Gogoi et al., 2015).

Ash content represents the total mineral content in food, and it is essential in maintaining several bodily functions (Akuamoa et al., 2019). In this study, the average ash content on day 0, 30, 60, 90, and 120 were 8.98 $\pm$ 0.59 %, 9.00 $\pm$ 0.50 %, 8.83 $\pm$ 0.63 %, 10.39 $\pm$ 2.07 % and 9.13 $\pm$ 0.48 %, respectively. The average ash content value for PPT_1 of 13.82 % that contributes to day 90 overall average value of 10.39 $\pm$ 2.07 % is probably in error because there was an electricity outage during this time. The average ash content for PPT_1, PPT_2, HST_1 and HST_2 were 10.51 $\pm$ 1.68 %, 9.02 $\pm$ 0.66 %, 8.90 $\pm$ 0.47 % and 8.63 $\pm$ 0.30 %, respectively; thus, ash content was higher in PP than HS. This finding indicate that PP packaging material is better in maintaining the ash content of dried MW under both storage conditions which is important in several bodily functions. The difference in ash content under the two packaging materials indicated that storage material affected the changes in the levels of ash content of traditionally processed sun-dried MW with time. The reported increasing ash content of MW in this study with time agree with the results of Wijayanti et al. (2016) who reported increasing ash content in a study on milkfish floss stored polypropylene plastic and aluminium foil. However, a study by Olayemi et al. (2015) reported decreasing ash content with time in a study on dried smoked fish stored in different composite storage materials.

Ash contents of fresh foods rarely exceed 5 % (Headings and Rahnema, 2002), although some processed foods have ash contents of 12 % (Yilmaz and Demirci, 2010; Wijayanti et al. 2016). In the traditional processing of MW, salt is added to degutted MW prior to boiling and thereafter drying in the open sun (Kumirai, 2018). The addition of salt increases the mineral content traditionally processed sun-dried MW, because salt is composed of minerals (Fetriyuna et al., 2017). The differences in the reported ash content of MW could be attributed adding of different quantity of by two different traditional processors of MW because there is no standard measure of the quantity of salt added by different traditional MW processors. Further, the high ash content could be attributed to differences in geographic locations between the MW used in this study was sourced and the study by Headings and Rahnema (2002). Higher ash content in PP packaging material indicates high mineral content of dried MW.

Moisture content is a very important parameter in the stability of dehydrated foods (Villota et al., 1980). Complete removal of water does not eliminate product deterioration although the rate of deterioration is greatly reduced (Villota et al., 1980). In this study, moisture content of dried MW decreased with increasing storage time. The average moisture content on day 0, 30, 60, 90, and 120 were 5.88 ± 0.51 %, 3.80 ± 2.10 %, 3.54 ± 1.76 %, 4.89 ± 1.99 % and 4.08 ± 1.18 %, respectively. The moisture content of dried MW decreased in both PPT_1 and PPT_2 with increasing storage time. The average moisture content for PPT_1, PPT_2, HST_1 and HST_2 were 6.00 ± 0.82 %, 3.04 ± 1.10 %, 5.70 ± 0.38 % and 3.01 ± 1.82 %, respectively; thus, moisture content was higher in PP than HS. Mkandawire et al. (2018) reported moisture content of 9.23 – 11.2 % for dried MW, which is higher compared with the finds of this study 3.54 % - 5.88 %. The reported decreasing moisture content of dried MW with time agree in this study with results by Heitschmidt (2012) who reported decreasing moisture content in a study on health bar stored from week 0 to week 12 storage time. Similarly, the decreasing moisture content of dried MW agrees with results by Koral et al. (2010) who reported decreasing moisture content in a study on hot smoked Atlantic Bonito stored aluminium foil package.

However, a study by Olayemi et al. (2015) reported increasing moisture content with time in a study on dried smoked fish stored in different composite storage materials. Low moisture content in food products implies favourable the possibility of decreased water activity which may create unfavourable conditions for microbial development in dried MW that would result in increasing its shelf life.

Fat is important in flavour development of food Chukwu and Imodiboh (2009). The fat content of dried MW significantly ($p < 0.05$) decreased with increasing storage time. The average fat content on day 0, 30, 60, 90, and 120 were 12.54 ± 0.03 %, 12.32 ± 0.28 %, 12.65 ± 0.35 %, 10.79 ± 0.89 % and 11.03 ± 1.73 %, respectively. The average fat content for PPT_1, PPT_2, HST_1 and HST_2 were 12.16 ± 0.41 %, 11.77 ± 0.93 %, 12.24 ± 0.91 % and 11.28 ± 1.81 %, respectively; thus, fat content was slightly higher in HS than PP. Mkandawire et al. (2018) and Sekhwela (1989) reported fat content in the range 11.6 - 16.4 % of dried MW, which agrees with findings of this study 10.79 – 12.65 %. The decrease in fat content observed in this study is similar to previous research findings (Olayemi et al. 2015; Kamau et al. 2018). This can be attributed to microbial attacks and tissue enzyme activity, resulting in the oxidation of unsaturated fatty acids (Chukwu and Imodiboh, 2009). The fat content decrease of dried MW can be attributed to the possible high lipolytic and proteolytic activity of the corresponding enzymes which in turn led to the loss in the nutrients (Agrahar-Murugkar and Jha, 2011; Wijayanti et al., 2016). Decreasing fat content affect flavour of products due to oxidation of fat with increasing storage time (Mishra et al, 2017).

Protein is an essential nutrient for human body growth and development (Kwiri et al., 2014). The average protein content of traditionally processed MW on day 0, 30, 60, 90, and 120 were 67.20 ± 6.17 %, 68.63 ± 5.44 %, 68.53 ± 5.91 %, 68.80 ± 3.49 % and 70.28 ± 4.77 %, respectively. The protein content increased with increasing storage time. The reported increasing protein content of dried MW with time disagree with results by Luna et al. (2013) that reported decreasing protein content with time in a study on beef sausage quality treated with different salt levels and stored at 4 °C and -20 °C. The average protein content in this study for PPT_1, PPT_2, HST_1 and HST_2 were 61.32 ± 2.48 %, 72.78 ± 2.48 %, 73.19 ± 0.74 % and 67.47 ± 2.85 %, respectively. The protein content was higher in HS than PP. The protein content of dried MW increased in both HST_1 and

HST_2 with increasing storage time. Mkandawire et al. (2018) and Headings and Rahnema (2002) reported protein content of 50.5 – 69.8 % for dried MW, which is similar with the findings of this study 67.20 – 70.28 %. The reported increasing protein content of dried MW with time disagree with results by Olayemi (2012) who reported decreasing protein content in a study on smoked fish stored for a period of six months. This result might be attributed to combination of autolysis and rancidity in the storage Olayemi (2012). The increasing protein content might be influenced by high mineral content of dried MW.

One of the main purposes of modern packaging is to preserve the desired colour for possibly the longest period (Gazalli et al., 2013). The packaging materials, storage temperature and time significantly ($p < 0.05$) affected L*, a*, b* and ∆E* of dried MW in this study. Kamau et al. (2018) also reported a significant ($p < 0.05$) effect on 3-dimensional colour in a study on adult house cricket meals stored in polypropylene, plastic and polyethylene packages. In this study, the average L* level on day 0, 30, 60, 90 and 120 were 31.00 ± 0.48, 29.90 ± 2.84, 25.22 ± 3.61, 27.07 ± 2.87 and 28.39 ± 0.96, respectively for all treatments. The levels of L* decreased in HST_2 with increasing storage time. The reported decrease in L* with time agree with results by (Wazir et al., 2019) that reported decreasing L* in a study on shredded meat products stored at accelerated temperatures of 40 °C and 60 °C. However, Akoglu et al.(2018) reported increasing L* with increasing time in a study on Sous vide cooked Turkey cutlet stored at 4 °C and 12 ° C. The positive L* values indicate the degree of lightness of the dried MW. The average a* level for PPT_1, PPT_2, HST_1 and HST_2 were 3.55 ± 0.75, 3.98 ± 0.52, 3.70 ± 0.96 and 3.68 ± 0.62, respectively. The average b* level for PPT_1, PPT_2, HST_1 and HST_2 were 10.32 ± 0.98, 9.92 ± 1.22, 9.47 ± 2.00 and 9.44 ± 1.73, respectively. The findings in this study showed that a* and b* were positive which indicated the presence of redness and yellowness detected on the surface (Pathare et al., 2013). The positive a* and b* values indicates the degree of redness and yellowness of the dried MW. The total colour change, ΔE* indicates the magnitude of the difference between locations in the CIE L* a* b* colour system (Isdell et al., 2003). The average ∆E* level on day 0, 30, 60, 90 and 120 were 0.00 ± 0.00, 3.71 ± 0.97, 6.88 ± 4.07, 4.37 ± 2.74 and 3.21 ± 1.54, respectively. The total colour difference was higher on day 60 at 6.88 ± 4.07 and decreased from day 90 to 120 with increasing storage time. The positive values of colour observations in this study indicate that lightness, redness and yellowness were observed in the samples of dried MW and the total colour difference was acceptable.

In this study, yeast and mould count was used to assess the microbiological quality of dried MW. The detected yeast and mould in this study were *Penicillium*, *Fusarium* and *Aspergillus* types. These findings are supported by (Mujuru, 2014) who reported the presence of the type of yeast and moulds in a study on *Gonimbrasia belin* processed under different traditional practices in Gwanda, Zimbabwe. The average mould count for PPT_1, PPT_2, HST_1 and HST_2 were 0.30 ± 0.18 cfu/g, 0.20 ± 0.13 cfu/g, 0.30 ± 0.10 cfu/g and 0.36 ± 0.18 cfu/g, respectively; thus, mould count was higher in PP than HS. The treatments had no significant ($p > 0.05$) effect on yeast and mould of dried MW. The average yeast count on day 0, 30, 60, 90, and 120 were 0.22 ± 0.06 cfu/g, 0.53 ± 0.10 cfu/g, 0.37 ± 0.22 cfu/g, 0.53 ± 0.14 cfu/g and 0.33 ± 0.09 cfu/g respectively. The average yeast count for PPT_1, PPT_2, HST_1 and HST_2 were 0.32 ± 0.11 cfu/g, 0.46 ± 0.18 cfu/g, 0.33 ± 0.15 cfu/g and 0.47 ± 0.20 cfu/g, respectively; thus, yeast count was higher in PP than HS. Yeast increased under PPT_1, PPT_2 and HST_1, but decreased under HST_2 storage conditions with increasing time. Furthermore (Mujuru, 2014) stated that fungi were ubiquitously distributed in soil and air and further isolated *Aspergillus* in food products that are sun-dried owing to spores deposition. The 10^5 is the recommended minimum limit of microbial count safety of ready to eat foods at the point of sale according to the Public Health Laboratory Service guidelines (PHLS, 2000).

The microbial count of E-coli was not-detected at the start of the experiment and during the entire storage time in all the samples of dried MW. The reported not-detected coliform agrees with results by Kamau et al. (2018) that reported a similar finding in a study on semi-processed adult house crickets meal stored in polypropylene, plastic and polyethylene packages over time. Klunder et al. (2012) also reported no detection of coliform in a study on boiled and dried house crickets and mealworm larvae. The absence of coliform can be attributed to hygienic handling of dried MW during processing, and the efficacy of the two bulk packaging materials. These findings indicated that it is safe to consume traditionally processed sun-dried MW for a period longer than 120 days post-processing.

The overall acceptability of a product provides information about how well it is liked by consumers (Araújo et al., 2017). In this study, time significantly affected visual colour, taste, texture and overall acceptability of dried MW. The average sensory colour on day 0, 60 90, were 6.40 ± 0.20, 6.12 ± 0.29 and 6.06 ± 0.18 respectively. The reported significant effect of time on sensory attribute agree with findings by (Siah and Tahir, 2011) in a study on tilapia fillets packed in four different types of films. The interaction between packaging material, storage temperature and time, however, did not significantly affect all sensory attribute of dried MW. The participants' sensory liking scores for visual colour, taste, texture and overall acceptability were higher under T_1 storage T_2 storage conditions for both packaging materials. The average overall acceptability under PPT_1, PPT_2, HST_1 and PPT_2 were 6.57 ± 0.13, 6.38 ± 0.38, 6.54 ± 0.19 and 6.14 ± 0.42, respectively. The overall acceptability mean scores were above or close to 6.5 (between "like slightly" and "like moderately") on the 9 point hedonic scale (Potts et al., 2017). The overall acceptability results were least liked in HST_2 which then made the product in this packaging material and storage condition unfavoured product. The overall acceptability ratings for most foods on the market fall between 5.5 and 7.5, with a rating score above 7 considered good, 7.5 very good and 8 or above expectations (Potts et al., 2017). In this study the sensory overall acceptability liking score was most liked in PPT_1 and HST_1 with increasing storage time, which indicates a favourable storage condition to store dried traditionally processed MW.

3.6 Conclusion

From this study, PP performed better in maintaining the quality of dried MW. The use of PP and HS as packaging materials confers a certain degree of storage stability and protection against mould and yeast activity on the quality of dried MW. Packaging material significantly affected protein content of dried MW over time under the two storage temperatures. However packaging material did not significantly affect the ash, moisture and fat content of traditionally processed dried MW. Ash content and moisture content were higher in PP than HS, whereas fat content and protein content was higher in HS than in PP during storage. Storage temperature significantly affected moisture, fat and protein content of dried MW. However, storage temperature had no significant effect on ash content of dried MW. Storage time significantly affected moisture and fat content of dried MW. However, storage time had no significance on ash and protein content of dried MW. The three-way interaction between packaging materials, storage temperature and storage time significantly affected fat content of dried MW. Packaging material significantly affected protein content, L*, a*, b* and ∆E* of dried MW. The storage temperature significantly affected L*, a*, b*, and ∆E* of dried MW. Storage time significantly affected L*, a*, b* and ∆E* of dried MW. All two-way and three-way interaction among treatments significantly affected L*, a*, b* and ∆E* of dried MW. The three-way interaction between packaging material, storage temperature and time had no significant effect on yeast and mould of dried MW. The detected yeast and mould in this study were *Penicillium*, *Fusarium* and *Aspergillus* type. Yeast and mould were higher in PP than in HS packaging materials. The coliform was not detected in all treatments. The microbial count in this study did not exceed the safety limit of ready to eat 10^5 thus, traditionally processed MW is safe to the consumers for up to 120 post processing under the storage conditions. Sensory colour, taste, texture and overall acceptability of dried MW is not significantly affected by for up to 120 days under the bulk packaging materials and the ambient and accelerated temperature of 33 ° C. However, storage temperature significantly affected the overall sensory acceptability of dried MW. The sensory scores for visual colour, taste, and overall acceptability were higher in T_1 than T_2 storage conditions. Storage time significantly affected sensory colour, taste, texture and overall acceptability of dried MW. Although PP performed better than HS material in preserving the nutritional, microbial and sensory qualities of the dried MW. The length of the study was not adequate to arrive at the shelf life of the dried MW. Consequently, study further research is recommended to enable the determination of the shelf life of the dried MW when packed in these commonly used materials.

3.7 References

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CHAPTER FOUR

EFFECT OF SELECTED RETAIL PACKAGING MATERIALS, STORAGE TEMPERATURE AND TIME ON QUALITY OF DRIED MOPANE WORM

Abstract

This study assessed the effects of selected retail packaging materials, storage temperature and duration on quality and shelf life of traditionally processed and sun-dried mopane worm *(I. belin).* Changes in the quality of dried mopane worm (MW) was 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 and colour (L*, a*, b* and ∆E*), microbiological (yeast, mould and coliform count), and sensory (colour, taste, texture, and overall acceptability) qualities. The results of the experiment were subjected to ANOVA means separated using the 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, mould count and colour parameters of dried MW were significantly ($p < 0.05$) affected by packaging material. Storage time significantly ($p < 0.05$) affected moisture, fat, protein content, colour parameters and sensory qualities of dried MW. Temperature significantly ($p < 0.05$) affected ash, moisture content and colour parameters of dried MW. The interaction between packaging material, storage temperature, and time on all proximate composition and microbial quality parameters of dried MW was not significant ($p > 0.05$). HDPE performed better than LDPE in preserving the nutritional and sensory quality parameters of dried MW.

Keywords: mopane worm, retail packaging materials, temperature, time.

4.1. Introduction

Retail packaging, also known as packaging ready for shelving, is the preparation of products to be delivered to retailers in commercialised units ready for sale (FAO, 2014). Some of the common retail packaging materials include low-density polyethylene (LDPE), high-density polyethylene (HDPE), Polypropylene (PP), Polytetrafluoroethylene (PTFE), and Nylon (Polyamide) (Han, 2005). Wholesalers trading in MW usually repackage it into smaller sealed and labelled retail packages for sale.. It is important to consider the packaging in which the food is stored, distributed, displayed and purchased by the consumer because it should offer protection against microorganisms, and biological and chemical changes (Zekiri and Hasani, 2015; WWF, 2017); and thus, determines the length of a product’s shelf life (Verkerk et al., 2007; Grobbel, 2008).

Packaging materials also affects the nutritional and sensory quality attributes of food such as appearance, water capacity, colour, microbial quality, lipid stability, nutritive value, and palatability assessed in terms of texture, colour, and taste (Taylor, 1985; Renerre and Labadie, 1993; Zhao et al., 1994; Singh and Singh, 2005). Once a food product is ready for consumption, its nutritional and sensory quality decreases with time owing to several interacting factors (Mastromatteo et al., 2011; Nikzade et al., 2019). The quality and shelf life of foods are also affected by the primary processing operations such as drying, freezing, blanching, or cooking that a product undergoes before packaging (Risch, 2009). Factors that contribute to losses in the nutritional quality of dehydrated products such as dried mopane worm (MW) include moisture, fat content, temperature, packaging material, and time of storage (Villota et al., 1980).

Temperature determines the rate of deteriorative reactions, and in certain situations, the packaging materials can affect the temperature of the food (Robertson, 2013). The surrounding temperature to which a food product is exposed affects both its quality and shelf life (Villota et al., 1980). Increasing the surrounding temperature under which a food is stored increases the rate of its chemical reaction thus increasing its rate of quality deterioration and shortening the shelf life (Uzzaman et al., 2018). In addition increasing surrounding temperature influences increase in the moisture loss of products packages that are not airtight (Heitschmidt, 2012) resulting in a tough or brittle products (Labuza et al., 2004). Heitschmidt (2012) reported significant changes in organoleptic characteristics of ready-to-eat Bison meat under an accelerated temperature storage temperature of 40 °C. Several researchers (Taoukis et al., 1997; Heitschmidt, 2012; Sloan et al., 2016) have reported rapid deterioration in nutritional quality and sensory attributes of foods stored under elevated temperatures compared to ambient storage condition.

Studies have established that packaging material, storage conditions and time either singly or in combination have effect on the quality and storage stability of food products (Taoukis et al., 1997), thereby decreasing the shelf life. Therefore, this study was designed to evaluate the combined effect of some commonly used retail packaging materials (high density polyethylene and low density polyethylene), storage temperature (ambient and accelerated) and storage time on the microbiological, physicochemical and sensory characteristics of traditionally processed dried mopane worm.

4.2. Materials and Methods

4.2.1. Packaging, storage and sampling of dried mopane worm

The dried mopane worm (*I. belin*) samples were subdivided into small portions of 1 kg each. The 1 kg portions were then randomly filled into high-density polyethylene (HDPE), and low-density polyethylene (LDPE) Figure 4.1. The open ends of all the packages containing the samples were thereafter twisted and fastened tightly to make them airtight. There were four (4) packages two (2) of each type of package. The two packages were then stored under ambient temperature and the other two at accelerated temperature for 120 days see Figure 4.2. The accelerated storage was done using an oven temperature of 33 °C. Ambient storage was done by placing the MW samples in a typical kitchen cupboard.

Sampling was done on day zero and thereafter at 30-day intervals. To obtain samples for analysis at the different intervals, the packages were opened and approximately 100 g of dried MW was picked from the two storage (ambient and accelerated temperature) environments and the samples analysed for the different quality parameters following the method described by Kamau et al. (2018).

(a) (b)

Figure 4.1. Two commonly used retail-packaging materials used for dried MW storage. (a) Low-density polyethylene and (b) High-density polyethylene.

4.2.2. Experimental design and data analysis

A three-factor full-factorial design comprising of (packaging materials, storage temperature and storage time) was used. The factors studied were packaging materials (Low-density polyethylene and High-density polyethylene), storage temperature (ambient and accelerated) and storage time (0, 30, 60, 90 and 120 days) with three replications. The structure of the experimental design and treatments are presented in Figure 4.2.

All data were obtained in triplicates and reported as mean. The microbial data was transformed to $\log_{10}$ to meet the requirements of equal variance and normal distribution Kung et al. (2017). The effects of packaging materials, storage temperature and duration as well as 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 Tukey test.

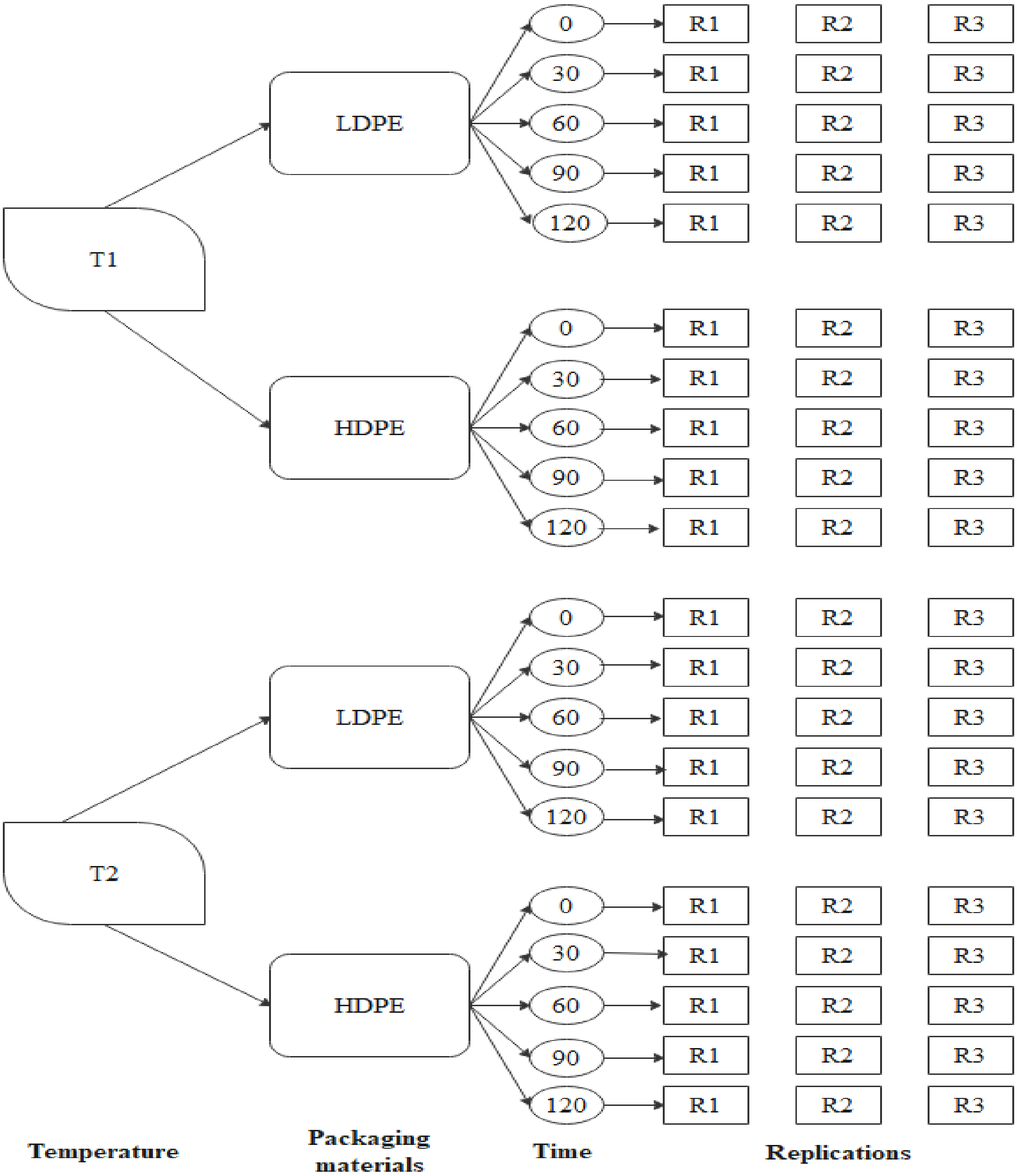

Figure 4.2. Schematic presentation of the experimental treatment structure with three factors (Temperature, Packaging materials, Time and three replications).

4.3. Analysis of the physicochemical, microbiological qualities and sensory evaluation of dried mopane worm

Like was the case in Chapter 3, the quality of traditionally processed dried MW was done by monitoring changes in protein, fat, ash. moisture content, 3 dimensional colour, yeast, mould, coliform count, and sensory evaluation. The approaches detailed in Chapter 3, Section 3.3 was used.

4.6. Results

4.6.1 Proximate Composition

A summary of the proximate composition of dried MW, is presented in Table 4.1. Packaging materials had no significant ($p > 0.05$) effect on ash, moisture, fat and protein content of dried MW. Storage time had no significant ($p > 0.05$) effect on ash content of dried MW. However, the storage time significantly ($p < 0.05$) affected moisture, fat and protein content of dried MW. Storage temperature significantly ($p < 0.05$) affected ash and moisture content of dried MW. However, storage temperature did not significantly ($p > 0.05$) affect fat and protein content of dried MW.

The interaction between packaging material and time, and packaging material and storage temperature did not significantly, ($p > 0.05$) affect the ash content of dried MW. The three-way interaction between packaging material, storage temperature and time, had no significant ($p > 0.05$) effect on the ash content of dried MW. Only the interaction between storage temperature and time significantly ($p < 0.05$) affected the ash content of dried MW (Table 4.1).

The mean values of the ash content of dried MW stored in the two retail packaging materials (LDPE and HDPE) under T_1 and T_2 storage conditions from day 0 to day 120 is shown in Figure 4.3. The level of ash content in $LDPET_1$ and $LDPET_2$ (Figure 4.3 (a)) increased with increasing storage time. The ash content of dried MW in $LDPET_1$ was higher when compared to ash content in $LDPET_2$. The ash content of dried MW for $LDPET_1$, and $LDPET_2$, ranged from 8.89 to 11.41 %, and 8.50 to 10.22 %. The levels of ash content in $HDPET_1$ and $HDPET_2$ (Figure 4.3 (a)) increased with increasing storage time. The ash content in $HDPET_1$ was higher than ash content in $HDPET_2$. The ash content of dried MW for $HDPET_1$, and $HDPET_2$, ranged from 7.40 to 11.25 %, and 7.55 to 9.22 %

The interaction between packaging material and storage temperature, and packaging materials and time had no significant ($p > 0.05$) effect on moisture content of dried MW. The three-way interaction between packaging material, storage temperature and time, had no significant ($p > 0.05$) effect on the moisture content of dried MW (Table 4.1). Only the interaction between storage temperature and time significantly ($p < 0.05$) affected the moisture content of dried MW.

Table 4.1. 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
T_1	LDPE	Ash %	$9.01^{a} \pm 0.41$	$9.55^{a} \pm 1.54$	$10.17^{a} \pm 0.51$	$8.89^{a} \pm 0.64$	$11.41^{a} \pm 3.80$
T_2	LDPE		$8.85^{a} \pm 0.10$	$9.91^{a} \pm 0.95$	$8.80^{a} \pm 0.15$	$10.22^{a} \pm 0.09$	$8.50^{a} \pm 0.36$
T_1	HDPE		$9.41^{a} \pm 0.10$	$7.40^{a} \pm 1.03$	$11.08^{a} \pm 1.99$	$11.25^{a} \pm 2.11$	$10.87^{a} \pm 2.83$
T_2	HDPE		$8.99^{a} \pm 0.10$	$8.80^{a} \pm 0.73$	$9.22^{a} \pm 0.25$	$7.55^{a} \pm 0.26$	$8.40^{a} \pm 0.04$
T_1	LDPE	Moisture %	$5.38^{abcdef} \pm 0.64$	$5.32^{abcdef} \pm 0.71$	$5.08^{abcdef} \pm 0.16$	$6.93^{ab} \pm 0.78$	$5.75^{abcd} \pm 2.95$
T_2	LDPE		$5.57^{abcde} \pm 0.99$	$2.69^{fg} \pm 0.37$	$2.07^{g} \pm 0.04$	$3.50^{cdefg} \pm 0.11$	$3.43^{cdefg} \pm 0.04$
T_1	HDPE		$7.28^{a} \pm 0.40$	$5.07^{abcdef} \pm 0.68$	$5.18^{abcdef} \pm 0.04$	$6.08^{abc} \pm 0.15$	$5.55^{abcde} \pm 1.05$
T_2	HDPE		$5.79^{abcd} \pm 1.70$	$4.17^{bcdefg} \pm 0.63$	$3.26^{defg} \pm 0.18$	$2.88^{efg} \pm 0.16$	$3.16^{defg} \pm 0.11$
T_1	LDPE	Fat %	$14.03^{a} \pm 3.28$	$11.26^{a} \pm 0.39$	$12.40^{a} \pm 0.46$	$12.04^{a} \pm 0.88$	$10.75^{a} \pm 1.39$
T_2	LDPE		$12.31^{a} \pm 0.55$	$11.72^{a} \pm 1.08$	$13.52^{a} \pm 0.15$	$11.48^{a} \pm 0.33$	$11.58^{a} \pm 0.37$
T_1	HDPE		$12.63^{a} \pm 0.89$	$12.86^{a} \pm 0.92$	$12.13^{a} \pm 0.63$	$13.37^{a} \pm 1.92$	$12.10^{a} \pm 0.65$
T_2	HDPE		$11.90^{a} \pm 0.19$	$13.04^{a} \pm 0.67$	$12.68^{a} \pm 0.32$	$11.72^{a} \pm 0.61$	$10.81^{a} \pm 0.84$
T_1	LDPE	Protein %	$63.08^{a} \pm 5.55$	$67.66^{a} \pm 2.92$	$65.74^{a} \pm 2.61$	$64.19^{a} \pm 6.00$	$63.45^{a} \pm 1.42$
T_2	LDPE		$67.64^{a} \pm 4.71$	$62.00^{a} \pm 3.48$	$64.32^{a} \pm 5.82$	$64.39^{a} \pm 3.28$	$65.01^{a} \pm 4.42$
T_1	HDPE		$67.57^{a} \pm 5.11$	$71.69^{a} \pm 3.96$	$68.30^{a} \pm 3.74$	$68.12^{a} \pm 6.74$	$60.93^{a} \pm 2.61$
T_2	HDPE		$65.50^{a} \pm 6.23$	$69.41^{a} \pm 3.14$	$62.83^{a} \pm 3.01$	$65.74^{a} \pm 6.71$	$57.92^{a} \pm 3.19$

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 are not significantly different ($p < 0.05$).

The level of moisture content in $LDPET_1$ and $LDPET_2$ (Figure 4.3 (b)) decreased with increasing storage time. The moisture content of dried MW in $LDPET_1$ was higher when compared to moisture content in $LDPET_2$. The moisture content of dried MW for $LDPET_1$, and $LDPET_2$, ranged from 5.08 to 6.93 %, and 2.07 to 5.57 %. The levels of moisture content in $HDPET_1$ and $HDPET_2$ (Figure 4.3 (b)) decreased with increasing storage time. The moisture content in $HDPET_1$ was higher than moisture content in $HDPET_2$. The moisture content of dried MW for $HDPET_1$, and $HDPET_2$, ranged from 5.07 to 7.28 %, and 2.88 to 5.79 %.

All the two-way and three-way interaction among the treatments had no significant ($p > 0.05$) effect on fat content (Table 4.1). The mean levels of the fat content of dried MW stored in the two retail packaging materials (LDPE and HDPE) under T_1 and T_2 conditions are shown in Figure 4.3. The level of fat content in $LDPET_1$ and $LDPET_2$ (Figure 4.3 (c)) decreased with increasing storage time. The fat content of dried MW in $LDPET_2$ was higher when compared to fat content in $LDPET_1$. The fat content of dried MW for $LDPET_1$, and $LDPET_2$, ranged from 10.75 to 14.03 %, and 11.48 to 13.52 %. The levels of fat content in $HDPET_1$ and $HDPET_2$ (Figure 4.3 (c)) decreased with increasing storage time. The fat content in $HDPET_1$ was higher than fat content in $HDPET_2$. The fat content of dried MW for $HDPET_1$, and $HDPET_2$, ranged from 12.10 to 13.37 %, and 10.81 to 13.04 %.

All the two-way and three-way interactions among the treatments did not significantly ($p > 0.05$) affect protein content of dried MW (Table 4.1). The mean levels of the protein content of dried MW stored in the two retail packaging materials (LDPE and HDPE) under T_1 and T_2 storage conditions from day 0 to day 120 is shown in Figure 4.3. The level of protein content in $LDPET_1$ increased with increasing storage time. Whereas the protein content in $LDPET_2$ protein content decreased with increasing storage time (Figure 4.3 (d)).

The protein content of dried MW in $LDPET_1$ was greater than in $LDPET_2$. The protein content of dried MW for $LDPET_1$, and $LDPET_2$, ranged from 63.08 to 67.66 %, and 62.00 to 67.64%. The levels of protein content in $HDPET_1$ and $HDPET_2$ (Figure 4.3 (d)) decreased with increasing storage time. The protein content in $HDPET_1$ was higher than protein content in $HDPET_2$. The protein content of dried MW for $HDPET_1$, and $HDPET_2$, ranged from 60.93 to 71.69 %, and 57.92 to 69.41 %.

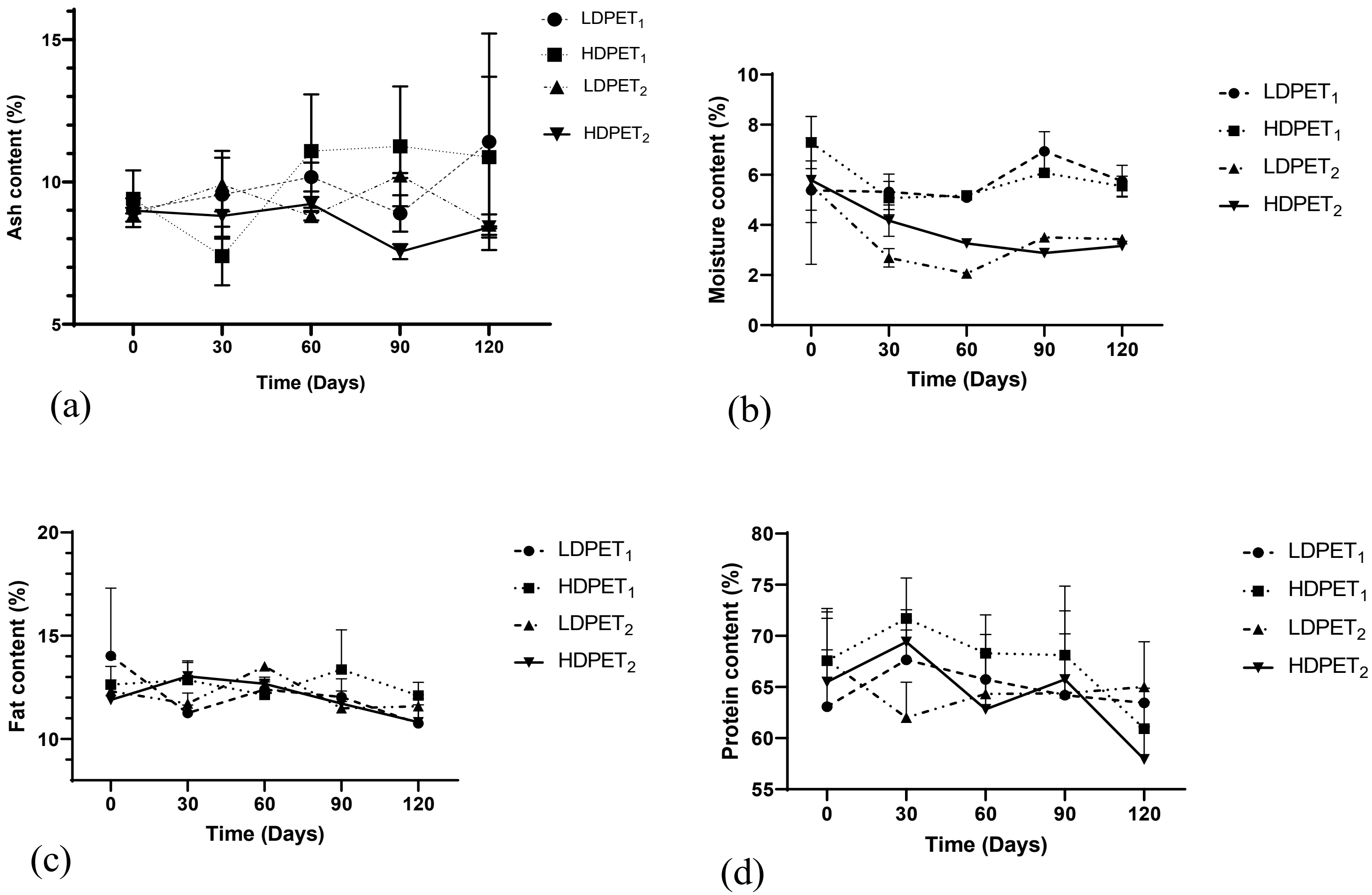

Figure 4.3. Variation of the mean levels of (a) ash content, (b) moisture content, (c) fat content and (d) protein content of dried MW packaged in retail packaging materials LDPE and HDPE stored under ambient (T_1) and accelerated (T_2) temperature conditions.

4.6.2. The 3 - dimensional colour

A summary of the 3-dimensional colour of dried MW, is presented Table 4.2. Packaging material significantly, ($p < 0.05$) affected lightness (L*), redness/greenness (a*), yellowness (b*) and total colour difference (ΔE*) of dried MW sample. Storage time significantly ($p < 0.05$) affected lightness (L*), redness/greenness (a*), yellowness (b*) and total colour difference (ΔE*) of dried MW samples. Storage temperature significantly ($p < 0.05$) affected lightness (L*), redness/greenness (a*), yellowness (b*) and total colour difference (ΔE*) of dried MW samples

All the two-way and three-way interactions among treatments significantly ($p < 0.05$) affected the lightness index of dried MW (Table 4.2). The levels of L* in $LDPET_1$ and $LDPET_2$ see (Figure 4.4 (a)) decreased with an increasing storage time. The levels of L* were higher in $LDPET_2$ when compared to the L* in LDPET1. The L* index of dried MW for $LDPET_1$, and $LDPET_2$, ranged from 23.37 to 34.01 and 23.15 to 33.67. The level of L* in $HDPET_1$ and $HDPET_2$ see (Figure 4.4 (a)) decreased with an increasing storage time. The L* in $HDPET_2$ was higher than L* in $HDPET_1$. The L* index of dried MW for $HDPET_1$, and $HDPET_2$, ranged from 23.04 to 34.43 and 23.57 to 32.31.

All the two-way and three-way interactions among treatments significantly ($p < 0.05$) affected a* index of dried MW (Table 4.2). The levels of a* in $LDPET_1$ and $LDPET_2$ decreased with increasing storage time see (Figure 4.4 (b)). The levels of a* were higher in $LDPET_2$ than levels of a* in $LDPET_1$. The a* of dried MW for $LDPET_1$, and $LDPET_2$, ranged from 2.73 to 4.20 and 3.35 to 5.11. The levels of a* in $HDPET_1$ and $HDPET_2$ decreased with increasing storage time see (Figure 4.4 (b)). The levels of a* in $HDPET_2$ were higher than the levels of a* in $HDPET_1$. The a* index of dried MW for $HDPET_1$, and $HDPET_2$, ranged from 3.09 to 4.91 and 2.68 to 5.26

All the two-way and three-way interactions among the treatments significantly ($p < 0.05$) affected b* index of dried MW (Table 4.2). The levels of b* in $LDPET_1$ and $LDPET_2$ decreased with increasing storage time see (Figure 4.4 (c)). The levels of b* were higher during storage in $LDPET_1$ when compared to levels of b* in $LDPET_2$. The b* index of dried MW for $LDPET_1$, and $LDPET_2$, ranged from 7.18 to 10.76 and 7.06 to 12.29. The levels of b* in $HDPET_1$ and $HDPET_2$ decreased with an increasing storage time see (Figure 4.4 (c)). The levels of b* in $HDPET_2$ were higher when compared to $HDPET_1$ during storage time. The b* index of dried MW for $HDPET_1$, and $HDPET_2$, ranged from 7.34 to 11.62 and 7.50 to 13.74...

Table 4.2. 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**
T_1	LDPE	L*	$34.01^{b} \pm 0.05$	$26.99^{k} \pm 0.02$	$27.59^{h} \pm 0.04$	$23.37^{p} \pm 0.04$	$27.27^{j} \pm 0.02$
T_2	LDPE		$31.30^{e} \pm 0.03$	$33.67^{c} \pm 0.01$	$28.33^{g} \pm 0.01$	$23.15^{q} \pm 0.05$	$25.41^{n} \pm 0.03$
T_1	HDPE		$23.04^{r} \pm 0.01$	$34.43^{a} \pm 0.03$	$25.45^{n} \pm 0.02$	$26.29^{m} \pm 0.03$	$26.64^{l} \pm 0.06$
T_2	HDPE		$31.31^{e} \pm 0.02$	$28.99^{f} \pm 0.02$	$23.57^{o} \pm 0.03$	$32.31^{d} \pm 0.04$	$27.37^{i} \pm 0.02$
T_1	LDPE	a*	$3.47^{f} \pm 0.04$	$3.26^{fgh} \pm 0.06$	$4.20^{d} \pm 0.05$	$2.73^{i} \pm 0.10$	$3.32^{fgh} \pm 0.03$
T_2	LDPE		$4.32^{d} \pm 0.03$	$4.72^{c} \pm 0.06$	$5.11^{ab} \pm 0.04$	$3.49^{f} \pm 0.12$	$3.35^{fg} \pm 0.05$
T_1	HDPE		$3.21^{gh} \pm 0.16$	$3.09^{h} \pm 0.09$	$3.12^{gh} \pm 0.01$	$4.91^{bc} \pm 0.08$	$3.87^{e} \pm 0.02$
T_2	HDPE		$4.32^{d} \pm 0.05$	$2.68^{i} \pm 0.04$	$3.83^{e} \pm 0.10$	$5.26^{a} \pm 0.04$	$4.13^{d} \pm 0.12$
T_1	LDPE	b*	$7.55^{gh} \pm 0.16$	$9.22^{e} \pm 0.01$	$10.76^{d} \pm 0.17$	$7.18^{gh} \pm 0.25$	$8.89^{e} \pm 0.10$
T_2	LDPE		$11.42^{c} \pm 0.05$	$12.29^{b} \pm 0.03$	$11.61^{c} \pm 0.12$	$7.55^{gh} \pm 0.20$	$7.06^{h} \pm 0.06$
T_1	HDPE		$7.34^{gh} \pm 0.45$	$11.27^{c} \pm 0.07$	$7.57^{g} \pm 0.12$	$11.62^{c} \pm 0.27$	$8.36^{f} \pm 0.10$
T_2	HDPE		$11.46^{c} \pm 0.02$	$9.33^{e} \pm 0.08$	$7.50^{gh} \pm 0.16$	$13.74^{a} \pm 0.04$	$8.92^{e} \pm 0.15$
T_1	LDPE	∆E*		$7.23^{de} \pm 0.08$	$7.23^{de} \pm 0.18$	$10.69^{b} \pm 0.07$	$6.88^{e} \pm 0.08$
T_2	LDPE			$2.55^{j} \pm 0.02$	$3.08^{i} \pm 0.01$	$9.06^{c} \pm 0.17$	$7.40^{d} \pm 0.10$
T_1	HDPE			$12.06^{a} \pm 0.10$	$2.46^{j} \pm 0.04$	$5.66^{f} \pm 0.46$	$3.81^{h} \pm 0.11$
T_2	HDPE			$3.54^{h} \pm 0.02$	$8.71^{c} \pm 0.04$	$2.67^{j} \pm 0.01$	$4.71^{g} \pm 0.08$

Treatments and Interactions	**Significance Levels (p value)**			
	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 are not significantly different ($p > 0.05$).

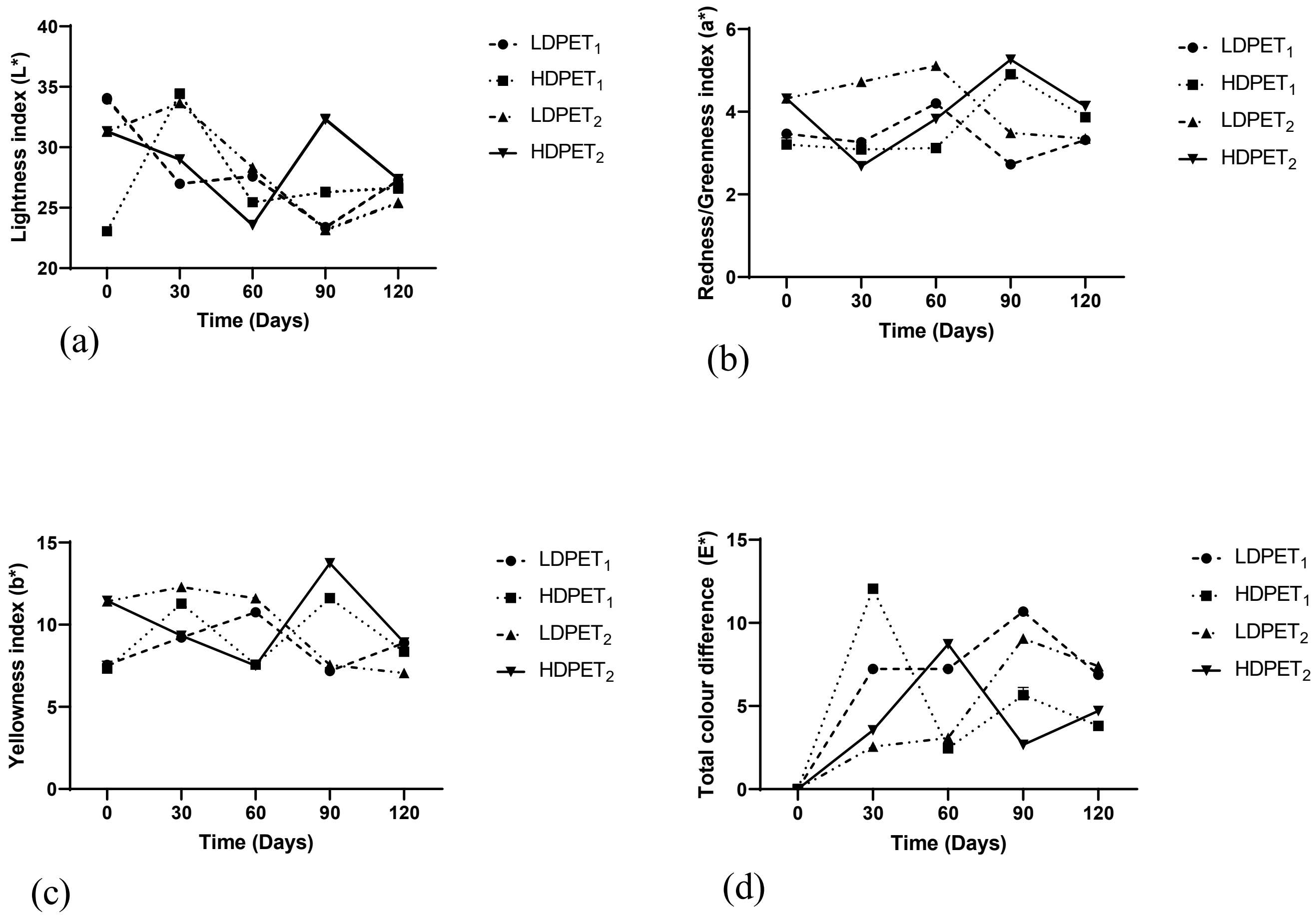

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Figure 4.4. Variation of the mean levels of (a) lightness index (L*), (b) redness/greenness index (a*), (c) yellowness index (b*) and (d) total colour difference (ΔE*) of dried MW packaged in retail packaging materials LDPE and HDPE stored under ambient (T_1) and accelerated (T_2) temperature conditions.

All the two-way and three-way interactions among the treatments significantly ($p < 0.05$) affected the ∆E* of dried MW (Table 4.2). The levels of ∆E* increased in $LDPET_1$ and $LDPET_2$ decreased with increasing storage time see (Figure 4.4 (d)). The levels of ∆E* were higher in $LDPET_1$ when compared to levels of ∆E* in $LDPET_2$. The ∆E* of dried MW for $LDPET_1$, and $LDPET_2$, ranged from 0.00 to 10.69 and 0.00 to 9.06. The levels of ∆E* decreased in $HDPET_1$ and increased in $HDPET_2$ with an increasing storage time see (Figure 4.4 (d)). The levels of ∆E* were higher in $HDPET_1$ when compared to $HDPET_2$ during storage time. The ∆E* of dried MW for $HDPET_1$, and $HDPET_2$, ranged from 0.00 to 12.06 and 0.00 to 8.71.

4.6.3. Microbiological qualities

A summary of the microbiological count of dried MW is presented in Table 4.3. Packaging material significantly, ($p < 0.05$) affected the mould count of dried MW. However, packaging material had no significant ($p > 0.05$) effect on yeast and coliform counts of dried MW. Storage time had no significant ($p > 0.05$) effect on yeast, mould and coliform count of dried MW. Storage temperature had no significant ($p > 0.05$) effect on yeast, mould and coliform count of dried MW throughout the experimentation period. All the two-way and three-way interactions among the treatments insignificantly ($p > 0.05$) affected yeast count (Table 4.3). The mean levels of the yeast count of dried MW stored in the two retail packaging materials (LDPE and HDPE) under T_1 and T_2 storage conditions from day 0 to day 120 are shown in Figure 4.5.

The yeast count in $LDPET_1$ increased and decreased in $LDPET_2$ with increasing storage time see of 120 days (Figure 4.5 (a)). The levels of yeast count were generally higher in $LDPET_2$ when compared to yeast count in $LDPET_1$ during storage. The yeast count of dried MW for $LDPET_1$, and $LDPET_2$, ranged from 0.16 to 1.08 log_{10}cfu/g and 0.16 to 0.89 log_{10}cfu/g. The levels of yeast count in $HDPET_1$ and $HDPET_2$ decreased with an increasing storage time of 120 days see (Figure 4.5 (a)). The levels of yeast count were higher in $HDPET_2$ when compared to yeast count in $HDPET_1$. The yeast count of dried MW for $HDPET_1$, and $HDPET_2$, ranged from 0.20 to 1.08 log_{10}cfu/g and 0.16 to 1.69 log_{10}cfu/g.

Table 4.3. Effect of packaging materials, temperature and time on microbiological quality of dried traditionally processed MW.

Temperature °C	Packaging materials	Microbiological count	Time (Days)				
			0	30	60	90	120
T_1	LDPE	Mould (log_{10}cfu/g)	$0.16^{a} \pm 0.28$	$0.00^{a} \pm 0.00$	$0.00^{a} \pm 0.00$	$0.00^{a} \pm 0.00$	$0.00^{a} \pm 0.00$
T_2	LDPE		$0.10^{a} \pm 0.17$	$0.26^{a} \pm 0.24$	$0.00^{a} \pm 0.00$	$0.36^{a} \pm 0.32$	$0.10^{a} \pm 0.17$
T_1	HDPE		$0.36^{a} \pm 0.39$	$0.10^{a} \pm 0.17$	$0.20^{a} \pm 0.35$	$0.73^{a} \pm 0.38$	$0.20^{a} \pm 0.35$
T_2	HDPE		$0.26^{a} \pm 0.24$	$0.10^{a} \pm 0.17$	$0.10^{a} \pm 0.17$	$0.20^{a} \pm 0.17$	$0.20^{a} \pm 0.35$
T_1	LDPE	Yeast (log_{10}cfu/g)	$0.16^{b} \pm 0.28$	$0.75^{ab} \pm 0.78$	$1.08^{ab} \pm 0.54$	$0.57^{ab} \pm 0.47$	$0.33^{ab} \pm 0.58$
T_2	LDPE		$0.16^{b} \pm 0.28$	$0.89^{ab} \pm 0.42$	$0.58^{ab} \pm 0.53$	$0.44^{ab} \pm 0.43$	$0.33^{ab} \pm 0.58$
T_1	HDPE		$0.26^{b} \pm 0.24$	$0.75^{ab} \pm 0.71$	$0.32^{ab} \pm 0.55$	$1.08^{ab} \pm 0.18$	$0.20^{b} \pm 0.35$
T_2	HDPE		$0.16^{b} \pm 0.28$	$0.46^{ab} \pm 0.56$	$0.39^{ab} \pm 0.36$	$1.69^{a} \pm 0.09$	$0.20^{b} \pm 0.35$
T_1	LDPE	Coliform (log_{10}cfu/g)	$0.00^{b} \pm 0.00$	$0.00^{b} \pm 0.00$	$0.00^{b} \pm 0.00$	$0.00^{b} \pm 0.00$	$0.00^{b} \pm 0.00$
T_2	LDPE		$0.00^{b} \pm 0.00$	$0.00^{b} \pm 0.00$	$0.00^{b} \pm 0.00$	$0.00^{b} \pm 0.00$	$0.00^{b} \pm 0.00$
T_1	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	$0.00^{b} \pm 0.00$
T_2	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 are not significantly different ($p < 0.05$).

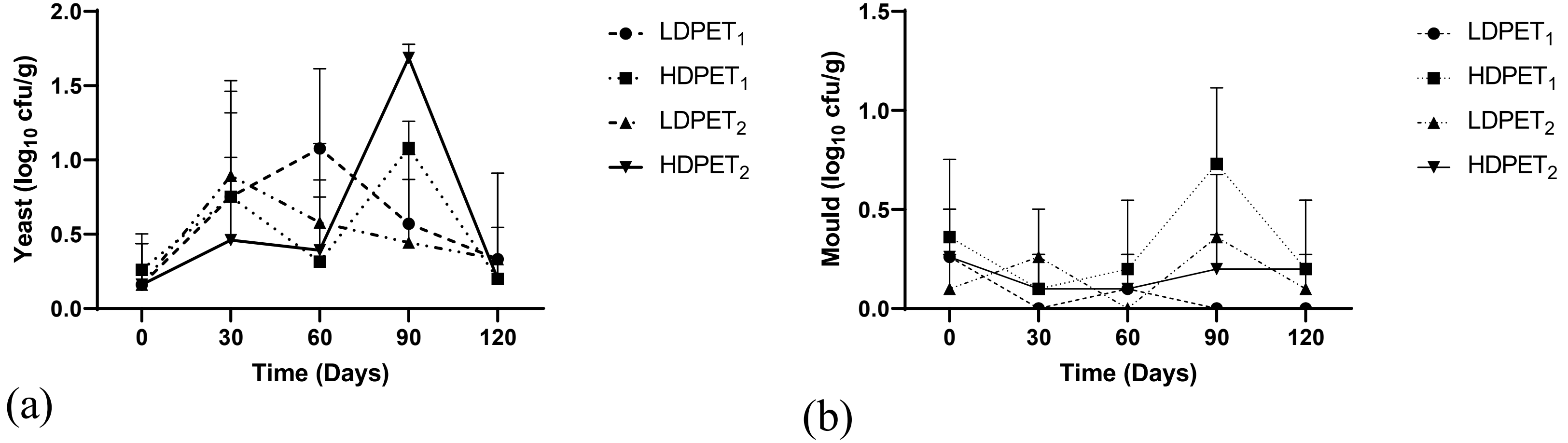

Figure 4.5. Variation of the mean levels of (a) yeast count and (b) mould count of dried MW packaged in retail packaging materials LDPE and HDPE stored under ambient (T_1) and accelerated (T_2) temperature conditions.

All two-way and three-way interactions among the treatments did not significantly ($p > 0.05$) affect the mould count (Table 4.3). The mean levels of mould count of dried MW stored in the two retail packaging materials (LDPE and HDPE) under T_1 and T_2 storage conditions from day 0 to day 120 is shown in Figure 4.5. The mould count in LDPET_1 decreased, whereas the levels of mould count in LDPET_2 increased with increasing storage time see (Figure 4.5 (b)). The levels of mould count were generally higher in LDPET_1 than mould count in LDPET_2 during storage time. The mould count of dried MW for LDPET_1, and LDPET_2, ranged from 0.00 to 0.16 log_{10}cfu/g and 0.00 to 0.36 log_{10}cfu/g. The levels of mould count in HDPET_1 increased and in HDPET_2 mould count decreased with increasing storage time see (Figure 4.5 (b)). The levels of mould count in HDPET_1 we higher when compared to mould count in HDPET_2. The mould count of dried MW for HDPET_1, and HDPET_2, ranged from 0.10 to 0.73 log_{10}cfu/g and 0.10 to 0.26 log_{10}cfu/g.

All the two-way and three-way interactions among the treatments insignificantly ($p > 0.05$) affected the coliform count of dried MW (Table 4.3). The coliform count in LDPET_1 and LDPET_2 was not-detected with increasing storage time. The coliform count of dried MW for LDPET_1, and LDPET_2, ranged from 0.00 to 0.00 log_{10}cfu/g and 0.00 to 0.00 log_{10}cfu/g. The levels of coliform count in HDPET_1 were not-detected, however in HDPET_2 coliform count was detected on day 90 of storage. The coliform count of dried MW for HDPET_1, and HDPET_2, ranged from 0.00 to 0.00 log_{10}cfu/g and 0.00 to 1.09 log_{10}cfu/g.

4.6.4. Sensory evaluation attributes

A summary of the sensory evaluation of dried MW is presented in Table 4.4. Packaging material had no significant ($p > 0.05$) effect on sensory colour, taste, texture and overall acceptability of dried MW. Storage time significantly ($p < 0.05$) affected sensory colour, taste, texture and overall acceptability of dried MW. Storage temperature had no significant ($p > 0.05$) effect on sensory colour, taste, texture and overall acceptability of dried MW.

All the two-way and three-way interactions among the treatments insignificantly ($p > 0.05$) affected the sensory colour liking score (Table 4.4). The mean levels of participants' liking scores for sensory colour of MW stored in the two retail packaging materials (LDPE and HDPE) under T_1 and T_2 storage conditions on day 0, 60 and day 90 is shown in Figure 4.6. The level of participants' liking scores in $LDPET_1$ decreased and the levels of participants' liking scores increased in $LDPET_2$ with increasing storage time see (Figure 4.6 (a)). The participants' liking scores were higher in $LDPET_1$ than participants' liking scores in $LDPET_2$ during the storage time. The sensory colour of dried MW for $LDPET_1$, and $LDPET_2$, ranged from 6.14 to 6.52 and 5.84 to 6.36. The participants' liking scores for sensory colour of dried MW decreased in both $HDPET_1$ and $HDPET_2$ with increasing storage time. The participants' liking scores were higher in $HDPET_1$ than participants' liking scores in $HDPET_2$ during storage time. The sensory colour of dried MW for $HDPET_1$, and $HDPET_2$, ranged from 6.31 to 6.50 and 5.63 to 6.69.

All two-way and three-way interactions among the treatments insignificantly ($p > 0.05$) affected sensory taste liking scores (Table 4.4). The level of liking scores for sensory taste of dried MW decreased in both $LDPET_1$ and $LDPET_2$ with increasing storage time (Figure 4.6 (b)). The liking scores for sensory taste were higher in $LDPET_2$ than in $LDPET_1$. The sensory taste of dried MW for $LDPET_1$, and $LDPET_2$, ranged from 6.09 to 6.43 and 6.02 to 6.56. The liking scores for sensory taste increased in $HDPET_1$ and decreased in $HDPET_2$ with increasing storage time. The liking scores for sensory taste were higher in $HDPET_1$ than in $HDPET_2$. The sensory taste of dried MW for $HDPET_1$, and $HDPET_2$, ranged from 6.29 to 6.36 and 5.50 to 6.72.

All the two-way interactions among the treatments did not significantly ($p > 0.05$) affect the sensory texture. The three-way interaction between packaging material, storage temperature and time significantly ($p < 0.05$) affected the texture of dried MW. (Table 4.4). The level of liking scores for sensory texture of dried MW decreased in $LDPET_1$ and increased in $LDPET_2$ with increasing storage time (Figure 4.6 (c)). The liking scores for sensory texture were higher in $LDPET_2$ when compared to liking scores for sensory texture in $LDPET_1$ during storage time. The sensory texture of dried MW for $LDPET_1$, and $LDPET_2$, ranged from 5.78 to 6.22 and 5.50 to 6.23. The liking score for sensory texture decreased in both $HDPET_1$ and $HDPET_2$ with increasing storage time. The liking scores for sensory texture were higher in $HDPET_1$ than liking scores for sensory texture in $HDPET_2$. The sensory texture of dried MW for $HDPET_1$, and $HDPET_2$, ranged from 5.93 to 6.18 and 5.40 to 6.58.

Table 4.4. 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**
T_1	LDPE	Colour	$6.52^{ab} \pm 2.12$	$6.16^{ab} \pm 2.04$	$6.14^{ab} \pm 2.21$
T_2	LDPE		$6.28^{ab} \pm 2.22$	$5.84^{ab} \pm 2.14$	$6.36^{ab} \pm 2.15$
T_1	HDPE		$6.44^{ab} \pm 2.12$	$6.50^{ab} \pm 1.68$	$6.31^{ab} \pm 2.06$
T_2	HDPE		$6.69^{a} \pm 2.06$	$6.02^{ab} \pm 2.15$	$5.63^{b} \pm 2.32$
T_1	LDPE	Taste	$6.43^{ab} \pm 2.13$	$6.20^{ab} \pm 2.15$	$6.09^{ab} \pm 2.21$
T_2	LDPE		$6.56^{a} \pm 2.22$	$6.02^{ab} \pm 2.28$	$6.33^{ab} \pm 2.01$
T_1	HDPE		$6.33^{ab} \pm 2.11$	$6.29^{ab} \pm 1.96$	$6.36^{ab} \pm 2.18$
T_2	HDPE		$6.72^{a} \pm 2.08$	$5.84^{ab} \pm 2.34$	$5.50^{b} \pm 2.33$
T_1	LDPE	Texture	$6.22^{ab} \pm 2.32$	$6.16^{ab} \pm 2.07$	$5.78^{ab} \pm 2.13$
T_2	LDPE		$6.15^{ab} \pm 2.20$	$5.50^{ab} \pm 2.47$	$6.23^{ab} \pm 2.02$
T_1	HDPE		$6.18^{ab} \pm 2.10$	$5.93^{ab} \pm 2.11$	$6.07^{ab} \pm 2.15$
T_2	HDPE		$6.58^{a} \pm 1.90$	$5.69^{ab} \pm 2.39$	$5.40^{b} \pm 2.45$
T_1	LDPE	Overall acceptability	$6.47^{ab} \pm 2.16$	$6.47^{ab} \pm 1.90$	$6.49^{ab} \pm 1.97$
T_2	LDPE		$6.77^{a} \pm 1.99$	$6.11^{ab} \pm 1.95$	$6.42^{ab} \pm 1.92$
T_1	HDPE		$6.67^{a} \pm 2.05$	$6.46^{ab} \pm 1.90$	$6.34^{ab} \pm 2.09$
T_2	HDPE		$7.03^{a} \pm 1.70$	$6.19^{ab} \pm 2.31$	$5.66^{b} \pm 2.38$

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. Same letters in rows are not significantly different ($p > 0.05$).

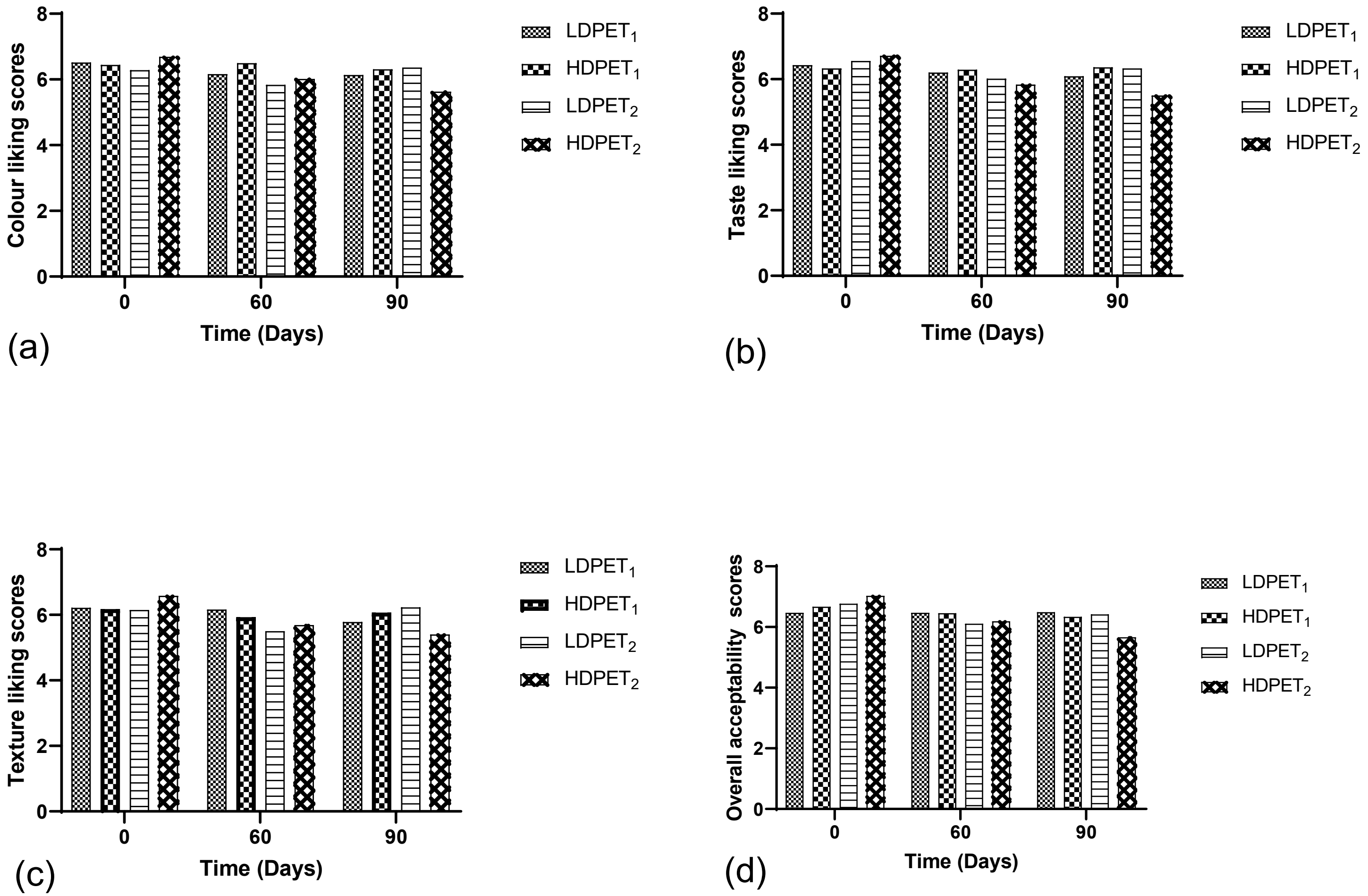

Figure 4.6. Variation of the mean levels of participants liking of sensory parameters (a) colour, (b) taste, (c) texture and (d) overall acceptability of dried MW packaged in retail packaging materials LDPE and HDPE stored under ambient (T_1) and accelerated (T_2) temperature conditions.

The interaction between packaging material and time, and storage temperature and time significantly ($p < 0.05$) affected the overall acceptability liking scores. Only the interaction between packaging material and storage temperature insignificantly ($p > 0.05$) affected the overall acceptability liking scores. The three-way interaction between packaging material, storage temperature and time had no significant ($p > 0.05$) effect on the overall acceptability liking scores of dried MW samples (Table 4.4).

The levels of participants' overall acceptability liking scores of dried MW increased in $LDPET_1$ and decreased in $LDPET_2$ with increasing storage time (Figure 4.6 (d)). The participants' overall acceptability liking scores were higher in $LDPET_1$ than in $LDPET_2$ during storage. The sensory overall acceptability of dried MW for $LDPET_1$, and $LDPET_2$, ranged from 6.47 to 6.49 and 6.11 to 6.77. The levels of participants' overall acceptability liking scores of dried MW decreased in both $HDPET_1$ and $HDPET_2$ with increasing storage time. The participants' overall acceptability liking scores were higher in $HDPET_1$ than in $HDPET_2$ during the experimental period. The sensory overall acceptability of dried MW for $HDPET_1$, and $HDPET_2$, ranged from 6.34 to 6.67 and 5.66 to 7.03.

4.7 Discussion

Previous researchers (Conrad, 2005;. Uzzaman et al., 2018; Chukwu and Imodiboh, 2009) have reported that packaging materials, storage conditions and storage time affect the quality and the shelf life of food products either singly or in combination. These researchers assessed the quality of stored food products by monitoring the changes in the physiochemical characteristics and sensory attributes over time under specified storage conditions (Conrad, 2005). In this study a similar approach was employed to assess the nutritional quality of traditionally processed sun-dried MW. The assessment of the quality was done by monitoring the changes in the levels of ash, fat, moisture, protein content, colour, yeast, mould and coliform count of dried MW. Sensory attributes were evaluated for colour, taste, texture and overall acceptability liking was done using 101 participants who are consumers of MW. Several past researchers (Ssepuuya et al., 2016; Padehban et al., 2018; Kamau et al., 2018) have used a similar approach to evaluate the quality and shelf life of food products.

Ash is an inorganic substance left over from the combustion of organic material (Rihayat et al., 2019). 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. The average ash content on day 0, 30, 60, 90, and 120 were 9.07 ± 0.21 %, 8.92 ± 0.96 %, 9.82 ± 0.88 %, 9.48 ± 1.39 % and 9.80 ± 1.36 %, respectively. The ash content values of dried MW increased with time for all the storage conditions. The average ash content for $LDPET_1$, $LDPET_2$, $HDPET_1$ and $HDPET_2$ were 9.81 ± 0.92 %, 9.26 ± 0.68 %, 10.00 ± 1.46 % and 8.59 ± 0.59 %, respectively. The higher value of ash content in dried MW under T_1 storage condition was attributed to salt added during MW traditional processing, which influence mineral content in food product (Chukwu and Imodiboh, 2009). The increasing ash content could be attributed to loss of water in dried MW muscles with time (Kdous. et al., 2018). This reported increasing ash content is in agreement with the results of Chakroborty and Chakraborty (2017) who reported increasing ash content in a storage study on salt-smoked dried shoal under three different temperatures and agree with the results of Luna et al. (2013) who reported increasing ash content with time in a study on beef sausage stored under temperatures of 4 °C and -20 °C in polypropylene plastic. However, a study by Olayemi et al. (2015) reported decreasing ash content with time in a study on dried smoked fish stored in different composite storage materials. The reported increasing ash content of dried MW indicates that there is an ongoing chemical reaction in the product with increasing storage time.

The water in food, its location and availability, are one of the most important factors influencing microbial growth and enzymatic activity (Mishra et al., 2017; Kim. et al., 2020). The average moisture content 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 of dried MW was significantly ($p < 0.05$) affected by storage time during storage. The moisture content values of dried MW decreased in all treatments with increasing storage time. The reported decreasing moisture content of dried MW with time agrees with results by Heitschmidt (2012) who reported decreasing moisture content in a study on Bison meat snacks stored from week 0 to week 12 of storage period. The average moisture content for $LDPET_1$, $LDPET_2$, $HDPET_1$ and $HDPET_2$ were 5.69 ± 0.66 %, 3.45 ± 1.18 %, 5.83 ± 0.81 % and 3.85 ± 1.06 %, respectively. The moisture content of dried MW was higher under T_1 storage conditions than under T_2 storage conditions in both packaging materials. The higher moisture content under T_1 is attributed to the fact that under T_2, increasing the surrounding temperature increased the ability of air to absorb more moisture from the surrounding air. Thus, the dried MW under T_2 is drier compared to that under T_1.

The moisture content of dried MW was significantly ($p < 0.05$) affected by storage temperature. The higher moisture content under T_1 indicates unfavourable storage environment since higher moisture content implies the possibility of increased greater water activity, which may create favourable conditions for microbial development in dried MW that would result in decreasing it shelf life. The reported decreasing moisture content of dried MW with time is in disagreement with findings of Chakroborty and Chakraborty (2017) who reported increasing moisture content in a study on salt-smoked dried shoal stored under three different temperatures. Whether moisture is gained or lost depends on packaging and atmosphere created by packing as well as the nature of the product that is stored (Labuza and Schimdl, 1985). In addiction, moisture gain or loss by a stored food product is affected by the geographic location, season, method of processing and packaging material used (Adebola and Halima, 2014).

Fat is a food substance that is important for the health of the human body (Rihayat et al., 2019). The level of fat content of dried MW was significantly ($p < 0.05$) affected by storage time during storage. The average fat content on day 0, 30, 60, 90, and 120 were 12.72 $\pm$ 0.80 %, 12.22 $\pm$ 0.75 %, 12.68 $\pm$ 0.52 %, 12.15 $\pm$ 0.75 % and 11.31 $\pm$ 0.56 %, respectively. The fat content values of dried MW decreased in all treatments with increasing storage time. The reported decreasing fat content of dried MW with time agree with results of Farid et al. (2014) who studied shoal fish treated with salt and salt-turmeric stored at room temperatures and Adenike (2014) who studied smoked catfish treated with sodium citrate and black pepper. The reported decreasing fat content of dried MW with time agrees with results of Makawa et al. (2014) who reported decreasing fat content in a study on Tilapia stored at ambient temperature. The average fat content for $LDPET_1$, $LDPET_2$, $HDPET_1$ and $HDPET_2$ were 12.10 $\pm$ 1.13 %, 12.12 $\pm$ 0.76 %, 12.62 $\pm$ 0.48 % and 12.03 $\pm$ 0.78 %, respectively. The fat content was generally, higher under T_1 storage condition than under T_2 storage condition in both packaging materials. The decrease of the fat content under T_2 could be a results of the relatively higher temperatures conditions damaging and resulting in reduce levels. Rihayat et al., 2019 reported similar findings and reported that increasing the surrounding temperature resulted in decreasing the fat content of tuna fish floss . The decreasing fat content of dried MW under the storage conditions used in this study indicates that packaging material and temperature caused greater oxidation of poly-unsaturated fatty acids. Oxidation of these lipids gives the dried MW a rancid flavour hence may explain the decline in consumer acceptability of the dried MW with increasing period of storage.

Storage time significantly ($p < 0.05$) affected protein content of dried MW during storage. The average protein content on day 0, 30, 60, 90, and 120 were 65.95 ± 1.87 %, 67.69 ± 3.58 %, 65.30 ± 2.02 %, 65.61 ± 1.57 % and 61.83 ± 2.68 %, respectively. Protein content in this study, decreased with increasing storage time. The reported decreasing protein content of dried MW with time agree with results of Olayemi et al. (2015) who reported decreasing protein content in a study on smoked fish stored in three different packaging materials for a period of six months and Ribah et al. (2020) who reported decreasing protein content in a study on *Balangu* ready-to-eat meat product. The average protein content for $LDPET_1$, $LDPET_2$, $HDPET_1$ and $HDPET_2$ were 64.82 ± 1.69 %, 64.67 ± 1.80 %, 67.32 ± 3.51 % and 64.28 ± 3.81 %. The protein content was higher under T_1 storage condition than under T_2 storage condition in both packaging materials. The higher protein content under T_1 indicates favourable storage environment since higher protein content implies high nutrition of MW. The reported lower levels and relatively higher decreasing rate of protein content under in T_2 is attributed to protein denaturation owing to the relatively higher temperature in this case. The practical implication of this observation is that storage of dried MW under elevated temperature is undesirable since protein is very important nutrition.

Colour is an important quality measure of food products and its measurement is particularly important following processing such as drying, where colour changes are likely to occur (Teon, 2010). The packaging materials, storage temperature and time significantly ($p <0.05$) affected L*, a*, b* and ΔE* of dried MW. The reported significant effect of packaging material, storage temperature and time on L*, a*, b* and ΔE* of dried MW agrees with results reported by Kamau et al. (2018) who reported a significant effect of packaging material, storage environment and time on L*, a*, b* and ΔE* in a study on semi-processed adult house cricket meal. The average L* level 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. The levels of L*, decreased in all treatment conditions with increasing storage time. The reported decreasing lightness (L*) of dried MW with time agrees with results of (Akonor et al., 2016) who reported decreasing lightness index in a study on shrimp meat as affected by different traditional drying techniques.

The decrease in L* index suggests that dried MW became darker in colour and darkening may have occurred because of Maillard browning reactions that took place during drying (Akonor et al., 2016). The a* index and b* index levels were higher in HDPE packages than LDPE packages in both T_1 and T_2 storage conditions with increasing storage time. The average a* index level for $LDPET_1$, $LDPET_2$, $HDPET_1$ and $HDPET_2$ were 3.40 ± 0.47, 4.20 ± 0.68, 3.64 ± 0.70 and 4.04 ± 0.83,and the average b* index level for $LDPET_1$, $LDPET_2$, $HDPET_1$ and $HDPET_2$ were 8.72 ± 1.28, 9.99 ± 2.21, 9.23 ± 1.84 and 10.19 ± 2.18, respectively. The reported decreasing a* and b* index agrees with results of (Ferreira et al., 2013) who reported decreasing a* and b* index in a study on dried salted pork meat with different sodium chloride levels. The levels of ∆E* generally decreased with increasing storage 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 agree with findings of Kamau et al. (2018) who reported decreasing total colour change in a study on semi-processed adult house cricket meal with increasing time. The findings of colour indicates that HDPE has better colour of L*, a*, b* and ∆E* of dried MW.

Microorganisms such as mould and yeast can grow in food products resulting in spoilage and poisoning the consumers (USDA, 2012). The average mould count for $LDPET_1$, $LDPET_2$, $HDPET_1$ and $HDPET_2$ 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 *Aspergillus* and *Penicillium* were the major groups of mould that were identified in the dried MW. This finding is supported by (Mujuru et al., 2014) who isolated *Aspergillus* and *Penicillium* species in degutted MW in a study on microbiological quality *Gonimbrasia* processed under different traditional practices in Gwanda in Zimbabwe and (Kamau et al., 2018) who isolated *Aspergillus* and *Penicillium* in a study on quality of semi-processed adult house cricket meal. 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 ± 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 lower moisture content attained by the dried MW during storage particularly under accelerated temperature (Idowu et al., 2010). 10^5 cfu/g is the recommended limit of microbial safety of ready to eat foods at the point of sale according to the Public Health Laboratory Service guidelines (PHLS, 2000). In this study, the acceptable limit of 10^5 was not exceeded because the highest serial dilutions was 10^3 (PHLS, 2000). The findings in this study indicate that the traditionally processed dried MW are safe to consume.

Coliform is a bacteria that most often inhabits the intestine of animals and do not utilize oxygen, but can grow in its presence (USDA, 2012). Coliform was not detected in $LDPET_1$ and $LDPET_2$ throughout the experimental period. The coliform was detected in dried MW on day 90 under $HDPET_2$. These findings agree with those of Benlacheheb et al.,(2019) who reported that total coliform was found in low numbers, then eliminated after 3 days in a study on dried salted meat. There was no coliform detected in $HDPET_1$. This result agrees with Klunder et al. (2012) who reported no coliform detected. The not-detected and presence of coliform count in edible insects can be attributed survival of spores in the process of boiling, and can be active again under optimal growth condition (Klunder et al., 2012). The presence of coliform under T_2 indicates unfavourable storage environment since higher temperature, affect the rate of microbial count growth, which implies the possibility of unsafe dried MW for consumption.

The sensory evaluation test has been conducted to evaluate how a product is liked by consumers (Kdous. et al., 2018). Time significantly ($p < 0.05$) affected the sensory quality of stored dried MW for all treatment conditions. The findings of this study agrees with results by (Siah and Tahir, 2011) who reported a significant effect of storage time on sensory qualities of tilapia fillets in a study on shelf life of modified packaged red 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 sensory colour liking score decreased with increasing storage time. The findings agree with results by (Agrawal, 2011) who reported decreasing sensory score values with increasing storage time in a study on shelf life of *khoa*. The interaction between packaging material, storage temperature and time significantly ($p < 0.05$) affected sensory texture. Texture mainly depends on moisture levels, connective tissue and fat contents. The enzymatic breakdown of myofibrillar proteins increases tenderness (Jin. et al., 2010). The average overall acceptability

$LDPET_1$, $LDPET_2$, $HDPET_1$ and $HDPET_2$ were 6.48 ± 0.01, 6.43 ± 0.27, 6.49 ± 0.14 and 6.29 ± 0.56. The mean scores were above or close to 6.5 (between "like slightly" and "like moderately") on the 9 point hedonic scale. The higher overall acceptability liking score in $HDPET_2$ could be attributed to the continuous greater drying of MW under accelerated storage conditions compared to ambient storage conditions. The overall acceptability ratings for most foods on the market fall between 5.5 and 7.5, with a rating score above 7 considered good, 7.5 very good and 8 or above as above expectations (Potts. et al., 2017). The sensory overall acceptability liking score was higher in $LDPET_1$, $HDPET_1$ than $LDPET_2$, and $HDPET_2$ indicates a favourable storage condition to store dried MW.

4.8 Conclusion

From this study, HDPE performed better in maintaining the quality of dried MW. The use of LDPE and HDPE as packaging materials confers a certain degree of storage stability and protection against nutritional quality and microbial activity in dried MW. Packaging material had no significant effect on ash, moisture, fat and protein content while storage time significantly affected moisture, fat and protein content of dried MW. However, storage time had no significant ($p > 0.05$) effect on ash content. Temperature significantly affected moisture content of dried MW with the accelerated temperature significantly lowering its moisture content with time. There was no significant interaction ($p > 0.05$) between packaging material, storage temperature and time on ash, moisture, fat and protein content of dried MW. Ash, fat, moisture and protein content was higher under T_1 than T_2 for both packaging materials. L* decreased with increasing time under the packaging materials and storage temperature for all treatment combinations. Packaging material significantly, ($p < 0.05$) affected the mould count of dried MW, but had no significant ($p > 0.05$) effect on yeast and coliform. The detected yeast and mould in dried MW were *Aspergillus* and *Penicillium.* Mould count increased with increasing storage time, whereas yeast count decreased with increasing storage time for all combinations of storage conditions. Although storage time significantly affected sensory parameters of dried MW during storage, the interactions between packaging materials and temperature had no significant ($p > 0.05$) effect the sensory parameters. The interaction between packaging, temperature and time significantly ($p < 0.05$) affected participants' texture liking score of dried MW implying that these three dictate the sensory quality of dried MW.

Sensory overall acceptability liking scores was higher in T_1 and T_2 storage condition. Although the HDPE performed better than LDPE material in preserving the nutritional, microbial and sensory qualities of MW. Based on these findings, it was concluded that length of the study was not adequate to arrive at the shelf life of dried MW. Consequently, study further research was recommended to enable the determination of the shelf life of dried MW when packed in these commonly used materials.

4.9 References

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CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study sought to establish the changes in the quality parameters of traditionally processed sun-dried mopane worm over a predetermined storage period of 120 days. The study investigated the effect of selected conventional bulk and retail packaging materials, storage temperature and duration on physicochemical, microbiological and sensory qualities of dried MW.

Based on the experimental results, the following conclusions were made:

(a) Bulk packaging materials, storage temperature and duration affected the physicochemical, microbial and sensory qualities of dried MW. Storage temperature and time showed a significant ($p < 0.05$) effect on the dried MW colour parameters. The interaction between storage temperature and time significantly affected the quality parameters of dried MW. The storage temperature significantly affected the ash, moisture, protein and fat content, overall acceptability, L*, a*, b* and ΔE* during storage. PP was the most effective in retention of moisture, fat, protein content, and overall sensory acceptability. HS packaging material was found as the least effective in moisture control, which led to an increased microbial count and loss of colour. Polypropylene woven sack is better than the hessian sack. The nutritional and microbial quality of MW stored in bulk in polypropylene woven sack had no detected level of coliform and low yeast and mould counts, and the changes in the physicochemical were not significantly ($p > 0.05$) affected throughout the storage.

(b) Selected retail packaging material, storage temperature and time affected the physicochemical, microbiological and sensory qualities of dried MW. Storage temperature and time significantly ($p < 0.05$) affected moisture content of dried MW during storage. Packaging materials used in this study significantly ($p < 0.05$)

affected the L*, a*, b* ΔE* and mould count qualities. Low-density polyethylene is better than high-density polyethylene. The coliform count was only detected in the $HDPET_2$ on day 90 during storage. The nutritional and microbial quality of MW stored in low-density polyethylene had no detected level of coliform and low yeast and mould counts, and the changes in the physicochemical were not significant ($p > 0.05$) for ash, moisture, fat and protein content through the duration of the storage.

5.2 Recommendations for further research

(a) The bulk packaging materials used currently have some limitations in protecting dried MW. The dried MW stored in bulk HS packaging material had relatively low nutritional value and consumer acceptability at the end of the experimental period. These two bulk storage materials were highly porous and could not be made airtight. This calls for further research on other materials such as plastic and glass containers that are airtight for the bulk storage of dried MW in the warehouse.

(b) Packaging material, temperature and duration were factors studied in this study. During this period the quality change was insignificant for bulk packaging materials. However, for some retail packaging materials coliform was detected in $HDPET_2$ which made quality changes significant. These findings justified the need for extended studies and probably extended coverage of at least more than one accelerated temperature. The purpose of this would be to subject the dried MW to more than two accelerated temperatures and longer storage duration to determine shelf life of traditionally processed sun-dried dried MW.