

**The Development of Indigenous Marula (*Sclerocarya birrea*) Fruit Leather:  
Effect of Drying Temperature and Sugar Concentration on the Drying  
characteristics, Physico-Chemical and Consumer Sensory Properties of  
Marula Fruit Leathers**

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Submitted in partial fulfilment of the degree of Master of Science in Agriculture

Horticultural Science

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South Africa

December 2016

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## **DECLARATION**

I, **Phindile Faith Ndlovu**, declare that the research reported in this thesis, except where otherwise indicated, is my own and original work. This thesis has not been submitted for any degree or examination at any other university.

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## ACKNOWLEDGEMENTS

I would like to extend my appreciation to the following individuals:

My supervisors, Dr Mduduzi Ngcobo and Dr Samson Tesfay for their guidance, motivations and support in this study.

I am indebted to Dr Obiro Wokadala for whom this study would not have been easily accomplished without your great expertise.

Tshimangadzo Malindi and Anna Zikhali are highly appreciated and valued for giving me the technical laboratory guidance, assistance and support in preparation for my experimental trials.

Karen De Jager is highly appreciated for her assistance in allowing me to use their research equipment and on sharing some of the indigenous fruits and processed products photos.

Mr Mhlanga and Mr Mpangane for their assistance in recruiting students and allowing me to conduct my sensory evaluation trials in the premises of their Universities.

The Agricultural Research Council is highly appreciated for the financial support that allowed me to be further equipped with new research skills.

My mother, Ms Delisile Cynthia Ndlovu for her unconditional love, support and encouragements that enabled me to successfully complete this study.

My colleagues and friends who in many ways assisted me during the course of this study.

Most of all, I would like to extent my gratitude to the Almighty for giving me strength and wisdom from day to day.

## **DEDICATION**

This thesis is dedicated to my sister, Nomboniso Keith Ndlovu, who sadly did not live to see this work. Her impact and influence in my life within a short time will never be forgotten.

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## LIST OF CONFERENCE PRESENTATIONS

Thin-Layer Drying Kinetics and Effective Moisture Diffusivity of Carambola (*Averrhoa Carambola*) During Forced Convection Hot Air Drying. Oral presentation at the 21<sup>st</sup> South African Association for Food & Technology (SAAFoST) International Congress, Tsogo Sun Elangeni Maharani Complex, Marine Parade, Durban - South Africa, 7 - 9 September 2015.

Marula (*Sclerocarya birrea*) Fruit Leather Drying Kinetics and Textural Characteristics as Affected by Temperature and Sugar Content. Oral presentation at the 1<sup>st</sup> Autumn International Scientific Conference on Food Security and Safety, Johannesburg- South Africa, 16-18 May 2016.

Marula (*Sclerocarya Birrea*) Fruit Leather Product Development Using Textural and Sensory Evaluation. Oral presentation at the 19th Indigenous Plant Use Forum. Theme: Indigenous Plant Products: The Reality, 4–6 July 2016.

## RESEARCH SUMMARY

Fruits indigenous to African countries are highly recognised and valued by rural communities for food security purposes. An examples of such fruits include but not limited to marula fruits (*Sclerocarya birrea*), which is indigenous to many parts of Southern Africa.

In some parts of the continent, the role and usefulness of indigenous fruit species still receives little attention in agricultural research. Amongst others, this results from the magnitude postharvest quality losses due to the high moisture content characteristic of these fruits and a lack of access to required postharvest infrastructure by small-scale farmers. The processing of high moisture content commodities offers a convenient way of preserving their quality. The main aim of this research was to develop fruit leathers from the indigenous marula fruits as means of quality preservation. The development of new products from indigenous fruit crops as a means of preserving the fruits quality (nutrients) has a potential of enabling farmers, particularly small-scale farmers, to diversify on their on-farm business and farming activities. It also has the potential of improving the nutrition security and economy of the rural communities.

Marula fruit are normally processed and conserved into various product forms (e.g. jams, juice, flavoured water, sweets, essential oils, traditional beer and world exported beverages such as Amarula Cream) which are readily available in the market. The production of such products from the indigenous fruits involves different processing techniques and these techniques ranges from highly sophisticated processes to simple traditional ones. The choice of the processing technique used is dependent on the characteristics of the intended product. Drying is one of the techniques that have not been widely applied in the processing of indigenous fruits. The application of this technique offers the potential to produce healthy, nutritious and flavourful



ready to eat snack from the indigenous fruits such as fruit energy bars and fruit rolls which can be accessible and available throughout the year.

Very little information have been reported on product development of indigenous marula fruit in previous years. The study conducted independent drying experiments to evaluate the effects of different drying temperature (50, 60 and 70 °C) and different added sugar concentrations (0, 5 and 10% w/w) on the drying kinetics of the marula fruits pulp. Moisture loss from the fruits' pulp and different drying models in explaining the heat and mass transfer processes and for predicting the drying behaviour of the fruit leathers during drying were assessed. The textural, colour and consumer sensory attributes of the dried fruit leathers were also evaluated.

The moisture loss and drying behaviour of the marula fruit leathers were significantly ( $p \leq 0.05$ ) affected by the drying temperature and added sugar content. During the evaluation of the colour properties, the drying temperature and the added sugar content increased significantly ( $p \leq 0.05$ ) the colour of the fruit leathers. However, the colour properties of fruit leathers with high added sugar concentration for each drying temperature were significantly ( $p \leq 0.05$ ) reduced.

The texture attributes of the marula fruit leather significantly ( $p \leq 0.05$ ) increased with drying temperature (50 and 60 °C) and sugar concentration (0, 5 and 10% w/w), but significantly decreased at 70 °C for 10% w/w treated fruit leathers. The consumer sensory evaluation was also conducted to assess the acceptability of the fruit leathers. In general, all fruit leathers were accepted by panellists, and this demonstrated that marula fruit leather would form an acceptable new product. The sensory analysis showed that the mostly liked and preferred fruit leathers by the panellists were the ones prepared at 50 °C with 10% w/w added sugar.

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## Chapter 1: General Introduction

### 1.1 Introduction

Marula (*Sclerocarya birrea*) is one of the traditionally essential indigenous tropical fruit species in many African countries (Petje, 2008, Bille et al., 2013). It is highly known as an important source of food, medicine and as an extra source of income when marketed (Leakey and Akinnifesi, 2008). It also has significant roles in the tradition and culture of various rural African communities (Shackleton et al., 2002). According to Wynberg et al. (2003) the most valuable assets of this species are the fruits it bears. The fruit pulp is rich in valuable nutritional qualities such as vitamin C (Mdluli, 2005) and the kernels are a good source of essential oils (Petje, 2008). This makes marula fruit a major contributor in improving and sustaining the livelihoods of different households.

The marula pulp is commonly processed and conserved in either jams, sweets, juice, flavour water, traditional beer and world exported Amarula© Liquor. However, marula fruit are a seasonal crop species and have a relatively short ripening period (Wynberg et al., 2002). They are highly perishable, due to their characteristic high moisture content of approximately 85% (Mdluli, 2005). It is through this perishable nature that the marula fruits' pulp is therefore processed.

Using low temperatures during post-harvest usually involves relatively higher costs (Chang et al., 2016). Processing techniques such as drying can be used as an effective means of optimising marula fruit utilisation in producing other value-added products (Bille et al., 2013). Drying is the oldest industrial processing technique used in the preservation of fruits (Doymaz, 2009). It involves simultaneous heat and mass transfer processes during which moisture is removed from

material to a level that will not adversely affect fruit quality but allow safe storage over an extended period of time (Doymaz, 2009, Fernandes et al., 2011).

Fruit leathers or fruit rolls are other products that can be developed from marula fruit pulp through drying. Fruit leathers are manufactured by dehydrating mixed fruits pulp or puree with other ingredients (such as sugar, pectin etc.) into dried sheet like structures (Al-Hinai et al., 2013). Most fruit leathers are produced through the hot air drying method (Maskan et al., 2002b). Hot air drying is considered simplest and most economical (Maskan et al., 2002b) among other methods such as sun drying (which is prone to product quality loss) (Sharma et al., 2009b), microwave and freeze drying etc. (which are the most expensive methods) (Fernandes et al., 2011).

During fruit leather processing, temperature along with additives play a critical role as it can affect the material drying behaviour (Diamante et al., 2014). For instance, high temperatures were reported to increase heat transfer and moisture loss, thereby decreased total drying time required to safely reduce the moisture content of kiwifruit slices (Doymaz, 2009) and durian fruit leathers (Irwandi et al., 1998), respectively.

Moreover, drying temperature and added additives such as sugar can greatly affect the internal structures and organoleptic quality properties such as colour and texture of fruit leathers (Man and Sin, 1997). Decreasing temperature and increasing sugar levels have been reported to increase  $L^*$  value and chroma ( $c^*$ ) values of the gold kiwifruit-apple fruit leathers (Diamante and Dong, 2015). High temperatures were reported to increase the loss of moisture and texture of African wild medlar while the addition of sucrose and meltodextrin reduced texture of the final product and increased the acceptability of product by consumers (Chiau et al., 2013).

Drying temperature and additives will mainly affect the materials' moisture content removal consequently, affecting quality (colour and texture) and seriously influence consumers' buying

interest of the final product (Chong et al., 2008, Chen and Opara, 2013, Diamante et al., 2013). Maskan et al. (2002b) reported undesirable quality colour changes of grape leather after being sun dried for 14 hours. Therefore, proper temperature management and good additive concentration are of paramount importance to ensure the quality and marketability of product in retail markets.

## **1.2 Problem statement**

In South Africa, the drying of indigenous fruits has received little attention in the scientific research world and development (Akinnifesi FK, 2009, Du Preez et al., 2012). This owes to the fact that more research and focus has been paid on improving the globally marketed exotic ('cash crops') fruits (e.g. bananas, avocados, mangoes, pears, apple, kiwifruits etc.) (Schreckenberget al., 2006, Leakey and Ajayi, 2007, Leakey and Akinnifesi, 2008, Chivandi et al., 2015). Even though the processing of indigenous fruits has always been present, kept and known by rural communities in South Africa (Shackleton et al., 2003, Awodoyin et al., 2015), drying and its' recognition in indigenous fruits' commercialisation has been scarce (Leakey and Akinnifesi, 2008). This is due to the lack of knowledge in utilising the method, absence of processing or storage facilities, lack of consistent indigenous fruit supply, and lack of information on potential markets for dried indigenous produce (Saka et al., 2008).

The indigenous marula fruits are highly perishable commodities owing to their high moisture content characteristic (Dube et al., 2012). Reports have stated that during peak harvesting periods the loss of this highly valued indigenous fruits is relatively high due to inadequate post-harvest preservation and storage techniques (Kalaba et al., 2009) and this is a major limitation to its availability throughout the year and in commercialising the species as fresh fruits (Emongor and Tautsagae, 2016).



### **1.3 Justification**

The scientific approach to the development of marula fruit leather is new and no research has been conducted. Drying is one of the techniques that have not been widely applied in the processing of indigenous marula fruits. The drying of high moisture content produce, such as marula fruits, can be a complicated process involving a simultaneous heat and mass transfer processes (Kumar et al., 2012) and undesirable changes in quality of the product may occur (Sablani, 2006).

This study intends introducing a convenient method in the processing of indigenous marula pulp. Therefore, considerable knowledge and understanding of the drying behaviour of marula fruit leather is of paramount importance to better optimise drying process and quality of the final product. The application of this technique offers the potential to produce healthy, nutritious and flavourful ready to eat snack from the indigenous fruits such as fruit energy bars, and fruit rolls which can be accessible and available throughout the year. In order to mitigate the problems of fruits shelf life and availability, that is mainly associated with inadequate post-harvest techniques, and in the essence of nutrient deficiencies, promoting the processing of indigenous fruits, and job creating; efforts to therefore optimise the utilisation of indigenous fruits through product development is at utmost important.

The development of new products from indigenous fruit crops as a means of preserving the fruit quality (nutrients) has a potential of enabling farmers, particularly small-scale farmers, to diversify on their on-farm business and farming activities, and also improvement of the rural economy as well as the nutrition security of the rural communities. It will also generate opportunities to cottage industries to diversify the processing of marula fruits. This also will provide fundamental approach of optimising the utilisation of other indigenous fruits widely distributed in the country and other African countries.

## 1.4 Objectives

The main objective of the study was to develop indigenous marula fruit leather, through the method of hot air drying, by studying the effect of different drying temperature (50, 60 and 70 °C) and sugar concentration (0, 5 and 10% w/w) on the drying kinetics, physiochemical properties and consumers acceptance on the produced marula fruit leather.

This main objective was achieved through the following specific objectives:

- Determining the effect of drying temperature and sugar concentration on the drying kinetics and to identify the best model to describe the drying behaviour of marula fruit leather.
- Evaluating changes in colour of the final product, marula fruit leather, associated with the applied drying temperature and sugar concentration treatments.
- Conducting instrumental texture analysis in order to evaluate the effect of drying temperature and added sugar on the texture properties of the fruit leathers.
- By conducting consumer sensory evaluation in order to evaluate the effect of drying temperature and sugar concentration on the marula fruit leathers acceptability.

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## **Chapter 2: Literature Review - Perspectives in the Processing and Utilisation of Indigenous Fruits and Drying as the Potential Processing Method**

### **2.1 Introduction**

In many countries, different methods are employed during the processing and utilisation of indigenous fruits. The objective of this chapter is to review literature and highlight aspects on perspectives in the utilization and processing of various indigenous fruits and to introduce the technical aspect of drying as a potential technique for preserving marula fruits.

In this review, a brief discussion on a wide variety of indigenous fruits widely distributed in South Africa and African regions with potential for new product development is briefly discussed. Also common processing techniques used by rural communities to preserve these indigenous fruits are highlighted. The indigenous marula fruits, the study's main focus, is also briefly discussed in terms of its' ecology and taxonomy, fruit description, nutritional composition; uses and socio economic importance and on methods of processing its' pulp. This chapter also compares and highlights common processing methods for marula fruits with other various indigenous fruits in South Africa and some parts of African regions.

The last part of this chapter introduces the potential of drying where the theory and principle of drying, aspects of managing the drying process, advantages of drying indigenous fruits; fruit leathers from indigenous fruits; marula fruit leather processing are discussed. Methods of sun drying, hot air drying, microwave, freeze drying, heat pump drying, hybrid drying and other mild processing techniques and their influence on product quality are also briefly discussed.



### **2.1.1 Overview of indigenous fruits processing**

As stated by Schreckenberget al. (2006), indigenous fruits are regarded as a variety of species that are genuinely traditional or have originated from the region. This definition also takes into account naturalized variety of species that have evolved from materials introduced into the country from other regions over a long period of time (Jamnadass et al., 2011). Indigenous fruits are an important source of food in many rural African countries (Leakey and Akinnifesi, 2008). They contain essential macro and micro-nutrients such as vitamin A and C, fibre, sugars and minerals (Du Preez et al., 2012). Others are rich in essential oils and proteins with some used for medicinal purposes in various rural communities (Van Wyk, 2011). Indigenous fruits also offer a source of livelihood when marketed and also contribute to on-farm diversity (Shackleton, 2004).

Several fruit species are encompassed in the indigenous fruits category with a wide variation in sizes, tastes, shapes and colours (see Figure 2.1.2 for examples). Various surveys by Van Wyk (2011), Du Preez et al. (2013) and Rampedi and Olivier (2013) on indigenous fruits use (Table 2.1.1), indicates that the fruits' pulp is overwhelming the most commonly used part of the indigenous fruits (Table 2.1.1). Different rural communities commonly utilise the fruits' pulp in the processing from species such as those listed in Table 2.1.1. These fruits are mostly consumed fresh or the pulp processed into different products such as traditional wines/beer, juice, jams, (Table 2.1.1) (Shackleton, 2004, Saka et al., 2008, Rampedi and Olivier, 2013). A few studies have reported on drying of fruits such as Masau (*Ziziphus mauritiana*) (Nyanga et al., 2008) (see Table 2.1.1).



Figure 2.1.1: Examples of Southern African Indigenous Fruits. (A) Marula (*Sclerocarya birrea*); (B) Kei Apple (*Dovyalis caffra*); Num-num (*Carissa macrocarpa*); (D) African mangosteen (*Garcinia livingstonei*); (E) Stem fruit (*Engelerophyllum magalismontanum*); (F): (Mispel/ Wild medlar (*Vangueria infausta*); (G) Jacket plum (*Pappea capensis*); (I) Monkey orange (*Strychnos cocculoides*) (H) Stem fruit (*Engelerophyllum magalismontanum*); (J) Moepel/Red milwood (*Mimusops zeyheri*); (K) Baobab (*Adansonia digitata*) and (L) Mobola Plum (*Parinari curatellifolia*). Source of pictures: Agricultural Research Council (ARC) Institute for Tropical and Sub-Tropical Crops, South Africa.



Figure 2.1.2: South African examples of commonly processed indigenous fruit products. (A): Variety marula (*Sclerocarya birrea*) products (Left- Marula Nectar, Middle- Marula Jam and Right- Marula Jelly). (B) Top middle- Stem fruit/stamvrug (*Engelerophyllum magalismontanum*) Jam and bottom- variety of Kei apple (*Dovyalis caffra*) Jams. Source of pictures: Agricultural Research Council (ARC) Institute for Tropical and Sub-Tropical Crops, South Africa.

Table 2.1.1: Various indigenous fruits identified for utilization by rural communities

<b>Indigenous fruit</b>	<b>Fruit Part(s) used</b>	<b>Utilization</b>	<b>Reference</b>
<b>Marula</b> ( <i>Sclerocarya birrea</i> )	Pulp and Seeds	Ripe fruit edible fresh, mostly processed into liquor, traditional beer, flavourant, jams, sweets, nuts and edible/cosmetics oil	Hillman et al. (2008), Van Wyk (2011)
<b>Red Milkwood</b> ( <i>Mimusops zeyheri</i> )	Pulp	Ripe fruit edible fresh	Du Preez et al. (2013)
<b>Kei Apple</b> ( <i>Dovyalis caffra</i> )	Pulp	Edible ripe fruit, processed into jelly, jams, drinks flavourant, fruit salads.	Loots et al. (2006), Van Wyk (2011)
<b>Num-num</b> ( <i>Curissa macrocarpa</i> )	Pulp	Unripe fruit used to make pickles. Ripe fruit edible fresh, processed into jam and jellies	Van Wyk (2011)
<b>Monkey Apple</b> ( <i>Strychnos spinose</i> )	Pulp	Edible fresh ripe fruit, jam, jellies, various fruit wines, dry fruit rolls	Van Wyk (2011)
<b>Sand Apricot Vine</b> ( <i>Landophia kirkii</i> )	Pulp	Edible fresh, juice, beer	Rampedi and Olivier (2013)
<b>Sweet Prickly Pear</b> ( <i>Opuntia ficus indica</i> )	Pulp	Edible fresh, juice, beer	Rampedi and Olivier (2013)
<b>Large Sour-plum</b> ( <i>Ximenia caffra</i> )	Pulp	Edible fresh, juice, beer	Rampedi and Olivier (2013), Du Preez et al. (2013)
<b>Baobab</b> ( <i>Adansonia digitata</i> )	Pulp and seeds	Fruit edible fresh. Dried pulp, seeds edible raw as nuts, juice	Van Wyk (2011)

Table 2.1.1 (continued): Various indigenous fruits identified for utilization by rural communities

<b>Indigenous fruit</b>	<b>Fruit Part(s) used</b>	<b>Utilization</b>	<b>Reference</b>
<b>Brown ivory</b> ( <i>Berchemia discolor</i> )	Pulp	Edible fresh, processed into juice and beer	Du Preez et al. (2012)
<b>Stem fruit</b> ( <i>Engelerophytum Magalismsontanum</i> )	Pulp	Edible fresh, processed into juice and beer	Du Preez et al. (2013)
<b>Blue Sour-plum</b> ( <i>Ximenia American</i> )	Pulp	Fruit edible fresh, processed into juice, sweets	Du Preez et al. (2013)
<b>Mobola Plum</b> ( <i>Parinari curatellifolia</i> )	Pulp and seeds	Ripe fruit edible fresh, cooked as porridge, traditional beer, pulp for making juice, dried food, oil-enriched nuts edible raw or mix with vegetable for relish, oil for cooking	Oladimeji and Bello (2011), Du Preez et al. (2013)
<b>Monkey orange</b> ( <i>Strychnos cocculoides</i> )	Pulp	Fruit edible fresh, juice	Van Wyk (2011), Bille et al. (2013)
<b>Masau</b> ( <i>Ziziphus mauritiana</i> )	Pulp	Edible fresh, processed into traditional juice, beer and cakes, sun dried, processed into spirits	Nyanga et al. (2008), Van Wyk (2011)
<b>African Plum/ Safou</b> ( <i>Dacryodes edulis</i> )	Pulp and seeds	Edible fresh, boiled or roasted, used as an ingredient for porridge making, traditional beer and juice	Leakey et al. (2003), Van Wyk (2011)
<b>Bush Mango/ Dika nut</b> ( <i>Irvingia gabonensis</i> )	Pulp and seeds	Edible fresh, kernels dried and mixed with sauces and stews, traditional beer and juice	Leakey et al. (2003), Van Wyk (2011)

Table 2.1.1 (continued): Various indigenous fruits identified for utilization by rural communities

<b>Indigenous fruit</b>	<b>Fruit Part(s) used</b>	<b>Utilization</b>	<b>Reference</b>
<b>Ilala Palm</b> ( <i>Hyphaene coriacea</i> )	Stem	Traditional Beer	Rampedi and Olivier (2013)
<b>Brown ivory</b> ( <i>Berchemia discolor</i> )	Pulp	Juice and beer	Du Preez et al. (2013)
<b>Red ivory</b> ( <i>Berchemia zeyheri</i> )	Pulp	Beer	Du Preez et al. (2013)
<b>Blue bush</b> ( <i>Diospyros lycioides</i> )	Pulp	Juice	Du Preez et al. (2013)
<b>Jackal berry</b> ( <i>Diospyros mespiliformis</i> )	Pulp	Juice	Du Preez et al. (2013)
<b>Natal Mahogany</b> ( <i>Trichilia emetic</i> )	Pulp	Edible fresh, juice, beer	Rampedi and Olivier (2013)
<b>Stem fruit</b> ( <i>E. magalismontanum</i> )	Pulp	Juice and beer	Van Wyk (2011)
<b>Magic quarry</b> ( <i>Euclea divinoru</i> )	Pulp	Juice and beer	Du Preez et al. (2013), Rampedi and Olivier (2013)
<b>Wild fig</b> ( <i>Ficus thonningii</i> )	Pulp	Juice and beer	Du Preez et al. (2013), Rampedi and Olivier (2013)

Table 2.1.1 (continued): Various indigenous fruits identified for utilization by rural communities

<b>Indigenous fruit</b>	<b>Fruit Part(s) used</b>	<b>Utilization</b>	<b>Reference</b>
<b>Whiteberry bush</b> <i>(Flueggia virosa)</i>	Pulp	Juice and beer	Rampedi and Olivier (2013)
<b>African mangosteen</b> <i>(Garcinia livingstonei)</i>	Pulp	Juice	Rampedi and Olivier (2013)
<b>Spiny gardenia</b> <i>(Hyperacanthus Amoenus)</i>	Pulp	juice	Van Wyk (2011), Rampedi and Olivier (2013), Du Preez et al. (2013)
<b>Sand apricot vine</b> <i>(Landophia kirkii)</i>	Pulp	juice and beer	Van Wyk (2011), Rampedi and Olivier (2013), Du Preez et al. (2013)
<b>Cape gooseberry</b> <i>(Physalis peruviana)</i>	Pulp	Juice	Du Preez et al. (2013)
<b>Common forest grape</b> <i>(Rhoicissus tomentosa)</i>	Pulp	Juice	Du Preez et al. (2013)

Drying indigenous fruits allows their preserving for approximately more than a year (Akinnifesi et al., 2002). However, according to Haq et al. (2008) and Du Preez et al. (2013), the scientific information on their preservation through drying and on the use of their products in the dried state is still inadequate. As highly valued species, indigenous fruits processing allows the reduction of postharvest losses, preservation for later use, provides more palatable products through value addition, allows the supply of quality products which can be used in the preparation of other products and allows the extraction of nutrients (Saka et al., 2008, Van Wyk, 2011).

## **2.2 The Marula fruit**

### **2.2.1 Ecology and taxonomy**

According to Peters (1988), marula (*Sclerocarya birrea*) is one commonly distributed indigenous fruit species throughout the semi-arid savannahs of the African continent. It is a member of the Anacardiaceae family of mainly tropical and subtropical evergreen, deciduous trees, shrubs and wood vines, alongside with species such as the pistachio, cashew and mango (Chirwa and Akinnifesi, 2008). As a universal wild fruit in Africa, its distribution is recognised in three sub-species, which are *Sclerocarya birrea* subsp. *Caffra* (which mostly occurs in east tropical Africa i.e. Kenya and Tanzania, South tropical Africa i.e. Angola, Malawi, Mozambique, Zambia and Zimbabwe, and Southern Africa i.e. Botswana, Namibia, South Africa and Swaziland); *Sclerocarya birrea* subsp. *multifoliolata* (Engl.) Kokwaro (mostly found in mixed deciduous woodland and grassland in Tanzania, and *Sclerocarya birrea* subsp. *Birrea* (mostly occurring in the West, North-East and East tropical and Northern tropical Africa) (Van Wyk and Gericke, 2000, Shackleton et al., 2002, Kadu et al., 2006, Akinnifesi et al., 2006). In South Africa the *Caffra* sub-species is widely distributed in Mpumalanga,



Limpopo and some parts of Northern KwaZulu-Natal (Shackleton, 2004, Wynberg and Laird, 2007).

### **2.2.2 Fruit Description**

*S. birrea* is a large deciduous tree (Figure 2.2.2.1) with a drought tolerant characteristic (Shackleton et al., 2003). It is usually considered a dioecious species, meaning the male and female reproductive organs occur separately on individual trees (Jacobs and Biggs, 2002). Although on some occasional basis the male and female may occur on the same tree (Van Wyk, 2002). The fruits are round or oval in shape with a diameter of 30- 40 mm with a thick soft leathery exocarp with tiny round spots enclosing a juicy mucilaginous flesh (Mojeremane and Tshwenyane, 2004). The fruits flesh clings to the hard stone, which usually enclosed 2-4 locules containing nuts rich in fats, proteins and non-drying oils (Wynberg and Laird, 2007). The flesh or pulp is characterised with a tart-sweet refreshing taste of slightly turpentine like aroma (Chirwa and Akinnifesi, 2008). According to Thiong'o et al. (2000) on average the fruits' contains approximately 85% moisture content. The marula fruit can be considered climacteric fruit, since it ripens on the ground after it has abscised (Emongor and Tautsagae, 2016).



Figure 2.2.2.1: Marula fruit tree and marula fruit in unripe and ripened states

### 2.2.3 Nutritional composition

Nutritionally, the marula pulp contains essential macro and micro nutrients; such include ascorbic and citric acid, being the most abundant organic acids, and glutamine, arginine and asparagine being the most abundant amino acids (Mdluli and Owusu-Apenten, 2003). In terms of mineral composition, the pulp is also rich in potassium, calcium and magnesium (Thiong'o et al., 2000, Petje, 2008, Hiwilepo-van Hal et al., 2012). Moreover, the fruits' pulp is reported to have a very high viscosity, thus its handling and processing is expected to be more difficult (Fundira et al., 2002).

#### **2.2.4 Uses and socio economic importance of marula fruit**

Literature reviewed considers marula as a multipurpose valuable edible fruit species because of its ability to provide both food and medicine in various tradition and cultures (Shackleton et al., 2003, Schreckenberget al., 2006, Mokgolodi et al., 2011). It is also used as a source of income when marketed (Shackleton, 2004). The nutrient rich fruits are consumed fresh, processed in to juices, or jams, fermented into beer or distilled into liqueur while the kernels provide another food supplement as they can be consumed roasted or processed in oil for cooking and cosmetic products (Thiong'o et al., 2000, Shackleton et al., 2002, Schreckenberget al., 2006).

According to Wynberg and Laird (2007) the most prevalent use of marula fruits so far is through the production of the traditional beer (traded locally) and Amarula Cream, which is traded both locally and sold to international markets. In South Africa, approximately 150-350 litres of marula beer are traded and consumed locally by rural households (Wynberg et al., 2002), while 2000 tons of liqueur per year is exported to 28 countries around the world (Shackleton, 2005). Moreover, over 1500 tons of marula fruits are processed into oil in Namibia (Wynberg and Laird, 2007). From these activities, extra local incomes vary approximately from US\$15 to US\$166 per household annually, that is, for fruit collection and fruit processing (Shackleton, 2004) and for oil processing incomes vary from \$23-\$65 annually (Wynberg et al., 2003, Wynberg and Laird, 2007). A variety of other uses arises from the bark and leaves, with medicinal properties, which are utilized for the treatment of diseases such a diarrhoea, amongst many (Van Wyk and Gericke, 2000). The wood is utilised by rural populace for fencing, carving and fuel etc. (Shackleton et al., 2002).

### **2.2.5 Common processing methods for marula fruit and various indigenous fruits in some African regions and South Africa**

Indigenous fruits are mainly processed in order to improve their natural taste, to preserve for later use during times of low fruit supply, to manufacture products which can be further utilised in preparing other food (Kadzere et al., 2004, Saka et al., 2004). The often processed products from these fruits are jams and jellies (shown in Figure 2.1.2), juice, traditional and commercial wines (Shackleton, 2004, Saka et al., 2008, Rampedi and Olivier, 2013). Southern African countries have conducted several studies on the processing of marula juice (Hiwilepo-van Hal et al., 2012), and traditional wines from marula pulp (Shackleton et al., 2003) and jams from fruits such as Monkey orange (*Strychnos cocculoides*), Baobab (*Adansonia digitata*), wild loquat (*Uapaca kirkiana*) (Saka et al., 2007, Bille et al., 2013). Techniques used during the processing of juices, jams and traditional wine closely resemble those of exotic fruits. Except, slight differences occur region to region with the availability of processing equipment for pulp extraction, and the type of fruit used.

For instance, Saka et al. (2007); Ndabikunze et al. (2010) and Ndabikunze et al. (2011) describes methods used in Malawi and Tanzania for preparation juice and jam from indigenous fruits of marula (*Sclerocarya birrea*), Monkey orange (*Strychnos cocculoides*), smelly berry (*Vitex mombassae*), wild loquat (*Uapaca kirkiana*) and Baobab (*Adansonia digitata*). The fruits, except for Baobab fruits, are first soaked in warm water (80 °C) for duration of about 2 minutes in order to remove microbial load from the surface. For fruits of *Vitex mombassae* since they are characterised with tough skin, after washing they are boiled for approximately five minutes to soften the skin. The fruits will then be pulped manually in a mortar and pestle. The resulting pulp mixture is separated from the seeds.

*Sclerocarya birrea* fruits also have a tough outer skin and the pulp clings on the fruits stone. The pulp is then separated from the stone using an egg beater. Fruits of *Uapaca kirkiana* and

*Strychnos cocculoides* are characterized with soft friable skin, which is easily cut open with a knife, pulped in a mortar and pestle to obtain the pulp mixture. For fruits preparation of *Adansonia digitate*, the fruits of this species are characterised with hard shells, so they are usually opened manually using a machete to obtain seeds which are embedded in a whitish powdery soft pulp. The pulp for juice making is obtained by first pulverising the seeds into a fine powder, then dissolving the fine powder in warm water (40 °C) and sieving to obtain the juice. For all fruit, the obtained pulp is added with water in a 1:1 ratio. The mixture is then heated for about 20 minutes and thereafter sieved. The resulting filtrate is collected for juice making and the residues are used for jam making.

For jam making, fruit residue pulps saved during the sieving process are first characterised in terms of total soluble solids (TSS), total titratable acidity (TTA) and pH to determine any additional amounts of acid to sugar ratio required to meet the requirements of jam products. For each fruit pulp, varying amounts of commercial powder pectin, lemon peel extracts and baobab powder will be incorporated. The mixture will be cooked and there afterwards the hot jam will be filled into sterilised, air tight closed glass bottles and store at room temperature for further utilisation (Ndabikunze et al., 2010, Ndabikunze et al., 2011).

Furthermore Bille et al. (2013), describes processing methods, for marula and monkey orange juice and jams preparation in Namibia as follows: Monkey orange juice preparation process closely follows that described in Malawi and Tanzania for the other indigenous fruits above. Pulp is extracted from ripe fruits by crack opening the fully ripe fruits, seeds removed and discarded. The extracted pulp is added with small amounts of water, mixed for about 10 minutes then sieved to obtain juice extracts.

As for marula juice preparation, fruits are pressed to extract the pulp utilising a juice presser. The resulting pulp is mixed with water and stored overnight followed by filtration of the juice

and the pulp. The clear marula juice is then neutralised with sodium hydroxide solution in order to minimise the acidity. Sugar and commercial food egg yellow colourant will be added to improve the taste and visual appearance of the juice. The obtained juice (from both Monkey orange and Marula fruits) will then be pasteurized at 80 °C for about 30 minutes to inactivate enzymes and micro-organisms responsible for spoilage and browning reactions. In the process, sugar and egg yellow food colour are added to improve the taste and the appearance of the final product. The resultant monkey orange and marula juice are bottled hot in sterile bottles, sealed and cooled in refrigerators for late consumption.

The marula and monkey orange jam making in Namibia starts with the boiling of pulp and juice. In the process, pectin, sugar and food colour are mixed, dissolved in the pulp mixture to avoid lumping. The mixture will be heated up until the boiling point for one minute, filled into sterile jars, leaving a headspace, sealed and tilted to sterilise the head space and left to cool and jell at ambient temperature for further consumption (Sun-Waterhouse, 2011, Bille et al., 2013).

## **2.2.6 Common processing methods for marula fruit and various indigenous fruits in**

### **South African**

In South Africa, the post-harvest processing of marula fruit involves two methods, i.e. the processing of the pulp into various products and the processing of the kernels into edible nuts and oils. Figure 2.3.1 below shows a brief summary in the processing of the pulp and figure 2.3.2 shows a brief summary of steps in the processing of oil.

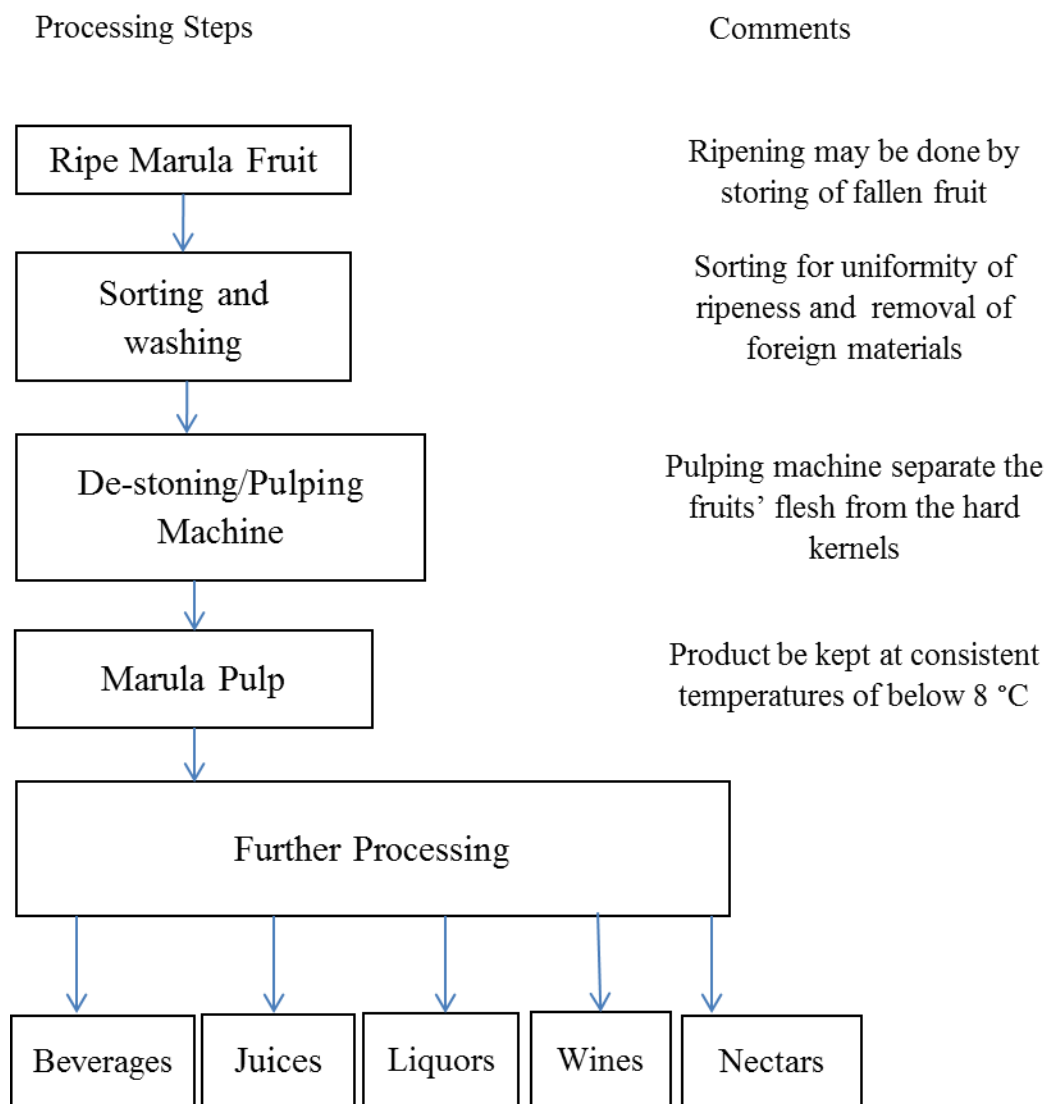


Figure 2.3.1: Steps in processing of marula pulp. Adapted from Bille et al. (2013)

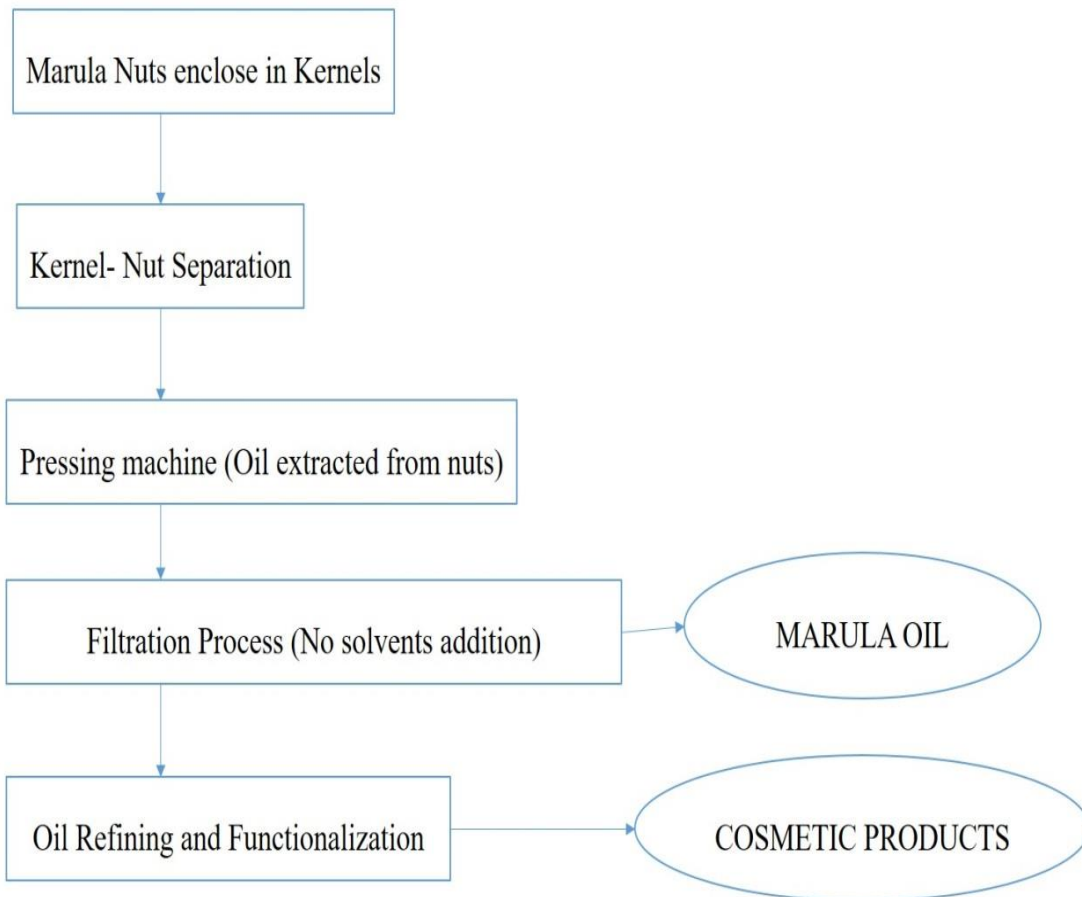


Figure 2.3.2: The processing of marula oil. Adapted from: Bille et al. (2013)

### 2.2.6.1 Marula Juice

According to Rampedi and Olivier (2013) methods applied during marula juice, jams, jellies (products shown in Figure 2.1.2) and traditional beer preparation are also applicable for other indigenous fruits processing, such as Kei Apple (*Dovyalis caffra*), Mobola Plum (*Parinari curatellifolia*), Wild Medlar (*Vangueria infausta*), Monkey Apple (*Strychnos spinose*), Sand apricot vine (*Landophia kirkii*), Sweet prickly pear (*Opuntia ficus indica*), sour plum (*Ximenia caffra*) etc. In the context of South Africa, *S. birrea* lays a base example representing other indigenous fruits since it has thrived its way to the international markets.

As described by Rampedi and Olivier (2013), refreshing marula juice is prepared from fully ripe fresh marula pulp. Where after the removal of fruits' skin, the fruits pulp are collected into clean containers and water is added to dilute them in a ratio of approximately one part per ten



parts. The mixture is allowed to soak overnight. The next day the fruits pulp mixture is squeezed by hand in order to extract the juice, seeds removed. Figure 2.3.3 below also illustrates flow steps involved in the making of marula juice.

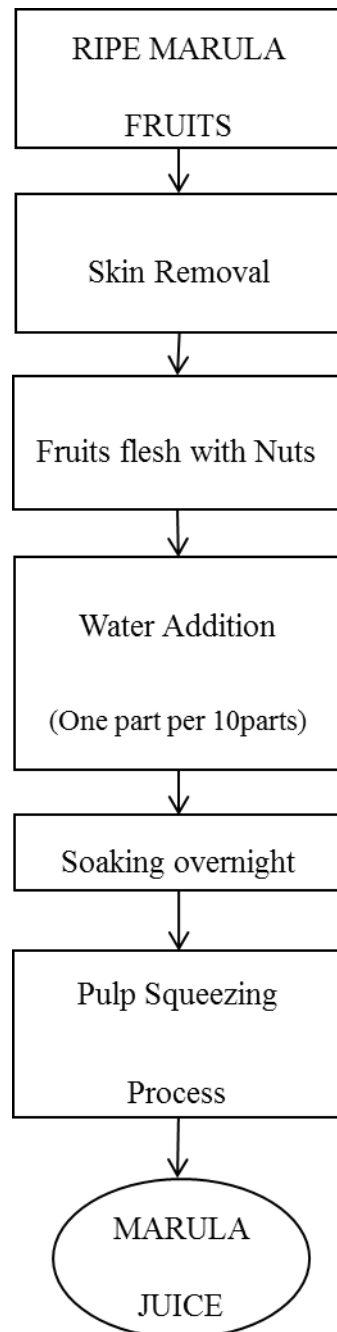


Figure 2.3.3: Flow diagram for the preparation of marula juice. Adapted from: Rampedi and Olivier (2013).

### 2.2.6.2 Traditional Marula Beer

The processing method for traditional marula beer slightly differs from making juice and Figure 2.3.4 below summarises steps involved. The first step in the processing of marula beer is the separation of the skin from the flesh with either a fork or knife. The pulp is then squeezed and the resulting juice is collected into containers. The nuts with the remaining fruits flesh are mixed with water to release any remaining juice and pulp (Shackleton, 2004). Making marula beer requires the fruits pulp mixture to be concentrated in traditional clay pot. In so doing, ambient temperatures of approximately 25 °C must be maintained (Shackleton, 2004, Rampedi and Olivier, 2013).

The pulp mixture is left and allowed to ferment spontaneously for a period of two to four days (Shackleton, 2004, Rampedi and Olivier, 2013). After this period, the pulp mixture will resemble semi-solid masses of slurry suspended on top, having bubbles, signalling that the breakdown of fermentable sugars into alcohol has occurred (Rampedi and Olivier, 2013). During the fermentation process, the slurry formed on top of the liquid is removed once or twice daily (Shackleton, 2004), within the 2-4 days period mentioned. After this stage the mixture is carefully filtered, and the beer is ready for drinking. The shelf-life of the beer is however limited, that is, it last for about 2-4 days, depending on the ambient temperatures (Shackleton, 2004). In a study by Shackleton (2004), the author mentions that other producers could make the beer last longer if they topped it with fresh marula juice on a daily basis, and this added 2-3 days in its' shelf-life or they stored it into fridges. Unlike any traditional beer, marula beer preparation requires no additional supplementary ingredients like brown sugar, maize, yeast, sorghum (Rampedi and Olivier, 2013). For instance, traditional beer derived from bitter fruits of sour plum (*Ximenia caffra*) will require some sugar addition to improve its sensory taste, (Rampedi and Olivier, 2013).

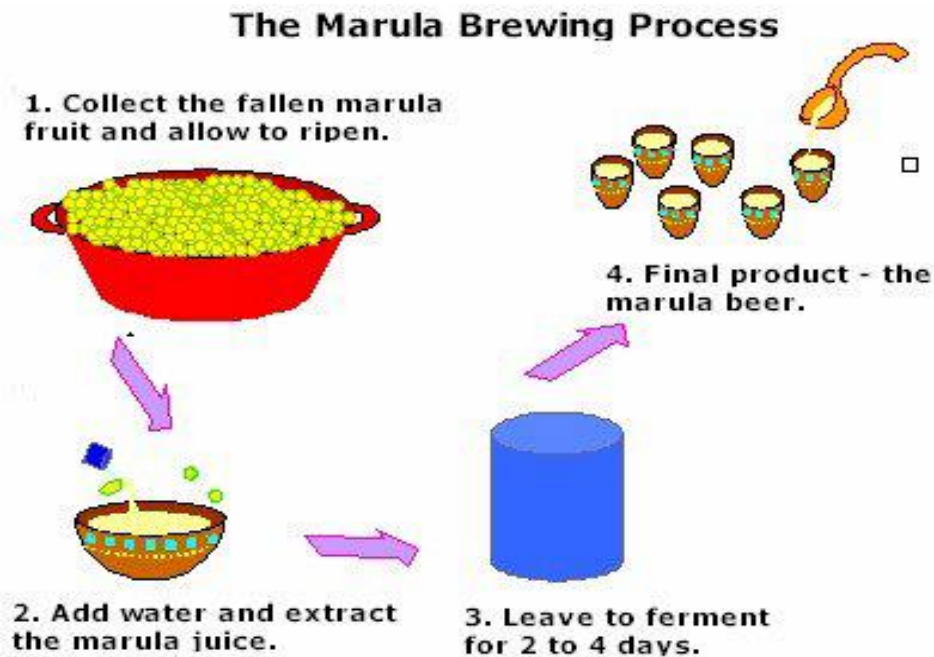


Figure 2.3.4: The marula beer process. Source: Nwonwu (2006)

### 2.2.6.3 The processing of Marula Liqueur (Amarula Cream)

Gathered by the rural populace, approximately 2435 tonnes per year of marula fruits are bought by Mirma (company involved in the production and processing of Amarula Cream). Ripe marula fruits are pulped or crushed, the kernels are removed in a destoner and the flesh is crushed from the skin. The marula pulp is then fermented under conditions similar to those of making grape wine. However, after fermentation, the marula wine undergoes a double process of distillation making use of copper pot-stills. The juvenile and immature liqueur will then be matured into small casks of oak for a period of about 2 years.

During this period, the liqueur will be enriched with pure marula extracts obtained from a special process that captures the unique flavour of the marula in a concentrated form. Following this is the creaming process; the obtained spirit will be blended with fresh cream until a smooth consistency is reached. The creaming process results into a rich and soft stable product, the

Amarula Cream liqueur, with an alcohol content of 17% by volume (Amarula website, <http://www.superbrands.com/za/pdfs/pdf2010/amarula.pdf>, Accessed 07 August, 2016).

#### **2.2.6.4 Other marula derived products**

The nuts found inside the marula kernels are also utilized to supplement the diet of rural households. They are either consumed roasted or ground into powder and used as a flavourant during meat and vegetable cooking, or used as a mix during cake and biscuit making. The residues from oil extraction can be used to produce marula seed meal, a protein rich by-product which can be used as a dietary feed for livestock (MlamboV et al., 2011).

### **2.6 Drying: A potential processing technique for indigenous fruits**

#### **2.6.1 Theory and principle of drying**

Drying is the oldest industrial processing method with many applications in the food processing sector (Chang et al., 2016). It is defined as a process whereby moisture of a certain material is removed through the utilization of heat as an input (Hawladar et al., 2006b, Kucuk et al., 2014, Baradey et al., 2016). Depending on the technique used for drying, this supply of heat may be of convective or radiation type (Fernandes et al., 2011).

According to Kucuk et al. (2014), drying occurs under the mechanism of combined heat and mass transfer processes. It is considered a three phase phenomenon process (Schlünder, 2004), where, during the first phase heat is supplied to the wet material and the drying velocity increases to correspond to the rise of temperature of the product until it reaches equilibrium. During this time the product receives as much heat from the surrounding air in order to vaporize moisture. The second phase is the period of constant drying velocity, where the vaporization of free moisture on the surfaces of the product will be permanently renewed by the moisture coming from inside the product. The third phase is the slowing down phase which involves

heat and mass transference from the inside of the product to its surfaces through the external transport of moisture to the surroundings (Schlünder, 2004, Kumar et al., 2014, Kucuk et al., 2014, Baradey et al., 2016). Moreover, moisture transportation within the solid material is through one or combination of the following mechanisms explained in table 2.6.1 below.

Table 2.6.1: Mechanisms of mass transfer involved during a typical drying process.

<b>Mechanism</b>	<b>Explanation</b>
Hydrostatic flow	Differences in pressure when an internal vaporization rate exceeds the rate of vapour transport through the solid material to the surroundings
Vapour Diffusion	Liquid vaporization within the wet material
Liquid Diffusion	When the wet material is at a temperature below the boiling point of the liquid
Knudsen Diffusion	Drying taking place at very low temperatures and pressure, e.g. freeze drying
Thermal Diffusion	Water flow caused by vaporization-condensation sequences during drying of porous and granular materials
Surface Diffusion	Water/moisture flow from the internal surfaces through pore surfaces of material

Adapted from Mujumdar and Devahastin (2000) and Erbay and Icier (2010)

### **2.6.2 Factors affecting the drying process**

The drying phenomenon can be a complicated and least understood process in practice (Erbay and Icier, 2010, Mitrevski et al., 2013). This arises from the difficulties in understanding the

drying process as a whole, improper selection and management of the drying techniques and deficiencies in mathematical explanations employed during drying (Erbay and Icier, 2010). Proper management of one drying system revolves and is governed by different inter-related factors. Such factors include air temperature, relative humidity (RH) and airflow rate (Mujumdar and Devahastin, 2000).

### **2.6.2.1 Air temperature**

The use of high temperatures during drying will increase the heat transfer and increases the moisture transfer rate within the product (Doymaz, 2009, Doymaz and İsmail, 2012). Also, high temperatures decreases the total drying time required to reduce the products moisture content to a safe level, and increases the drying rate (Doymaz, 2009, Doymaz and İsmail, 2012) by increasing the system's ability of drying air to hold moisture and increasing the vapour pressure when the heated air heat the product (Mujumdar and Devahastin, 2000, Niamnuy et al., 2014). Similar findings have been reported elsewhere in literature for the drying of apple slices (Akpınar et al., 2003, Seiedlou et al., 2010) , during the drying of pear (Mrad et al., 2012) and drying of litchi (Janjai et al., 2011). The drying rate is regarded as the loss of moisture removed from the wet material being dried per each unit time (Doymaz and İsmail, 2012). This rate is noted operating when temperature, pressure, humidity and airflow are constant under experimental conditions (Schlünder, 2004, Doymaz and İsmail, 2012).

### **2.6.2.2 Relative humidity**

As for relative humidity, decreasing RH will lower the vapour pressure of air and results into higher mass transfer rate (Doymaz, 2009, Doymaz and İsmail, 2012) and increase the system's ability or capacity to hold the air in its surroundings (Mujumdar and Devahastin, 2000), thereby shortening the drying period (Doymaz, 2009, Doymaz and İsmail, 2012). In a study of thin-layer drying of kiwifruit slices (Doymaz, 2009) and drying of pear slices (Doymaz and İsmail,

2012) authors found that decreasing RH decreases the total drying time however, the authors also specifies that this will depend on the materials nature of thickness.

### **2.6.2.3 Airflow rate**

Whereas, increasing the airflow rate will result into lower temperature increments. High airflow rate may cause problems in the efficiency of drying arising from inadequate air contact with the food material being dried (Niamnuy et al., 2014) and insufficient airflow rate will result into slow moisture removal (Mujumdar and Devahastin, 2000, Niamnuy et al., 2014). Doymaz (2009) concludes that the airflow rate controls the rate of the drying process up to some level, however, further increments in airflow rate will cause no substantial influence on the drying time. The transportation of moisture within the wet material being dried will occur by one or a combination of different mass transfer mechanism explained above in table 2.6.1 (Mujumdar and Devahastin, 2000, Erbay and Icier, 2010).

### **2.6.3 Measuring the drying process through mathematical modelling**

The drying process is usually measured through the application of certain thin-layer drying models or equations. Thin-layer models are a set of detailed mathematical equations simplified enough to adequately explain, describe and predict the drying, process, characteristics or behaviour of different biological material (Erbay and Icier, 2010, Kumar et al., 2012, Kucuk et al., 2014). These models are mostly utilised during the drying of agricultural materials, especially during the drying of fruits. They are a set of linear regression equations (Table 2.7.1 below) suitable for explaining and selecting the optimum drying conditions, help predict the simultaneous heat and mass transfer mechanism and to design new drying systems (Erbay and Icier, 2010, Kumar et al., 2012, Kucuk et al., 2014).

Table 2.7.1: Mathematical models mostly utilized in the thin-layer drying of fruits.

Model Name	Equation	Reference
Newton/ Lewis	$MR = \exp(-kt)$	Bruce and Goldberg (1985), (Ayensu, 1997)
Page	$MR = \exp(-kt^n)$	Page (1949), Diamante and Munro (1993)
Henderson and Pabis	$MR = a \exp(-kt)$	Pabis and Henderson (1961), Pal and Chakraverty (1997)
Logarithmic	$MR = a \exp(-kt) + c$	Yaldýz and Ertekýn (2001), Tođrul and Pehlivan (2002)
Verma	$MR = a \exp(-kt) + (1 - a) \exp(-gt)$	Verma et al. (1985)
Approximation of Diffusion	$MR = a \exp(-kt) + (1 - a) \exp(-kat)$	Yaldiz et al. (2001)
Two-Term	$MR = a \exp(-kt) + b \exp(-kt)$	Henderson (1974)
Wang & Singh	$MR = 1 + at + bt^2$	Wang and Singh (1978)
Simplified Fick's	$MR = a \exp(-c(t/L^2))$	Diamante and Munro (1991)
Modified Page II	$MR = \exp\left(-c\left(\frac{t}{L^2}\right)^n\right)$	Diamante and Munro (1991)
Midilli-Kucuk	$MR = a \exp(-kt^n) + bt$	Midilli et al. (2002)
Hii, Law & Cloke	$MR = a \exp(-kt^n) + c \exp(-gt^n)$	Hii et al. (2009)

The drying of agricultural material also involves evaluating the thin-layer models and selecting which model suitably described the drying behaviour of the material under specific study. This is clarified through mathematical modelling, based on statistical linear regression and correlation analyses (Erbay and Icier, 2010, Kucuk et al., 2014). However, before that, these thin-layer drying models also require experimental data of the moisture ratio (MR) and time; these are obtained during the drying experiments. Thus, the regression analysis need be performed so as to determine best model to describe the drying characteristic of certain agricultural material (Erbay and Icier, 2010, Kucuk et al., 2014).



To determine the appropriate model, the widely used method in literature involves conducting the correlation analysis tests using equations in Table 2.7.2, where correlation coefficient/ or coefficient of determination ( $R^2$ ) is determined; reduced chi-square tests ( $\chi^2$ ) and root mean square error (RMSE) tests analysis are evaluated (Erbay and Icier, 2010, Kucuk et al., 2014). These three statistical criteria have been used in the drying products such as carrot pomace (Awodoyin et al., 2015); tomato slices (Demiray and Tulek, 2012) mango and pineapple fruit leather (Schlünder, 2004) and mango slices (Akoy, 2014); bamboo slices (Kumar et al., 2013); pear slices (Doymaz and İsmail, 2012). The general rule in using these statistical criteria (Table 2.7.2) and that governs the determination of the appropriate model is that the best suitable model to describe the drying characteristics of a dried product will be the one with highest  $R^2$  and lower  $\chi^2$  and RMSE values (Erbay and Icier, 2010, Kumar et al., 2012, Kucuk et al., 2014). The equations used to perform calculations of  $R^2$ ,  $\chi^2$  and RMSE are presented below in Table 2.7.2.

Table 2.7.2: Equations used in validating the drying characteristics of agricultural materials

Equation name	Expression	Reference
Coefficient of determination ( $R^2$ )	$R^2 = \frac{\sum_{i=1}^N (M_{R,pre,i} - M_{R,ex,i}) / (M_{R,ex,i} - M_{R,ex,i})^2}{\sum_{i=1}^N (M_{R,pre,i} - M_{R,ex,i})^2}$	Erbay and Icier (2010), Kumar et al. (2012), Doymaz and İsmail (2012)
Reduced Chi-square ( $\chi^2$ )	$\chi^2 = \sum_{i=1}^N \frac{(M_{R,ex,i} - M_{R,pre,i})^2}{N - z}$	Erbay and Icier (2010), Doymaz and İsmail (2012), Kumar et al. (2012)
Root Mean Square Error (RMSE)	$RMSE = \left[ \frac{1}{N} \sum_{i=1}^N (M_{R,ex,i} - M_{R,pre,i})^2 \right]^{\frac{1}{2}}$	Erbay and Icier (2010), Doymaz and İsmail (2012), Kumar et al. (2012)
Moisture Ratio (MR)	$MR = \frac{M - M_e}{M_o - M_e}$	Erbay and Icier (2010), Doymaz and İsmail (2012), Kumar et al. (2012)
Arrhenius Type Equation (use to relate $D_{eff}$ and $E_a$ with temperature)	$D_{eff} = D_o \exp\left(-\frac{E_a}{RT}\right)$	Erbay and Icier (2010), Doymaz and İsmail (2012), Kumar et al. (2012)

After validating the appropriate model, two more concepts in drying need to be considered. These are the effective moisture diffusivity ( $D_{eff}$ ) and activation energy ( $E_a$ ) (Erbay and Icier, 2010, Kucuk et al., 2014). The effective moisture diffusivity is a phenomenon in drying which describes the manner in which moisture/water is removed from the material (Kumar et al., 2012). It mainly varies with internal conditions during drying, such include products temperature, moisture content, drying rate, and products' structure (Erbay and Icier, 2010, Kucuk et al., 2014).

The effective moisture diffusivity is one vital concept to calculate, which is used to clarify the drying characteristics of dried materials (Erbay and Icier, 2010). The  $D_{eff}$  is obtained from a straight line plot of the natural logarithm of Moisture ratio (MR) against drying time (Doymaz and İsmail, 2012). The MR is derived from measurements data of moisture content measured during the drying experiments. Whereas, the activation energy on the other hand, gives an indication of the amount of power/ or energy required to trigger each reaction during drying (Erbay and Icier, 2010). This concept is also significant to determine as it tells us the effectiveness of an employed drying technique, in terms of energy saving and operation costs (Erbay and Icier, 2010).

The activation energy relates the effects of temperature on effective moisture diffusivity (Erbay and Icier, 2010, Kucuk et al., 2014) and tells us the sensitivity of effective moisture diffusivity on temperature (Erbay and Icier, 2010, Kucuk et al., 2014). In addition, the effect of temperature on the effective moisture diffusivity is described via an Arrhenius type equation (Erbay and Icier, 2010, Kucuk et al., 2014) (Table 2.7.2). The greater the value of the  $E_a$ , means  $D_{eff}$  was more sensitive to temperature (Erbay and Icier, 2010, Kucuk et al., 2014). So, the effective moisture diffusivity is an important tool useful in describing the drying characteristics and the activation energy is useful in describing the sensitiveness of  $D_{eff}$  on temperature (Erbay and Icier, 2010, Kucuk et al., 2014).

#### **2.6.4 The advantages of drying indigenous fruits**

A number of benefits result from the drying of perishable produce, such as indigenous fruits. Dried fruits are regarded as healthy food snacks that provide a different concentrated form of fresh fruits (Chang et al., 2016). They provide sources of energy, minerals, health promoting antioxidants (e.g. Vitamin A and C ) and phytochemicals (Fernandes et al., 2011, Chang et al., 2016). In the context of indigenous fruits, drying is another value adding and a niche market promoting techniques to generate revenues (Du Preez et al., 2013).

Through the removal of moisture contained in the material, drying reduces certain enzymatic reactions responsible for the deterioration of the product (Doymaz, 2008), hence promoting the products shelf-life (Sagar and Kumar, 2010, Mujumdar and Law, 2010, Zhang et al., 2016). Drying also brings a substantial reduction in products weight and volume, which consequently minimises the packaging, storage and transportation costs (Dev and Raghavan, 2012, Mujumdar and Law, 2010, Sagar and Kumar, 2010, Sablani, 2006). Moreover, it enables products storability at ambient temperatures and promotes product diversification as dried produce, fruits in particular, can either be used as stand-alone products or as constituents of other food products (Rawson et al., 2011).

The drying of indigenous fruits adds value and promotes a niche market to generate revenues for the rural populace (Leakey et al., 2003, Nyanga et al., 2008, Van Wyk, 2011, Du Preez et al., 2013). The drying of indigenous fruits is also an effective way of preserving and making them available during off season times and throughout the year (Saka et al., 2008). Unique tasting products such as fruit leathers can be processed and developed through the utilization of the fruit pulps (Du Preez et al., 2013).

### **2.6.5 Indigenous fruits based fruit leathers**

In general fruit leathers are fruit rolls (Al-Hinai et al., 2013), manufactured by dehydrating a certain fresh fruit pulp/puree or a mixture of fruit juice concentrates with other ingredients (Diamante et al., 2014). The process involves the removal of moisture from the wet pulp/puree, laid on flat trays, up until the pulp/puree changes into a cohesive leathery sheets like structures, with a chewy texture and different degrees of hardness (Al-Hinai et al., 2013, Diamante et al., 2014). Figure 2.6.5.1 below illustrates a flow chart process for dried fruit leather production. Fruit pulp based leathers are nutritious dietary products, consumed as snacks (Diamante et al., 2014).

Although in literature, fruit leathers are relatively well established products for exotic fruits, few research studies have been carried out with emphasis on utilising indigenous fruits. Nevertheless, of the few studies conducted, the standardised protocol applied in the preparation of fruit leathers follows that employed for exotic fruits (Figure 2.6.5.1). However, differences arise from the use of drying technology, specialised equipment to thoroughly disintegrate the fruits during pulp extraction, the ingredients and various concentrations used as per desired product (Babalola et al., 2002, Valenzuela and Aguilera, 2015).

Fruit leathers are prepared from fully ripe fruits with or without any addition of preservatives or additives (Maskan et al., 2002b) (Figure 2.6.5.1 below). The puree is pre-treated using blanching method, additive flavourant like sugar, lemon juice etc. (Figure 2.6.5.1) or preservatives such as sodium metabisulphite, citric acid etc., prior to drying in order to hinder the darkening of the fruits' pulp/puree and to prevent the occurrence of pathogens responsible for spoilage and food borne illnesses (Orrego et al., 2014). In some cases, various pre-treatments such as sugar, pectin, ascorbic acid, juice blends etc. can be used to enhance the flavour, texture, colour, acceptability of the final product and prevent microbial contamination, mentioning the few (Azeredo et al., 2006, Fulchand and Pralhad, 2015).

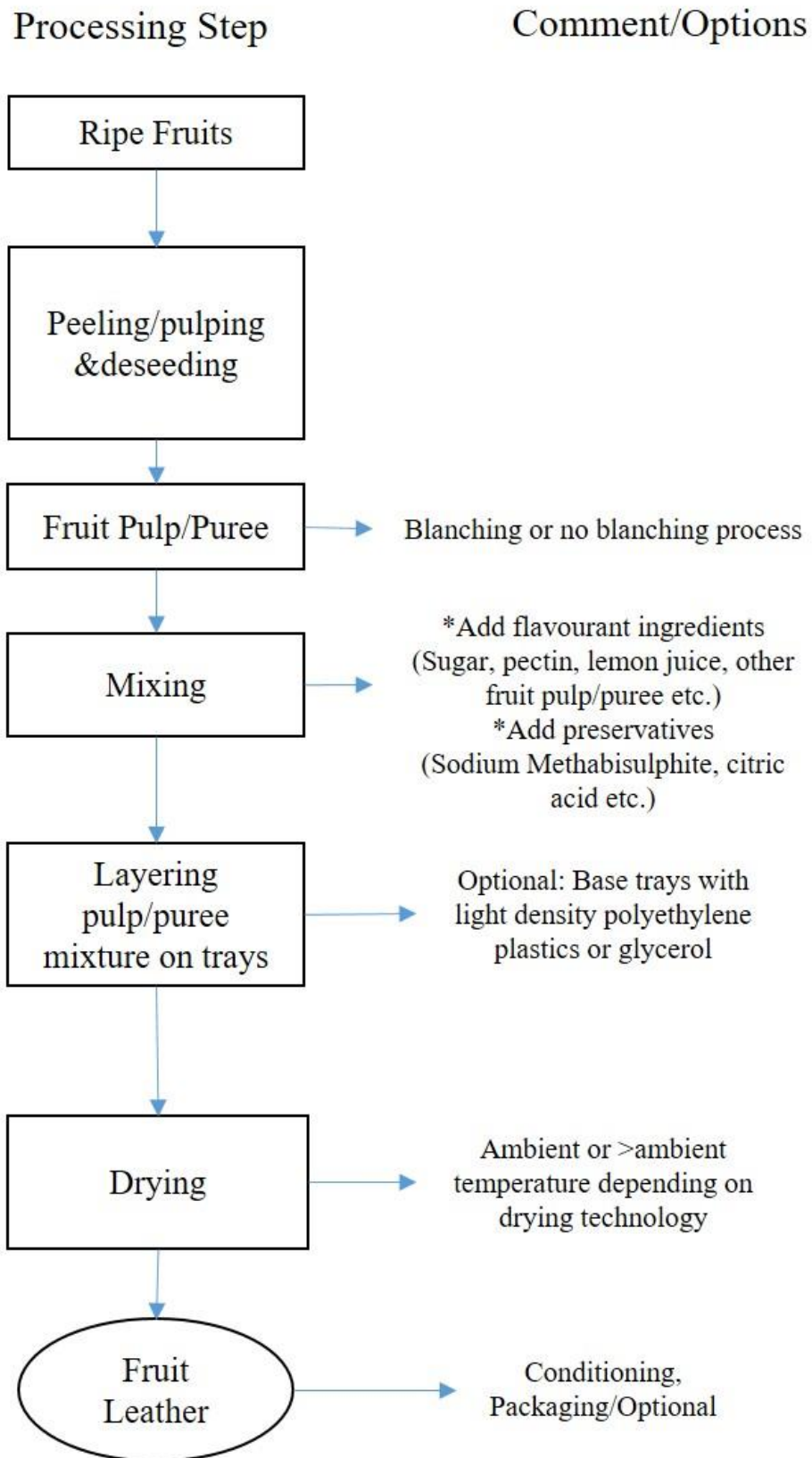


Figure 2.6.5.1: General process for the production of fruit leathers. Adapted from: Diamante et al. (2014).

Studies on jackfruits, wild medlar, and marula fruits have shown that fruit leathers from indigenous fruits are effective in promoting and optimising indigenous fruit products.

Pua et al. (2007) performed the drying of jackfruit puree in a double drum dryer and found that the resultant product gave satisfactory quality results of final product. Okilya et al. (2010) also investigated the processing of jackfruit leather using solar, cabinet and convective oven drying. They found that all methods investigated reduced the moisture content of the fruit leathers to an acceptable level. However, solar drying negatively affected the colour, texture, aroma and consumer acceptability of the final product when compared to cabinet and convective drying.

During the optimisation of wild medlar, Chiau et al. (2013) evaluated the influence of drying temperature, maltodextrin and sucrose treatments on water content, water activity, texture and acceptability using hot air drying. It was reported that fruit leathers gave a safe water activity level (0.63), the addition of maltodextrin and sucrose also resulted into reduced hardness and were more acceptable compared to the untreated fruit leathers. Sharma et al. (2013) developed wild medlar fruit bars with different proportions of sugar and pectin and evaluated its' quality sensory acceptability and storage stability. The sensory evaluation of the developed fruit bars was acceptable and stable for a period of six months under ambient temperatures.

#### **2.6.6. Marula fruit leather processing procedures**

As for the context of this study marula fruit leathers were developed and convectively dried following the process flow diagram in Figure 2.6.5.1, with modifications. Briefly, fully ripe marula fruits of uniform maturity and without bruises were selected and washed for pulp extraction (Figure 2.10.1 below). The pulp extraction process is the most critical, since the fruits' pulp clings with the seeds, and involves repetitive extraction. That is, the separation of the flesh from skin and seeds which results into a rough textured pulp and the extraction which removes skin impurities resulting into smooth textured pulp that is ready for drying. The

obtained pulp is treated with sodium metabisulphite (to preserve colour and prevent micro-organism growth) and added with sugar to enhance flavour. The basic processes on how to prepare marula fruit leathers are shown below in Figures (2.10.1 and 2.10.2), where Figure 2.10.1 illustrates the pulp extraction process and Figure 2.10.2 illustrates preparation of pulp prior to drying and the resultant marula fruit leather.





→ Ripe marula fruits for pulp extraction



→ Rough textured pulp after first extraction



→ Smooth textured pulp after second extraction ready for mixing and drying

Figure 2.10.1: Demonstration of marula pulp extraction



Figure 2.10.2: Drying of marula pulp and the resultant marula fruit leather.

### 2.6.7 Drying techniques and their influence on product quality

Fruits leathers can be manufactured through different drying methods with a right combination of drying temperature, humidity and air flow currents (Araya-Farias et al., 2011). According to Janjai et al. (2011) an ideal drying process must be able to retain products quality in terms of nutrients, maintain products appearance, prevent undesirable changes; use minimum energy, friendly to the environment and maintain a balance between initial and final operational costs.

Different drying techniques have been used to preserve fruit leathers and other agricultural products. Such techniques are depicted in Figure 2.6.7.1 below and in order of advancement include sun/solar drying, hot-air (conventional) drying, microwave, freeze drying, heat pump drying, combined/ hybrid drying and mild processing methods.

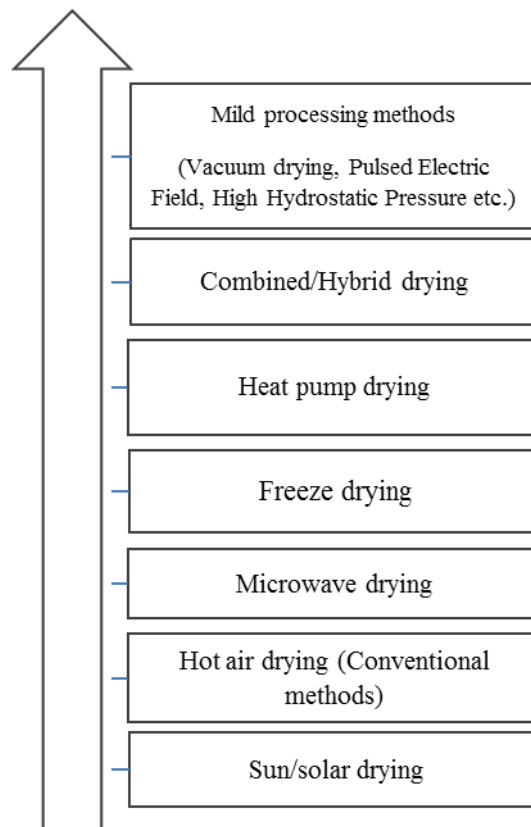


Figure 2.6.7.1: Different drying techniques for agricultural produce. Adapted from Sablani (2006)

### 2.6.7.1 Sun/solar drying

Various types of sun drying exist in the literature, viz open sun drying, mechanised sun drying and solar drying. Sun drying refers to the process of drying that harnesses the sun's radiation energy as the main source of heat in order to dry the material (Pal and Chakraverty, 1997). Sun drying has been widely used in the tropical and sub-tropical regions to preserve fruits like figs (Kumar et al., 2012). Open sun drying involves spreading the material being dried into thin layers on trays and exposing it to the sun and wind (Verma et al., 1985).

During the open sun drying, short wavelengths from the sun's radiation energy fall on the material surface, some of this energy will be reflected back and the remaining will be absorbed by the surface of the material (Pal and Chakraverty, 1997). The absorbed radiation will be converted into thermal energy that will increase the material's temperature, and some will be transferred into the inside parts of the product (Diamante and Munro, 1993). The temperature and formation of water vapour inside the material will increase, diffuses towards the surfaces and then the thermal energy will be lost in the form of evaporation (Pal and Chakraverty, 1997).

During the process, long wavelength radiation loss occurs from the material's surface (Yaldyz and Ertekyn, 2001). Moreover, the convective heat loss will occur due to the blowing air over the material's surface (Pal and Chakraverty, 1997, Diamante and Munro, 1993). Therefore, moisture evaporation takes place and the material is dried (Verma et al., 1985). Drying using the sun is still practiced because it is relatively cheap, the sun's energy is abundant, inexhaustible, non-pollutant, renewable and environmental friendly (Kumar et al., 2012). However, since with open sun drying the material is not subjected to any covers (Ayensu, 1997), the final product is likely to encounter considerable losses due to contamination with dust, micro-organisms (e.g. fungi), rodents, birds and insects (Bruce and Goldberg, 1985). In general drying with the sun is weather dependent (Kumar et al., 2012) and open sun drying depends on the environmental factors such as sun's radiation and wind (Page, 1949) hence, undesirable changes in colour of the final product (Diamante and Munro, 1993). For example, three months open sun drying of *Ziziphus mauritina* and *Garcinia livingstonei* fruits resulted into moist products which were darker in colour and reduced vitamin C content (Tembo et al., 2008). Sun dried date fruits were reported to have reduced quality sensory attributes in terms of colour, taste and flavour (Al-Farsi et al., 2005). Spoilage of the product due to unpredictable rain also arises (Pal and Chakraverty, 1997).

Apart from deteriorating the products quality, this technique is more labour intensive, relatively slow and requires more land to spread out the produce (Sharma et al., 2009a). In addition, produce preserved with open sun drying do not meet the international quality standards (Diamante and Munro, 1993, Zhang et al., 2016). With these limitations, open sun drying was replaced by mechanised sun drying.

Mechanised sun drying refers to drying occurring in closed vessels (i.e. boilers) (Jairaj et al., 2009). This type of sun drying utilises fossil fuel and electricity to heat the drying air and to force the dry air through the material, respectively (Sharma et al., 2009a). It consists of boilers that heat the incoming air and fans that force air out at a much faster rate (Wakjira, 2010). Mechanised sun drying is considered faster than open sun drying and consists of boilers (for heating the incoming air) and fans (to force air through at higher rates) (Ayensu, 1997).

Solar drying is considered a modified version of sun drying. It uses the sun as the main source of energy for drying while utilising equipment to collect the suns radioactive energy during drying (El-Sebaili and Shalaby, 2012). It is more effective than open sun drying and has lower operating costs than mechanised drying (Gutti et al., 2012). Solar drying has the following advantages over the open sun drying, amongst many such include protection of dried products from contamination from insects, dust etc.; the faster rate of drying reduces chances of mould infestation, saves labour and the quality in terms of nutrients, colour and hygiene of the final product is better retained (Gutti et al., 2012).

#### **2.6.7.2 Hot air drying (conventional methods)**

According to Fernandes et al. (2011), hot air drying is the most commonly used technique for drying fruit leathers because it is simple to use and cost effective amongst other methods. The method uses hot air to dry fruit leathers to a safe moisture level, approximately ranging between 15 – 25% (Maskan et al., 2002b, Phuong et al., 2016). Hot air drying systems are composed of

build in rotating fans promoting better air circulation and moisture removal from the material (Ratti, 2001, Mujumdar, 2006). During hot air drying, hot air circulates inside the chamber and onto materials' surfaces until surface moisture reaches equilibrium state and then evaporates through airflow valves (Mujumdar, 2006).

Hot air dried African star apple and African mango immersed in different sucrose solutions resulted into improved taste (Falade and Aworh, 2005). Hot air dehydrated figs with and without pre-treatment were reported to give good quality attribute results (in terms of flavour and chewiness), and reduced drying time for untreated figs compared to treated figs (Piga et al., 2004). Osmo-convectively dried jackfruits were found to show better retention of carotenoids and colour (Saxena et al., 2009).

Nevertheless, hot air drying may result into desirable and undesirable chemical reactions which may deteriorate quality properties of fruit leathers (Parimita, 2015). Such deterioration owes to under drying and long drying times resulting from low contact efficiency between drying system and the material, and over drying causing hard textured products (Jangam et al., 2008). Hot air drying comes in different forms of operating systems , for example oven drying, spray and fluidised bed drying (Dev and Raghavan, 2012), therefore in order to achieve high quality products, close monitoring of the drying air temperature, humidity, velocity and materials thickness is of paramount importance (Ratti, 2001).

### **2.6.7.3 Microwave drying**

Microwave processing utilises electromagnetic waves to dry a product. The electromagnetic waves cause molecules of the material to oscillate in a manner that will generate heat (Dev and Raghavan, 2012). The use of microwave rays influences structure, elasticity of the dried product, porosity, maintains the colour and shortens the drying time which in turn influences

the quality attributes of fruit leathers (Sablani, 2006, Sagar and Kumar, 2010) . However, achieving these attributes is possible when microwave drying is used in combination with other methods (Rawson et al., 2011), because when used as a standalone technique, moisture can remain on the surface of the product as the chamber infuses with moisture (Wray and Ramaswamy, 2015). High initial cost, loss of aroma and the degradation of texture are some drawbacks of microwave drying (Zhang et al., 2010, Wray and Ramaswamy, 2015).

#### **2.6.7.4 Freeze drying**

Freeze drying utilises the sublimation of ice fraction under which water passes from solid to the gaseous state (Argyropoulos et al., 2011). This method is considered one of the best methods of in terms of removing moisture and resulting into products of highest quality (Ratti, 2001). The materials submitted to freeze drying undergo a combination processes of low temperatures and absence of liquid water that are able to stop the degradation of some nutritional properties of foods that are sensitive to heat (Santos and Silva, 2008, Ceballos et al., 2012, Pei et al., 2014). Marques et al. (2006) found better retention of colour, taste and flavour after freeze drying pineapples, guavas, mangoes and barbados cherries. Freeze dried sapota pulp retained more colour compared to raw sapota pulp (Jangam et al., 2008). Despite its characteristic of maintaining the quality attributes of dried materials, freeze drying is also considered expensive which involves approximately 5-10 times more operating costs than hot air drying (Marques et al., 2006, Liu and Lee, 2015).

#### **2.6.7.5 Heat pump drying (HPD)**

HPD is one of the recently developed drying technologies, more advanced and effective for heat sensitive materials compared to other drying methods because of its ability to use low temperatures in an oxygen free environment and utilises less energy to dry materials (Chua et al., 2002, Chua et al., 2010, Mujumdar and Law, 2010). Hawlader et al. (2006a) studied the drying kinetics and quality of papaya and guava leather using nitrogen, carbon dioxide and

normal air as treatments in a heat pump drier. They found high effectiveness of the drying method on the drying kinetics and quality (retention of flavour, colour and vitamin C) of these fruits.

#### **2.6.7.6 Combined/ Hybrid drying**

The idea of combining different methods for processing arise from trying to reduce high operational costs incurred, and to increase on the benefits received from just a single drying process, such as improving quality retention (Santos and Silva, 2008). A vast number of possible combinations exist and most of them are in conjunction with microwave energy.

According to Wray and Ramaswamy (2015) microwave and vacuum drying (microwave-vacuum drying) provides a combination of advantages. That is, microwave heating shorten the drying time via rapid heating, is efficient and controllable. The vacuum part lowers the boiling point of water which allows water to evaporate at lower temperatures than in normal atmospheric environment, thus maintaining the product at lower temperatures which in turn limit product degradation (Wray and Ramaswamy, 2015). These two combined provides an energy efficient system and product of superior quality, even though the installations and operation costs are high (Jangam et al., 2008, Sagar and Kumar, 2010). An investigation consisting of an initial air drying step combined with a microwave-vacuum technique concluded that high value dried fruits with improved texture and colour are produced (Sagar and Kumar, 2010).

In a comparative study of combined microwave-vacuum and hot-air drying of various products (fruits, vegetables and aquatic products), (Zhang et al., 2010) reported high level of improvement in colour and texture of dried product compared with the hot-air dried one. Sharma and Prasad (2006) compared microwave drying (at 0.4 W/g) with hot air drying (at 60-70 °C) (microwave convective drying). Their results showed that the drying time could be



reduced by 80% while producing high quality dried products. Again, lychees were microwave-vacuum dried (Duan et al., 2015) their results showed that this method was able to produce dried lychees with better colour, less shrinkage and better taste in less time, consuming less energy than in convective air drying.

Andrés et al. (2007) studied the drying of mango by combining osmotic dehydration with microwave drying (osmotic microwave drying). The authors found that osmotic microwave drying reduced the drying time, improved on colour and energy consumption. They concluded that microwave power must have influenced the drying kinetics of mango and also have produced the charred pieces of mango. Dev et al. (2011) investigated the effect of microwave-hot air drying and conventional hot-air drying on the drying kinetics, quality and volatiles of *Moringa oleifera*. Their results showed a five times faster drying rate in microwave-hot air dried fruits than the corresponding conventional hot air dried fruits at the same temperature, a significant difference ( $p < 0.05$ ) in drying time and a significantly reduced loss of volatiles in microwave-hot air fruits. In addition to that, microwave-hot air dried fruits preserved most bioactive compounds (colour) when compared to conventional hot air dried fruits (Dev et al., 2011).

#### **2.6.7.7 Other mild processing methods**

Mild processing techniques are also regarded as non-thermal techniques. Their development was mainly due to minimising the loss of quality retention of dried product obtained when using the other methods, to improve on the drying rate of the system (Fernandes et al., 2011). According to literature, high temperatures used during the drying process are an important cause of losing quality and some important bioactive compounds (Rawson et al., 2011).

Low-Pressure Superheated Steam Drying (LPSSD), known as vacuum drying (Fernandes et al., 2011) is one other technique that has been identified as an alternative of drying heat

sensitive material. It uses reduced temperatures when compared to the conventional superheated steam drying (Fernandes et al., 2011). In a study by Amellal and Benamara (2008) on vacuum drying of dates, reported that a decrease in moisture content from 15% to 6% dry basis produced good quality in terms of colour.

In a comparative study between vacuum drying and intermittent LPSSD of dried banana, Thomkapanich et al. (2007) reported that LPSSD dried banana had a greater retention of vitamin C than vacuum dried banana. They concluded that low oxygen environment was related to this high retention of nutrients in LPSSD dried bananas. Rajkumar et al. (2007) in a foam mat drying investigation of alphonso mango pulp found higher vitamin C retention. They also reported that foam mat drying results in a higher drying rate, hence shorter drying time.

## **2.7 Conclusion and Future Remarks**

There are numerous indigenous fruits that are well known, highly valued and utilised by rural populace who often depend on them for various household utilisation. Product development from indigenous fruits nectars and pulps has shown a potential to produce unique tasting products that could be further developed into a niche market. The fruits' pulps could also be transformed into dried forms, such as fruit leathers, to produce unique nutritious snacks which can be used in the preparation of other foods.

Fruit drying has been possible through the use of many different drying methods. These methods range from the most affordable to the relatively expensive ones. Their limitations lie on the costs of operation and their capability to retain product quality. Therefore good knowledge in managing the factors such as drying temperatures, air flows and humidity inside the drying systems is necessary.

Drying is recognised for enhancing postharvest shelf of perishable produce, however, few studies have reported on the drying of indigenous fruits. A potential exist in generating dried indigenous fruits based products. However, this lies on the processing and value addition component. There is a need to optimise the indigenous fruits preservation and utilization. Drying is one efficient method which appears to be a practical alternative at this stage. The challenge of using this method lies on adequate control of the drying process to obtain quality products.

## 2.8 References

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### **Chapter 3: Effect of Drying Temperature and Sugar Concentration on the Drying Kinetics and Colour Properties of Marula (*Sclerocarya birrea*) Fruit Leather**

#### **Abstract**

Drying was used as a new approach of preserving marula (*Sclerocarya birrea*) fruits. In the current study, marula fruit leathers were developed. This was achieved by evaluating the drying kinetics and colour properties as affected by different temperature (50, 60 and 70 °C) and different sugar concentrations (0, 5 and 10% w/w). The drying experiments of marula fruit leather were carried out in a commercial scale convective hot-air dryer. The relative humidity and air flow speed were kept at  $15\pm 2\%$  and 0.3 m/s, respectively. Moisture diffusivity was determined based on Fick's law of Diffusion and six drying kinetics models (Newton, Page, Henderson and Pabis, Logarithmic, Midilli-Kucuk and Approximation of Diffusion) were used for assessing the drying kinetics. Colour properties were determined using the handheld CR-400 Chromameter (from Konica Minolta) and the results were expressed according to the Hunter CIELAB system ( $L^* a^* b^*$ ). The moisture diffusivity increased with sugar content and followed an Arrhenius type relationship with temperature. The Logarithmic model was found to be the most suitable for describing the marula leather drying based on regression coefficients ( $R^2$ ), Root Mean Square values ( $RMSE$ ), and  $k$  drying rate constant. The Yellowness Index (YI), Chroma ( $C^*$ ) and the Browning Index (BI) showed trends of increasing with temperature increase and decreasing with increasing sugar concentration. The study provides information to dry marula fruits pulp. The findings would be useful in facilitating the further development of marula fruit leathers into commercial products that can provide longer shelf-life and thereby increase the availability of derived nutrients such as vitamins to the population.

**Keywords:** Mathematical Models, Moisture Transfer, Quality Parameters, Statistical Coefficients.

### 3.1 Introduction

Indigenous fruits of species *Sclerocarya birrea*, commonly known as marula, are recognised as important sources of dietary food in the many rural African countries (Shackleton, 2004, Hillman et al., 2008). The fruits pulp is rich in valuable nutritional antioxidants such as vitamin C (Hillman et al., 2008, Hiwilepo-van Hal et al., 2012, Mngersquo et al., 2012), which is three times than that found in oranges (Nyanga et al., 2008, Leakey et al., 2003) , mango (Hiwilepo-van Hal et al., 2012) and pomegranate (Hillman et al., 2008). The kernels are a good source of essential oils (Bille et al., 2013). Marula fruit are also utilised as medicine in various tradition and cultures (Mariod and Abdelwahab, 2012). It offers a source of livelihood when marketed (Stadlmayr et al., 2013). It also has a drought tolerant characteristic (Sarkar et al., 2014). Moreover, it contribute both to household food security and on-farm diversity, especially for small-scale farmers (Bille et al., 2013) . With these fore-mentioned valuable assets, marula fruits are therefore regarded as a major contributor in improving and sustaining the livelihoods of different rural households (Wynberg et al., 2002).

Marula fruits are currently processed and conserved in various products such as jams, juice, flavoured water, sweets, essential oils, local traditional marula beer and world exported Amarula© Liquor. This is justified by the fact that the fruits biologically are characterised with an approximated 85% moisture content, which increases the fruits level of perishability and shortens its post-harvest period (Nyanga et al., 2008). Processing techniques such as drying can also be applied in the preservation of high moisture materials, such as marula fruits, as means of optimising its utilisation, increasing the fruits shelf-life and availability throughout the year (Kumar et al., 2012).

Fruit leathers are common products which can be produced from the marula fruits pulp by employing the drying technique (Mitrevski et al., 2013). In general, fruit leathers are

dehydrated sheet-like structures characterised with a chewy texture characteristic (Diamante et al., 2014) and consumed as fruit bars/or snacks (Ruiz et al., 2012, Orrego et al., 2014) However, fruit leathers preservation depends on the moisture content, which should range within 15-25% (Diamante et al., 2014) and on the incorporated ingredients and additives during their production (Diamante et al., 2014, Orrego et al., 2014). Sugar is the most common and abundantly added ingredient during the processing of fruit leathers (Orrego et al., 2014).

However, the drying of high moisture produce (marula fruits) can be a complex phenomenon involving dual mechanisms of heat and mass transfer processes (Hawlder et al., 2006b, Kumar et al., 2014, Kucuk et al., 2014, Chang et al., 2016). However, no research has been conducted on the drying of marula fruits. Therefore, since this is a new approach of preserving and processing this fruits', it is of important to study, measure and describe all possible mechanisms involve in the dehydration kinetics of marula fruits to better substantiate the drying process (Perea-Flores et al., 2012b). As part of new product development, it is also vital evaluate colour variations during its processing. Colour is a tool used to assess processing effects on product quality (Mujumdar and Devahastin, 2000). Therefore, the main objective of the chapter was to determine the effect of different drying temperatures and added sugar on the drying characteristics (moisture diffusivity) and colour attributes of marula fruit leather.

## **3.2 Materials and Methods**

### **3.2.1 Fruit Material and Preliminary Characteristics**

Marula (*S. birrea*) fruits were obtained from Freidemhein, one of the Agricultural Research Council farms in Nelspruit, South Africa. The fruits were sorted according to their ripeness and stored at 10 °C. Total Soluble Solids (TSS, in Brix %) was measured using a digital refractometer (PAL-3 Digital Brix Refractometer, Atago Co. Ltd, China, with an accuracy range 0-93%). The determined TSS average was 3.1±0.1. The total Titratable Acidity (TA) was

determined by titration with Sodium hydroxide solution (0.1562N) and measured average was  $25.1 \pm 0.2$ . The pH value measured using a microprocessor pH meter (Mettler Toledo, Microsep (Pty) Ltd, SA), with an accuracy range 0.0-14.0) was  $3.1 \pm 0.1$ . The initial moisture content of the samples (99.8% wet basis) was determined by employing the method of Association of Official Analytical Chemists (AOAC, 1984), using an analytical moisture balance analyser Mettler Toledo, Microsep (Pty) Ltd, SA). All chemicals used were of analytical grade and were obtained from Merck (Johannesburg, South Africa).

### **3.2.2 Sample Preparation**

Fully ripe marula fruits were sorted, washed, and pulped using a pulping machine. A total of nine kg marula fruit pulp was measured using a weighing scale (CFW-150, Adam Equipment Co Ltd, Dunbury, USA, min 0.01 kg). To prevent browning, 4 ppm of Sodium Metabisulphite was mixed with the fruits' pulp. Sugar was also used as a flavourant. A one kg marula pulp was measured (CFW-150, Adam Equipment Co Ltd, Dunbury, USA, min 0.01 kg) and mixed with 0, 5 and 10% w/w sugar concentration and each was replicated three times. Stainless steel trays (300 mm x 440 mm) were layered with light density polyethylene plastics to create easy removal of samples after drying. A one kg of marula fruit pulp was spread evenly using a stainless steel spoon. The trays with fruit pulp were inserted in a drying trolley carrier then loaded into the drying chamber.

### **3.2.3 The Drying Procedure**

The drying experiments were carried out in a commercial scale forced convection dryer (AD3000 Agri-Dryer, Dryers for Africa, Limestone Hill, SA). Where, the relative humidity (RH %) and speed (m/s) were kept constant at  $15 \pm 2\%$  and 0.3 m/s, respectively. In order to validate the drying conditions inside the dryer, the relative humidity and air temperature were also recorded using a data logger (Hobo U23 Pro v2, Onset Computer Cooperation, Bourne, USA). The drying runs were conducted at temperatures of 50, 60 and 70°C. For each

temperature three independent triplicates for each sugar treatment during drying were done. The fruit pulp weight/ or moisture loss, determined by the AOAC (1996) method, was measured at a one-hour interval during the drying process. The fruit samples were dried up until there was a  $\geq 1\%$  change in consecutive measurement readings. The marula fruit leather were obtained and were immediately packed in high density polyethylene bags, heat sealed to prevent further moisture loss, and stored at 5 °C for further analysis.

### 3.2.4 Marula fruit leather drying kinetics

In order to predict and describe the drying kinetics of marula fruit leather, it is vital to model its drying behaviour. In this study, the experimental moisture ratio data of marula fruit leather at the different drying temperatures (50, 60 and 70 °C) and different sugar concentrations was fitted using six empirical drying models (Table 3.2.6.1). The dimensionless moisture ratio (MR) of marula fruit leather during drying experiments was calculated by means of Eq. (3.2.4.1).

$$MR = \frac{M - M_e}{M_o - M_e} \quad (3.2.4.1)$$

Where  $M_o$  is the initial moisture content,  $M_e$  is the equilibrium moisture content and  $M$  is the moisture content at time  $t$  (Doymaz, 2011, Perea-Flores et al., 2012a, Sacilik, 2007). Based on the method described by Jain and Pathare (2004), the equilibrium moisture content was determined. From this method, the rate of change of moisture content versus the average moisture content was plotted. In order to determine the equilibrium moisture content, the intercept of the plot was extrapolated to the point where the rate of change of moisture content was zero.

The drying rate of marula fruit leather was calculated using Eq. (3.2.4.2).

$$DR = \frac{M_1 - M_2}{t_2 - t_1} \quad (3.2.4.2)$$



Where  $t_1$  and  $t_2$  are successive drying times in seconds;  $M_1$  and  $M_2$  are the moisture contents (kg water.kg<sup>-1</sup> dry matter) at time  $t_1$  and  $t_2$ , respectively (Doymaz, 2011, Doymaz and İsmail, 2012, Ngcobo et al., 2013).

### 3.2.5 Marula fruit leather effective moisture diffusivity

Fick's law of diffusion states, the moisture mass flow per unit area in a given material is proportional to the concentration gradient in that material (Crank, 1979). This law was applied to describe effective moisture diffusivity within marula fruit leather. The effective moisture diffusivity is a measure of the average flow of water through a material driven by different mechanisms. The diffusivity is mainly affected by; moisture content, temperature and material characteristics such as thickness (Pathare and Sharma, 2006). In order to study marula fruit leather moisture diffusivity, the shape of the fruit leather was assumed to correspond to a slab geometry. The diffusivity was then calculated using equations 3.2.4.1 and 3.2.4.2 with the following assumptions (Crank, 1979):

The initial moisture and temperature were uniform inside the marula fruit pulp.

The surface of the slices was in equilibrium with the drying air.

There was negligible shrinkage of marula fruit pulp during drying.

The marula fruit pulp had a solid symmetry.

The dimensionless moisture ratio (MR) of marula fruit leather was calculated by means of Eq. (3.2.4.1) above. The effective moisture diffusivity was calculated from the slope of a straight line obtained by plotting the natural logarithm of the moisture ratio (MR) versus drying time (Eq. 3.2.5.1) (Doymaz and İsmail, 2012).

$$\ln MR = \ln \left( \frac{8}{\pi^2} \right) - \left( \frac{\pi^2 D_{eff} t}{4L^2} \right) \quad (3.2.5.1)$$

This gives a straight line with a slope given by Eqn. 3.2.5.2:

$$Slope = -\frac{\pi^2 D_{eff}}{4L^2} \quad (3.2.5.2)$$

Where  $D_{eff}$  is the effective moisture diffusivity in  $m^2s^{-1}$ ,  $L$  is half the thickness of the pulp and  $t$  is the drying temperature.

The effective moisture diffusivity ( $D_{eff}$ ) and activation energy ( $E_a$ ) in  $kJmol^{-1}$ , were related to the temperature of convective drying by Arrhenius equation (Doymaz, 2005, Perea-Flores et al., 2012a) as shown by Eq. (3.2.5.3).

$$D_{eff} = D_o \exp\left(-\frac{E_a}{RT}\right) \quad (3.2.5.3)$$

Where  $D_{eff}$  is the effective moisture diffusivity ( $m^2s^{-1}$ ),  $D_o$  is the pre-exponential factor equivalent to the diffusivity at infinitely high temperatures ( $m^2s^{-1}$ ),  $E_a$  is the activation energy ( $kJmol^{-1}$ ),  $R$  is the universal gas constant ( $8.314 Jmol^{-1}$ ) and  $T$  is the absolute temperature (K). Taking logarithms of both sides of Eq. (3.2.4.6), results into a straight line variation as shown in Eq. (3.2.5.4) (Doymaz, 2005, Perea-Flores et al., 2012a):

$$\ln(D_{eff}) = \ln(D_o) - \frac{E_a}{RT} \quad (3.2.5.4)$$

### 3.2.6 Marula fruit leather mathematical modelling

In order to predict and explain the moisture loss and mass transfer characteristics of marula fruit leather, the experimental moisture ratio (MR), was fitted to the models shown in Table 3.2.6.1 using non-linear least squares regression analysis based on minimization of the chi-square value using Levenberg–Marquardt iteration. The regression was computed using Statistica<sup>®</sup> Software version 8 (StatSoft, Tulsa, USA). The statistical validity of the models was evaluated and compared by means of the coefficient of determination ( $R^2$ ) which was used as the main selection criteria for the best model. Additionally, other statistical parameters such as reduced chi-square value ( $\chi^2$ ) and root mean square error (RMSE) values were used to

determine the goodness of fit of the models. These parameters ( $R^2$ ,  $\chi^2$  and  $RMSE$ ) were calculated using Eq.'s (3.2.6.1), (3.2.6.2) and (3.2.6.3), respectively.

$$R^2 = \sum_{i=1}^N M_{R,pre,i} - M_{R,ex,i} / (M_{R,ex,i} - M_{R,ex,i})^2 \quad (3.2.6.1)$$

$$\chi^2 = \sum_{i=1}^N \frac{(M_{R,ex,i} - M_{R,pre,i})^2}{N-z} \quad (3.2.6.2)$$

$$RMSE = \left[ \frac{1}{N} \sum_{i=1}^N (M_{R,ex,i} - M_{R,pre,i})^2 \right]^{\frac{1}{2}} \quad (3.2.6.3)$$

Where  $M_{R,ex,i}$  is the  $i$ th experimental dimensionless moisture ratio;  $M_{R,pre,i}$  is the  $i$ th predicted dimensionless moisture ratio;  $N$  is the number of observations and  $z$  is the number of constants (Doymaz, 2011, Perea-Flores et al., 2012a, Sacilik, 2007).

Table 3.2.6.1: Mathematical models used to test the experimental data of marula pulp weight loss per unit time.

Model name	Equation	Reference
Newton	$MR = \exp(-kt)$	Ayensu (1997)
Page	$MR = \exp(-kt^n)$	Diamante and Munro (1993)
Henderson and Pabis	$MR = a \exp(-kt)$	Pal and Chakraverty (1997)
Logarithmic	$MR = a \exp(-kt) + c$	Yaldyz and Ertekyn (2001)
Verma	$MR = a \exp(-kt) + (1 - a) \exp(-gt)$	Verma et al. (1985)
Approximation of Diffusion	$MR = a \exp(-kt) + (1 - a) \exp(-kat)$	Yaldiz et al. (2001)

### 3.2.7 Marula Fruit Leather colour attributes evaluation

The colour measurements were based on Hunter's Lab, Commission Internationale de l'Eclairage (CIE)  $L^*a^*b^*$  system. Where the parameters  $L^*$  (Lightness) takes black (0) and white (100) measures;  $a^*$  takes (+) values for reddish and (-) values for greenish colours; and  $b^*$  takes (+) values for yellowness and (-) values for blueness (Granato and Masson, 2010, Pathare et al., 2013). The marula fruit leather surface colour was determined using a reflectance chroma meter (CR-400, Konica Minolta Sensing, INC, Japan). The instrument was first calibrated with a white ceramic tile before measurements were taken. Ten repetitions of colour measurements of  $L^*a^*b^*$  parameters were measured at different points of the fruit leathers and recorded. The obtained data was used to calculate the Chroma ( $C^*$ ), Yellowness Index (YI) and Browning Index (BI) of the marula fruit leathers.

Chroma was calculated using equation (3.2.7.1):

$$C^* = \sqrt{a^{*2} + b^{*2}} \quad (3.2.7.1)$$

The yellowness index was estimated according to Equation (3.2.7.2) (Pathare et al., 2013).

$$YI = \frac{142.86b^*}{L^*} \quad (3.2.7.2)$$

The browning index (BI) of fruit leathers was estimated according to Equation (3.2.7.3) (Mohapatra et al., 2010, Pathare et al., 2013).

$$BI = 100 * \frac{X-0.31}{0.17} \quad (3.2.7.3)$$

Where:

$$X = \frac{(a * +1.75L)a}{(5.645L + a * -3.012b *)}$$

In order to verify the occurrence of non-enzymatic browning, supplementary experiment was done on the samples 0, 5 and 10 percent sugar according to (Vega-Gálvez et al., 2008). Briefly, marula fruit leather samples prepared at 50 °C with 0, 5 and 10% w/w added sugar were selected for the experiment. The rehydration water was clarified by centrifugation at 3200xg for about 10 minutes. The supernatant was diluted with equal volume of ethanol (Merck Chemical, Johannesburg, South Africa) at 95%. The mixture was centrifuged again at 3200xg for approximately 10 minutes. The browning index of the extracts was determined in quartz cuvettes using a spectrophotometer (Jenway 7315 Spectrophotometer, Bibby Scientific Ltd Stone, Staffs, UK) with an absorbance of 420 nm. The experiment was repeated three times.

### 3.3 Results and Discussion

#### 3.3.1 Effective moisture diffusivity ( $D_{eff}$ ) of marula fruit leathers

The effect of drying temperature and sugar concentration on the effective moisture diffusivity of marula fruit leather is presented in Figure 3.3.1. It was observed that the moisture diffusivity increased with increasing temperature and with an increase in sugar concentration. This suggested increasing temperature increases the rate at which moisture flows out of the material. According to Jaya and Das (2003), additives affects the diffusivity and rate of moisture removal from the pulp during drying. The addition of sugar in this study contributed by increased the

conductivity of heat within the material which created a faster flow of heat from within the samples. Similar observation on the increase of the moisture diffusivity with temperature during drying of fruits have been reported by Janjai et al. (2007) during drying of longan fruits and Lee and Hsieh (2008) during drying of strawberry fruit leathers. The observations made on increasing moisture diffusivity with additive increase (sugar) are similar to those reported by Singh Gujral and Singh Brar (2003) during drying of mango leather with different hydrocolloids and Gujral et al. (2013) in the drying of mango and pineapple fruit leathers with different sucrose.

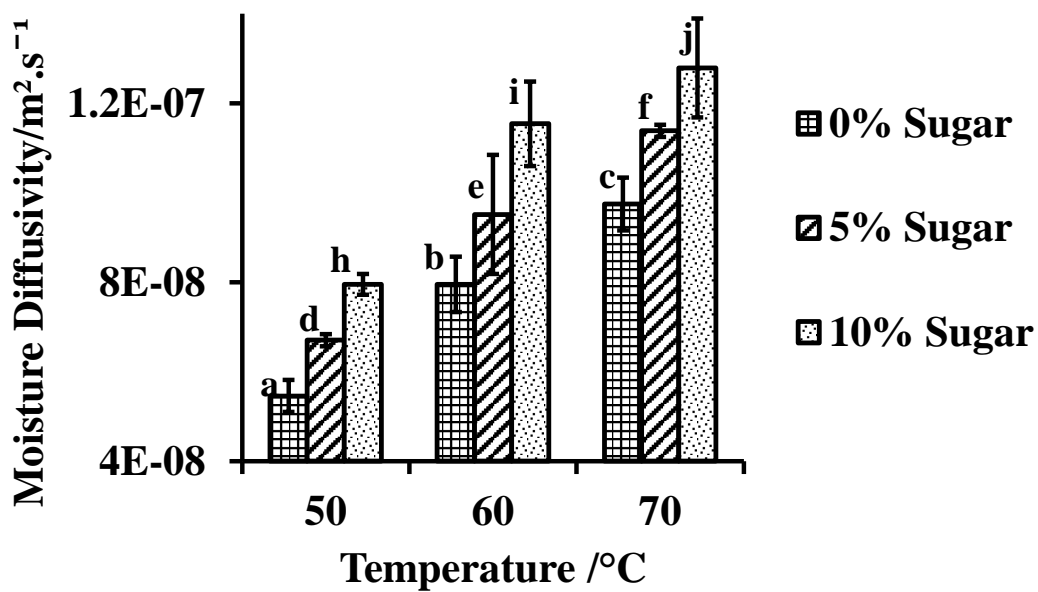


Figure 3.3.1: Moisture diffusivity ( $m \cdot s^{-1}$ ) of marula fruit leather dried at different temperature (50, 60 & 70 °C) and different sugar concentrations (0, 5 & 10%). Error bars indicate standard deviations of means. Columns with different letters are significantly ( $p \leq 0.05$ ) different.

### **3.3.2 Activation energy ( $E_a$ ) of marula fruit leathers**

The changes in activation energy ( $E_a$ ) as affected by drying temperature and sugar concentration (%) are shown in Figure 3.3.2. The activation energy is referred to as the amount of energy required to trigger each reaction during drying and was estimated by employing the Arrhenius type equation (Doymaz, 2009). It was then calculated by plotting the natural logarithm of moisture diffusivity against absolute temperature.  $E_a$  in this case shows how sensitive diffusivity was with the addition of different sugar concentration (%).

In general, when sugar is added onto a material it dissolves and goes into solution and that solution will be said to be saturated (Bhandari et al., 1993, Adhikari et al., 2004). That saturation point is different with different temperature, depending on the amount of sugar added (Adhikari et al., 2004). It was observed that  $E_a$  increases with an increase in sugar concentration (%). This means that any small variation in sugar concentration during the drying of marula fruit leather will result into significant changes on the manner at which moisture will be released from the sample. This then suggested that the increment of sugar resulted into more hydrogen bonding during drying, thus, more energy was required to break those hydrogen bonds in order to release the moisture from the samples.

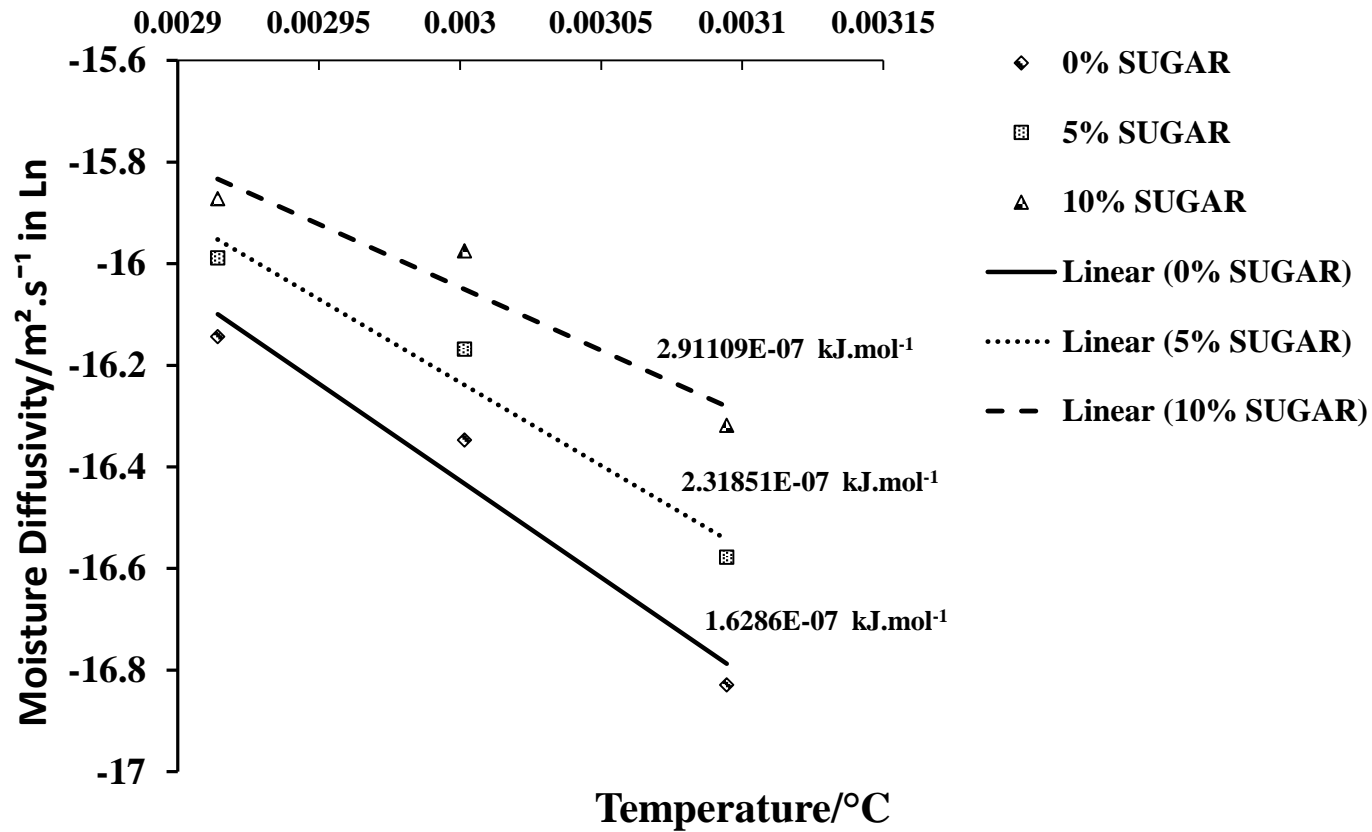


Figure 3.3.2: Arrhenius type relationship between logarithmic moisture diffusivity and absolute temperature of marula pulp dried at 50, 60 and 70 °C with added sugar contents of 0, 5, and 10% w/w.



### **3.3.3 Marula fruit leather drying kinetics**

Figure 3.3.3.1 (a, b and c) shows changes in drying rate as a function of moisture ratio while Figure 3.3.3.1 (d, e and f) show changes in moisture ratio with respect to time. Drying rate curves are of paramount important since they help explain the moisture transfer processes in order to better substantiate the drying process (Sacilik et al., 2006, Lee and Kim, 2009). They also determine exactly the total drying time required to reduce the products moisture content to a level that will not affect its quality (Hashemi et al., 2009).

It was observed that in all three independent repetitions of drying experiments, an increase in temperature results into a faster drying rate (Figure 3.3.3.1 a, b, and c). It was also observed that an increase in sugar concentration will result into prolonged drying time at low temperatures (Figure 3.3.3.1 d, e and f). The drying of marula fruit leather occurred in the falling rate period like most drying of agricultural material. In the falling rate period, this is where moisture migrates from the inside surfaces to the outside surfaces of the material by means of diffusion and the surface of the material is no longer saturated with water (Doymaz, 2005). Moreover, the drying rate in this period is controlled by diffusion of moisture from the inside to the outside of the material (Kashaninejad et al., 2007). As for the observations made in this study, the drying of marula fruit leather occurred in the falling rate period, which suggested that the material surface was no longer saturated with and the drying rate was controlled by internal diffusion phenomenon. Similar observation have been reported by Akpinar et al. (2003) in the dehydration of mango leathers and Kumar et al. (2012) during carrot pomace hot air thin layer drying.

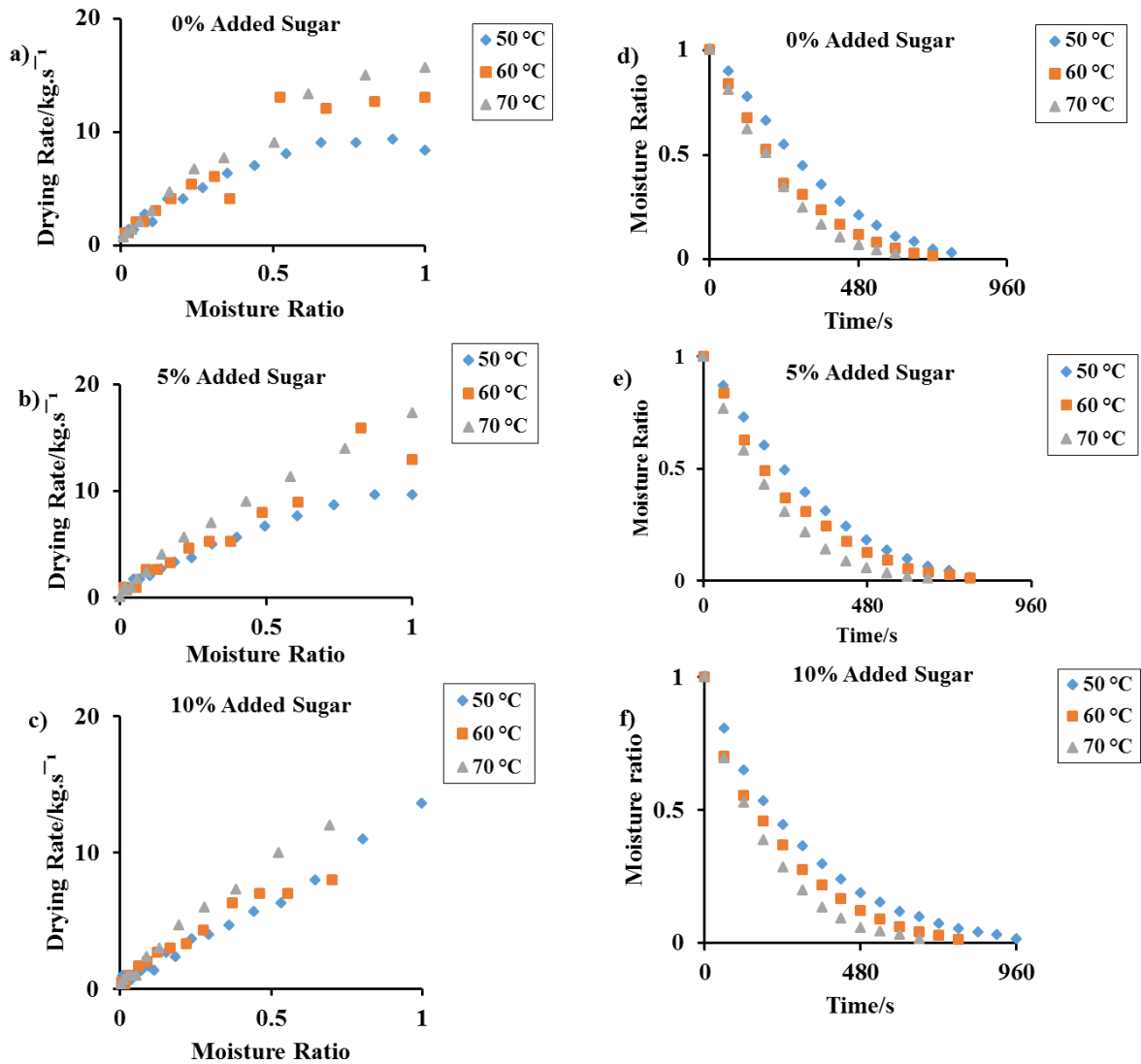


Figure 3.3.3.1: Effect of drying temperature and added sugar content on the drying rate (a, b & c) and moisture ratio (d, e & f) of marula fruit leather.

### 3.3.4 Mathematical modelling of the drying kinetics of marula fruit leather

In order to describe the drying kinetics of marula fruit leather it is essential to accurately model its drying behaviour. In this study, the experimental drying kinetics data was fitted in six commonly used drying models, shown in Table 3.2.6.1 above. The details of the statistical regression results of the six models, including the correlation coefficient ( $R^2$ ), Root Mean Square Error ( $RMSE$ ) and Chi-Squared ( $\chi^2$ ) are presented in Table 3.3.4.1 below.

The selection of the best model to describe the drying kinetics of marula fruit leather was based on the statistical coefficients ( $R^2$ ,  $RMSE$  and  $\chi^2$ ) and on the rate constant  $k$ . The  $k$  rate constant in this study was chosen as the concentration point in practically describing the drying process of marula fruit leather since it's commonly present in the six models used. In general, the best fitting of the experimental data will occur on the model with higher  $R^2$  value and lower  $RMSE$  and  $\chi^2$  values. Based on  $R^2$ ,  $RMSE$  and  $\chi^2$  (see Table 3.3.4.1 below) the assessment of the six models revealed that the Midilli-Kucuk model better fitted the experimental data and better explained the drying kinetics of marula fruit leather.

However, when closer observations were made and only concentrating on the models exponential rate constant ( $k$ ), it was observed that  $k$  on the Newton, Henderson and Pabis and Logarithmic models consistently showed sensitivity with both drying temperature and sugar concentration. For Page, Midilli-Kucuk and the Approximation of Diffusion models,  $k$  showed inconsistent variations in temperature and sugar concentration. It can be drawn from the results (Table 3.3.4.1) that Newton, Henderson and Pabis and Logarithmic models practically described the drying kinetics of marula fruit leather since the exponential rate constant  $k$  consistently increase with increasing temperature and with increasing sugar concentration. However, since the Logarithmic model showed high average  $R^2$ , and lower  $RMSE$  and  $\chi^2$  values of 0.99894, 0.01338 and 0.00261 when compared to Newton which had average  $R^2$  (0.99474),  $RMSE$  (0.02903) and  $\chi^2$  (0.01348) and Henderson and Pabis  $R^2$  (0.99595),  $RMSE$  (0.02579) and  $\chi^2$  (0.01034); it was then suggested that the Logarithmic model was the most satisfactorily to describe the thin layer drying kinetics of marula fruit leather both statistically and practically. The Logarithmic model has been reported as the best model to describe the drying kinetics of dried agricultural material such as apple pomace (Seiiedlou et al., 2010) and apricot (Mrad et al., 2012).

Table 3.3.4.1: Model coefficients and statistical parameter estimates for marula (*S. birrea*) at 50, 60 and 70 °C with different sugar levels (0, 5 and 10% w/w).

Model		0% Sugar			5% Sugar			10% Sugar		
		50° C	60° C	70° C	50° C	60° C	70° C	50° C	60° C	70° C
Newton	R <sup>2</sup>	0.985655	0.993781	0.992145	0.991871	0.997079	0.996735	0.999369	0.996849	0.999176
	RMSE	0.053556	0.034958	0.039976	0.039501	0.023281	0.025217	0.010179	0.022485	0.012105
	γ <sup>2</sup>	0.040158	0.015887	0.017579	0.021854	0.007588	0.007631	0.001761	0.007078	0.001758
	k	0.003028	0.004076	0.004629	0.003274	0.004078	0.005043	0.003505	0.004459	0.005511
Page	R <sup>2</sup>	0.999418	0.999094	0.998835	0.999437	0.999071	0.999577	0.999428	0.997584	0.999188
	RMSE	0.010824	0.013359	0.015422	0.010414	0.013140	0.009084	0.009698	0.019693	0.012015
	γ <sup>2</sup>	0.00164	0.00232	0.002616	0.001518	0.002417	0.00099	0.001599	0.005429	0.001732
	k	0.000328	0.001151	0.001084	0.000706	0.001967	0.002022	0.003117	0.006580	0.005221
	n	1.376163	1.222978	1.261886	1.262057	1.128077	1.166329	1.019983	0.931188	1.009966
Henderson & Pabis	R <sup>2</sup>	0.989685	0.995272	0.993502	0.99404	0.997757	0.997267	0.999369	0.997451	0.999186
	RMSE	0.045463	0.030493	0.036372	0.033849	0.020405	0.023074	0.010179	0.020226	0.012030
	γ <sup>2</sup>	0.028937	0.012088	0.014552	0.01604	0.005829	0.006389	0.001761	0.005727	0.001737
	a	1.076774	1.048584	1.044870	1.056536	1.033118	1.029319	1.000130	0.970215	0.996028
	k	0.003258	0.004264	0.004825	0.003456	0.004208	0.005181	0.003505	0.004326	0.005490
Logarithmic	R <sup>2</sup>	0.998519	0.998554	0.998393	0.999407	0.999177	0.999405	0.999812	0.997650	0.999507
	RMSE	0.017265	0.016874	0.018107	0.010690	0.012367	0.010776	0.005552	0.019421	0.009368
	γ <sup>2</sup>	0.004173	0.003702	0.003606	0.001591	0.002141	0.001393	0.000524	0.005280	0.001053
	a	1.298045	1.119224	1.150762	1.186365	1.069088	1.073686	1.016232	0.980906	1.009410
	k	0.002025	0.003412	0.003612	0.002468	0.003668	0.004419	0.003251	0.004109	0.005175
	c	-0.267164	-0.096011	-0.134374	-0.165567	-0.053156	-0.062310	-0.026506	-0.017284	-0.020385
Midili-Kucuk Model	R <sup>2</sup>	0.999922	0.999301	0.999223	0.999979	0.999323	0.999800	0.999911	0.999345	0.999598
	RMSE	0.003956	0.011735	0.012593	0.002005	0.011217	0.006233	0.003805	0.010256	0.008456
	γ <sup>2</sup>	0.000219	0.001790	0.001744	0.000056	0.001761	0.000466	0.000246	0.001473	0.000858
	a	0.995303	1.002073	0.994042	0.999110	1.007169	0.996157	0.998860	0.995885	0.996227
	k	0.004475	0.001497	0.001396	0.001080	0.002665	0.002408	0.004254	0.011643	0.006694
	n	1.298584	1.169507	1.204732	1.174945	1.068491	1.127476	0.956998	0.808644	0.954763
	b	-0.000058	-0.000034	-0.000054	-0.000061	-0.000033	-0.000031	-0.000037	-0.000097	-0.000045
Approximation Of Diffusion	R <sup>2</sup>	0.998673	0.999007	0.998573	0.999196	0.997079	0.999574	0.999501	0.996921	0.999253
	RMSE	0.016343	0.013989	0.017066	0.012445	0.023281	0.009112	0.009041	0.022226	0.011528
	γ <sup>2</sup>	0.003739	0.002544	0.003204	0.002168	0.007588	0.000996	0.00139	0.006916	0.001595
	a	1.908943	1.774004	1.797931	1.805977	0.998690	1.683938	1.361452	0.655179	1.330870
	k	0.004528	0.005617	0.006456	0.004615	0.004078	0.006587	0.003870	0.005206	0.005998

### **3.3.5 Colour properties of marula fruit leathers.**

Colour is one of the important quality attributes used in the food processing industries since it influences consumer's choice and preference (Pathare et al., 2013). It is also regarded as an indicator of heat treatment severity used to predict the corresponding deterioration of a product from heat exposure (Lozano and Ibarz, 1997). The effect of drying temperature and added sugar content on the chroma ( $C^*$ ), yellowness index (YI) and browning index (BI) of marula fruit pulp dried at 50, 60 and 70 °C, with added sugar contents of 0, 5, and 10% w/w are shown in Table 3.3.5.1 below.

Table 3.3.5.1: Effect of drying temperature and added sugar content on Chroma (C\*), the Yellowness Index (YI) and the Browning Index (BI) of marula pulp dried at 50, 60 and 70 °C, with added sugar contents of 0, 5, and 10% w/w.

Temperature (°C)	Sugar (%)	Chroma (C*)	Yellowness Index (YI)	Browning Index (BI)
50	0	26.79 ± 0.64 <sup>a</sup>	63.27 ± 1.41 <sup>a</sup>	232.22 ± 18.92 <sup>a</sup>
	5	27.04 ± 0.82 <sup>d</sup>	61.85 ± 2.32 <sup>d</sup>	54.92 ± 4.02 <sup>d</sup>
	10	26.03 ± 0.53 <sup>g</sup>	60.39 ± 0.81 <sup>g</sup>	-59.07 ± 6.14 <sup>g</sup>
60	0	28.74 ± 2.16 <sup>b</sup>	66.17 ± 2.65 <sup>b</sup>	472.15 ± 44.98 <sup>b</sup>
	5	28.75 ± 0.29 <sup>e</sup>	65.35 ± 0.78 <sup>e</sup>	117.32 ± 12.85 <sup>e</sup>
	10	28.34 ± 0.67 <sup>h</sup>	64.78 ± 1.91 <sup>h</sup>	52.78 ± 5.65 <sup>h</sup>
70	0	29.06 ± 0.50 <sup>c</sup>	68.09 ± 1.09 <sup>c</sup>	694.91 ± 29.37 <sup>c</sup>
	5	27.65 ± 0.53 <sup>f</sup>	65.28 ± 0.59 <sup>f</sup>	296.33 ± 35.66 <sup>f</sup>
	10	26.25 ± 0.08 <sup>i</sup>	60.96 ± 0.24 <sup>i</sup>	140.38 ± 12.92 <sup>i</sup>

Columns with the same letters are not significantly different ( $p \geq 0.05$ ). At least 10 measurements were taken on three independent samples

### 3.3.5.1 Chroma (C\*)

According to (Tijskens et al., 2001) changes in colour intensity of dried samples can be taken as a measure of browning formation, which is linked to increase in drying temperature (Alam, 2014). Chroma (C\*) deals with the qualitative attributes of colourfulness and is used to determine the degree of difference of hue in comparison to a grey colour with the same lightness (Tuyen et al., 2010). Higher Chroma values means higher colour intensity perceived by consumers (Guiné and Barroca, 2012). In addition, Chroma gives more indication about the spatial distribution of the amount of products saturated colour than the direct values of the tristimulus measurements (Sigge et al., 2001, Lin et al., 2004).

Depicted in Table 3.3.5.1 above are variations in Chroma ( $C^*$ ) of marula fruit leather as affected by drying temperature and sugar concentration. The results revealed slight increases in chroma as temperature increases and slight decreases in chroma as sugar is increased (Table 3.3.5.1).

The slight changes in chroma associated with temperature were as a result of increases in the yellowness. During spray drying of water melon powder, chroma values were reported to increase with increments in inlet temperature (145,155,165 and 175 °C) (Quek et al., 2007). It was suggested that this observation was due to colour transformation of the powders which became darker at higher temperatures. Moreover, it was mentioned that since watermelons are characterised with sugar, those sugars could have reacted and contributed to powder turning brown at higher temperatures. In another study, more colour intensity was observed by (Guiné and Barroca, 2012) during hot air drying of green peppers when temperature was increased from 30 °C to 70 °C. The possible explanation given was that this was caused by the breakdown of chlorophyll (with an intense blue-green colour) to pheophytin which has a brown colour and this was attributed to be as a result of heat treatment associated with colour loss. During apricot pistel preparation, chroma values were found higher during microwave drying even though the drying time was short and this was associated with high wavelengths of heat which resulted in the initiation of pigment loss and Maillard reaction (Suna et al., 2014).

The slight reductions in chroma associated with sugar concentration are as a result of pigment loss by drying temperature. During the drying of litchi fruits  $C^*$  values for fruits treated with 0.5% (Glycerol and Trehalose) and 0.3% (citric acid, malic acid and ascorbic acid) were reported to decrease compared to untreated samples (Mahayothee et al., 2009). This was attributed to pigmentation loss associated with Maillard browning reactions. In a pilot study, when 70% maltodextrin was added during the spray drying of strawberry puree (Abonyi et al., 2002) observed spray dried strawberry puree resembled decreasing  $c$  values and this was

attributed to less saturation of samples with maltodextrin and browning reaction occurrence. In another study by (Chun et al., 2012), dried blueberry samples were observed to resemble dark purple colour and reported a decrease in chroma values when different concentrations of 20, 50 and 80% maltodextrin were added. This observation was attributed to variations in the amount of anthocyanins that were released from the tissues of the fruits with the dehydrating agent during drying.

From these results it can be concluded that the variations in chroma values as affected by drying temperature and sugar concentration of marula fruit leather was associated with heat treatment, pigment degradation and non-enzymatic browning.

#### **3.3.5.2 Yellowness Index (YI)**

The Yellowness Index (YI) is associated with general factors of product degradation either by light, chemical exposure and processing. It measures and indicates the degree of yellowness of a certain product (Pathare et al., 2013). It has been reported that colour degradation is highly influence by the use of high temperatures during processing associated with long drying times (Abonyi et al., 2002, Suna et al., 2014). Also shown in Table 3.3.5.1 above are changes in the yellowness index of marula fruit leather as affected by drying temperature and sugar concentration. The results showed that the yellowness index of marula fruit leather increased with increasing drying temperature and decreased with increasing sugar concentration.

During the hot air drying of oyster mushrooms (Kotwaliwale et al., 2007) observed that the yellowness index of dried mushrooms increased as temperature increased. Their results were attributed to the sensitivity of mushrooms to temperature as the increments in temperature are likely to cause pigmentation. However, during hot air drying of kiwi fruit slices, yellowness index was found to decrease with increasing temperature and this was attributed to the decomposition of pigments and formation of brown pigments (Mohammadi et al., 2008).



Increases in yellowness of cashew apple juice were reported to increase with drying temperature and drying time and this was suggested to have occurred due to pigment transformation to brown colours as a result of increasing temperature (Damasceno et al., 2008). Colour change of grape juice was reported to show yellowness values increases during increments in temperature of concentrates and this was attributed to the destructions in pigmentation and the occurrence of Maillard reactions (Maskan et al., 2002a). Yellowness index of dried jumbo squids increase with increasing convective drying temperature (50-90 °C) and this was suggested to have been an indication of sample browning (Vega-Gálvez et al., 2011).

Similar findings were reported for mango fruit leather, where the addition of hydrocolloids lowered the yellowness of mango fruit leather and this was attributed to browning formation associated with non-enzymatic browning (Singh Gujral and Singh Brar, 2003). However, increasing pectin was reported to increase the yellowness of pineapple fruit leather (Phimpharian et al., 2011). Hot air dried strawberry fruits showed trends of decreasing yellowness after being treated with 2% ethyl oleate and this was attributed to decreasing carotenoids components during drying and browning reaction formation (Orak et al., 2012). During high pressure processing when strawberries were treated with 10% w/w sucrose, (Terefe et al., 2009) observed increases in the yellowness of fruits and possible explanation given was that this was due to pigment degradation which occurred processing at higher temperatures. The pigment degradation is as a result of using temperatures above 22 °C (Okilya et al., 2010, Patras et al., 2010, Khanal et al., 2010), is also as a result of the prolonged heat treatment (especially in our case for 5% and 10% w/w sugar added samples).

So, in the present study, it can be concluded that the changes in yellowness index of marula fruit leather as affected by drying temperature and sugar concentration was due to pigment loss and the occurrence of non-enzymatic browning. The yellowness reported in this study was also

different from those of other researches and the possible explanation for this could be that different additives will interact differently with different fruits and vice versa, due to different genetic make-up and their sensitiveness towards processing conditions.

### **3.3.5.3 Browning Index (BI)**

The browning index is a vital parameter indicating the occurrence and purity of browning in products containing sugar (Buera et al., 1986) and in quantifying the quality of dried fruits (Akoy, 2014). Moreover, evaluation of browning in dried products helps with the selection of appropriate drying technique so as to minimise the products quality in terms of colour (Pathare et al., 2013).

The changes of the browning index of marula fruit leather as affected by both drying temperature and sugar levels are depicted in Table 3.3.5.1. According to the results the browning index of marula fruit leather increased with an increase in temperature. On the other hand, the browning index of marula fruit leathers decreased with increasing sugar concentration at a specific temperature.

It has been stated that colour change during drying is mainly due to a number of many chemical and biochemical reactions which are affected by drying temperature and additive ingredients such as sugar, pectin, glucose and corn syrup, meltdextrin etc. (Man and Sin, 1997, Maskan et al., 2002b, Maskan et al., 2002a, Perera, 2005, Diamante et al., 2014). Thus, the formation of browning is a phenomenon likely to occur during the processing of any dried produce due to thermal effects of drying air (Cernîşev, 2010) and it prevails where processes of enzymatic and non-enzymatic reaction are taking place (Pathare et al., 2013, Cernîşev, 2010, Kotwaliwale et al., 2007).

Enzymatic browning results from an oxidation of phenolic compounds from the polyphenol oxidase to 0-quinones, which further polymerise to form dark pigmentation where as non-

enzymatic browning (Maillard reaction) results from the degradation of carbohydrate and amino acids associated with caramelisation (which occurs as a result of direct heating of carbohydrates such as sucrose and reducing sugars) (Perera, 2005, Pathare et al., 2013), enzymes denature reactions (Friedman, 1996) and ascorbic acid browning reactions (Vámos-Vigyázó and Haard, 1981, Tomás-Barberán and Espin, 2001, Perera and Baldwin, 2001, Perera, 2005). Maillard browning and caramelisation are most prominent at higher temperatures ( $>100\text{ }^{\circ}\text{C}$ ) (Vega-Gálvez et al., 2009, Damasceno et al., 2008). Therefore, in the present study, the reaction rates of these two reactions could have been very low because the marula pulp was dried between  $50\text{-}70\text{ }^{\circ}\text{C}$ .

Previous researchers have also demonstrated the occurrence of browning associated with heat treatment. For instance, hot air dried pepper was reported to reflect browning pigments due to increased temperature and this was attributed to the increase in kinetic reaction rate which showed higher values of non-enzymatic browning (Vega-Gálvez et al., 2009). During the drying of mango slices, Akoy (2014) reported the formation of browning in mango slices was due to a decrease in  $L^*$  values, which was attributed to high heat temperatures and prolonged drying times. In another study, where orange pulp and peels were hot-air dried (at  $30\text{ }^{\circ}\text{C}$  to  $90\text{ }^{\circ}\text{C}$ ), Garau et al. (2007) reported orange pulp dried at  $30\text{ }^{\circ}\text{C}$  had the highest browning formation as compared to pulp dried at  $70\text{-}90\text{ }^{\circ}\text{C}$  and attributed this observation to prolonged drying time associated at the lower temperatures. In a comparison study of cabinet (at  $65\text{ }^{\circ}\text{C}$  for 6 hours) vs. solar ( $36.7\text{ }^{\circ}\text{C}$  for 3 days) and convective oven (at  $50\text{ }^{\circ}\text{C}$  for 18 hours) dried jackfruit leathers, Okilya et al. (2010) reported that all fruit leathers changed from yellow-orange and turned brown during solar and oven drying. It was suggested that this was probably due to longer drying times that the fruit leathers underwent under those heat treatments. The change in yellow-orange colour to brown was suggested to occur because the temperature used was above  $22\text{ }^{\circ}\text{C}$  (Krokida et al., 1998, Okilya et al., 2010).

According to Friedman (1996), Rahman and Perera (2007) and Cernîşev (2010), the browning of fruit products could also result from non-enzymatic reactions of vitamin C oxidation of polyphenols. In the present research, naturally marula fruit pulp is yellow in colour and high in vitamin C content which is three times than that found in oranges (Mdluli, 2005, Dlamini and Dube, 2008). The fruits pulp is also characterised by high content of polyphenolics including flavonoids and condensed tannins (Mdluli, 2005, Borochoy-Neori et al., 2008, Mdluli and Owusu-Apenten, 2003) . So the formation of browning which resulted in these fruit leathers, was probably both due to enzymatic browning of polyphenols present in the fruits pulp and non-enzymatic browning of vitamin C oxidation and pigment degradation contributed in the formation of browning. However, since sodium metabisulphite was used in the preparation of the pulp, enzymatic browning was not expected. The oxidation of ascorbic acid (vitamin C) was reported to contribute in the formation of non-enzymatic browning of processed food products by López et al. (2010) during hot air drying of blueberries and Cernîşev (2010) for tomato drying. Thus, in the present research, it could be suggested that the browning was non-enzymatic, and it resulted from the oxidation of the polyphenols by the vitamin C that maybe present in high levels in the pulp.

Heat treatment can also result into sugar being caramelised to produce brown pigments during drying of products (Perera, 2005, Pathare et al., 2013). However, sugar and other additives such as pectin, glucose syrups, etc. are reported to minimise browning during drying of fruits (Perera, 2005, Diamante et al., 2014). Minimised browning was reported by Krokida et al. (2001) during drying of apple and banana slices after they have being sugar infused. In another study, Ruiz et al. (2012) reported reduced browning index for apple leather treated with sugar and citric acid as compared to the untreated leathers. During hot air drying of litchi, Mahayothee et al. (2009) reported that the addition of 0.5% Trehalose and 0.5% Glycerol reduced browning of the dried product. This again shows that adding or introducing additives

during drying of produce will minimise browning (Figure 3.3.5.3.1 below). In the present study, the added sugar is a non-reducing sugar (sucrose), it would not be expected to react with the amino acids through the Maillard browning. The sugar therefore probably reduces the browning by inhibiting the vitamin C catalysed oxidation of the polyphenols to brown pigments.

So the formation of browning which resulted in these fruit leathers, was probably both due to enzymatic browning of polyphenols present in the fruits pulp and non-enzymatic browning of vitamin C oxidation and pigment degradation contributed in the formation of browning. However, since sodium metabisulphite was used in the preparation of the pulp, enzymatic browning was not expected. The oxidation of ascorbic acid (vitamin C) was reported to contribute in the formation of non-enzymatic browning of processed food products by López et al. (2010) during hot air drying of blueberries and Cernișev (2010) for tomato drying.

The results from the verification of the occurrence of non-enzymatic browning through extraction from the leathers dried at 50 °C, with 0, 5 and 10% w/w sugar are shown in Figure 3.3.5.3.1 below. The non-enzymatic browning index decreased with increasing sugar content. Thus, in the present research, it could be concluded that the browning was due to non-enzymatic browning and that probably resulted from the oxidation of the polyphenols by the vitamin C.

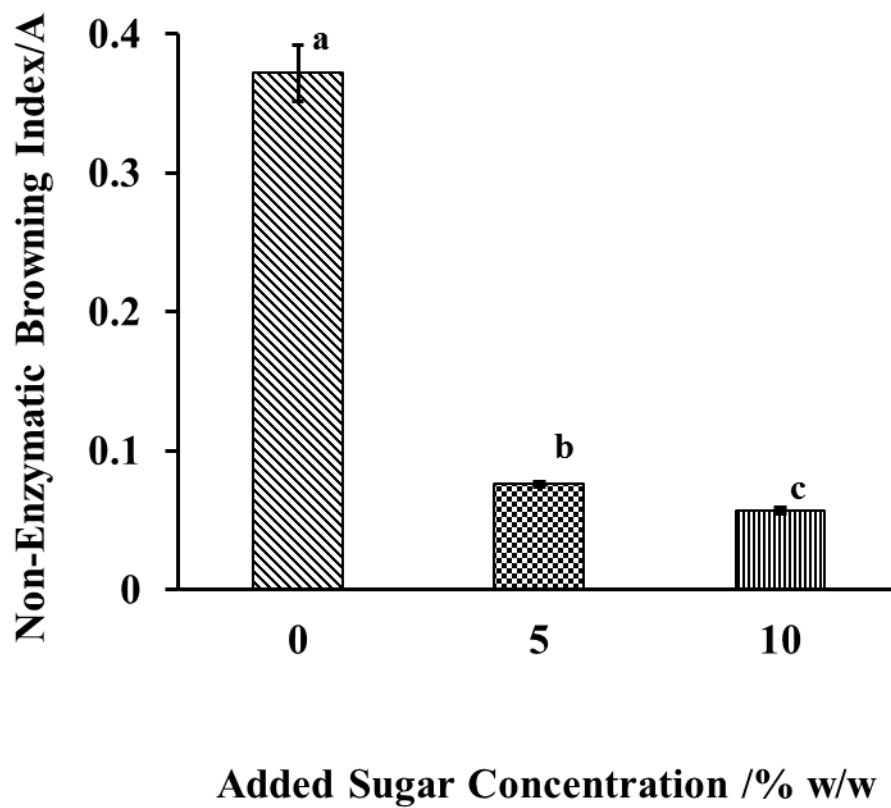


Figure 3.3.5.3.1: Effect of added sugar concentration of the non-enzymatic browning index of marula fruit leathers dried at 50 °C, with 0, 5 and 10%. At least three replications were done. Error bars are standard deviations of means. Non-enzymatic browning index unit A is absorbance.

### **3.4 Conclusion**

This study has demonstrated feasibility of producing hot-air dried marula fruit leather. The drying temperature and sugar concentration resulted in significant effects on the drying kinetics and colour attributes of marula fruit leather. The effective moisture diffusivity increased with temperature and sugar concentration and the temperature dependence of the effective moisture diffusivity was described by Arrhenius-type equation.

The activation energy was also observed to increase with sugar concentration while the drying behaviour of marula fruit leather was observed to occur in the falling rate period. Among the mathematical models used, the Logarithmic model best practically described the drying kinetics of marula fruit leather. Thus, this model can be applied to simulate the moisture and mass transfer during marula fruit leather drying in order to archive a final added-value product which can be an input to other products preparations.

The colour attributes (Chroma, Yellowness Index and the Browning Index) evaluated for the marula fruit leather were significantly affected by drying temperature and sugar concentration. The occurrence of colour changes in this study was attributed to non-enzymatic browning and vitamin C oxidation. The knowledge generated on the drying kinetics of marula fruit leather in this study can be used for effective drying control in the food processing industries. The determination of colour properties would be used as a pointer to the quality indices for marula fruits leather.

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## **Chapter 4: Effect of Drying Temperature and Sugar Concentration on the Texture Attributes and Consumer Acceptability of Marula (*Sclerocarya birrea*) Fruit Leather**

### **Abstract**

Marula fruit leathers were prepared by drying a mixture of marula pulp with different sugar concentrations (0, 5 & 10%) at 50, 60 & 70 °C drying temperatures. The effects of drying temperature and sugar concentration on instrumental texture properties and consumer sensory evaluation were investigated. The variations in both drying temperature and sugar concentrations significantly affected marula fruit leather textural properties (hardness, chewiness and tensile strength) and consumers overall acceptability and willingness to buy. Generally, increasing temperature increased hardness, chewiness and tensile strength of the fruit leathers. The addition of sugar increased hardness, chewiness and tensile strength of samples with 0, 5 and 10%. (at 50 and 60 °C), however at 70 °C, the hardness, chewiness and tensile strength of 10% w/w sugar treated samples decreased. The most acceptable marula fruit leathers by consumers were those prepared at 50 °C with 10% w/w sugar. The addition of sugar also induced the willingness to buy the fruit leathers. The Spearman's rank Correlation indicated that temperature negatively correlated with all the sensory attributes, while sugar positively correlated with the sensory attributes of the fruit leathers. The consumer liking of marula fruit leather could be induced by decreasing temperature and increasing the addition of sugar.

**Keywords:** Product Quality, Drying, Liking Perception, Spearman's Correlation.

## **4.1 Introduction**

Fruit leathers are made by dehydrating very thin layer of fruits' puree/pulp mixed with other ingredients or additives to produce cohesively dried leather sheets with different degrees of integrated textural and sensory properties (Vijayanand et al., 2000, Huang and Hsieh, 2005, Vatthanakul et al., 2010, Phimpharian et al., 2011). Fruit leathers are considered healthy food snacks with a greater nutritional value than the fresh fruits since all nutrients are concentrated in one dried form (Orrego et al., 2014).

Like any other processing technique, when drying, various biochemical reactions take place (Niamnuy et al., 2014), and these result into desirable or undesirable changes in texture and sensory attributes (Gujral and Khanna, 2002) and also alter with the microstructural system of the final product (Niamnuy et al., 2014). In many fruit leather production, texture and sensory properties are important features to study the impacts of processing conditions and to evaluate products quality (Alpaslan and Hayta, 2002). No research has been conducted on the textural properties and consumer acceptability of marula fruit leather. In the context of new product development process, such as that of marula fruit leather, evaluating textural properties provides a systematic approach to ensure that new products properties matches with the characteristics of the already existing products of similar nature (Al-Hinai et al., 2013). In addition, performing textural analysis indicates how studied treatments influenced the obtained quality textural attributes of the end product (Singh Gujral and Singh Brar, 2003). Sensory evaluation analysis during product development are also meant to voice out consumers preferences, satisfactions and overall liking acceptances on the products' quality to better improve the manufacturing process (de Wijk et al., 2003, Vatthanakul et al., 2010).

The main objective of this study was to evaluate the effects of different drying temperature and sugar concentrations on the textural and sensory quality attributes of the developed indigenous marula fruit leather. This type of evaluation prior to introducing the product to the market is of

paramount importance since this way can help in defining and improving products' quality with respect to consumers' expectations. The results of this part of the research could be utilised as a baseline for better quality control during the processing of marula fruit leather. Moreover, these results could give guidance to processing industries interested in the production of marula fruit leather or any other indigenous fruit leather.

## **4.2 Materials and Methods**

### **4.2.1 Fruit Materials**

Marula (*S. birrea*) fruits were obtained and hand-picked from Freidemhein, one of the Agricultural Research Council farms in Nelspruit, South Africa. The fruits were sorted according to their ripeness and stored at 10 °C. Total Soluble Solids (TSS, in Brix %) was measured using a digital refractometer (PAL-3 Digital Brix Refractometer, Atago Co. Ltd, China, with an accuracy range 0-93%). The determined TSS average was  $3.1\pm 0.1$ . The Total Titratable Acidity (TTA) was determined by titration with Sodium hydroxide solution (0.1562N) and measured average was  $25.1\pm 0.2$ . The pH value measured using a microprocessor pH meter (Mettler Toledo, Microsep (Pty) Ltd, SA), with an accuracy range 0.0-14.0) was  $3.1\pm 0.1$ . The initial moisture content of the samples (99.8% wet basis) was determined by employing the method of Association of Official Analytical Chemists (AOAC, 1984), using an analytical moisture balance analyser (Mettler Toledo, Microsep (Pty) Ltd, SA). All chemicals used were of analytical grade and were obtained from Merck (Johannesburg, South Africa).

#### **4.2.2 Fruit Leather Sample Preparation**

Fully ripe marula fruits were sorted, washed, and pulped using a pulping machine. A total of nine kg marula fruit pulp was measured using a weighing scale (CFW-150, Adam Equipment Co Ltd, Dunbury, USA, min 0.01 kg). To prevent browning, 4 ppm of Sodium Metabisulphite was mixed with the fruits' pulp. Sugar was also used as a flavourant. A one kg marula pulp was measured (CFW-150, Adam Equipment Co Ltd, Dunbury, USA, min 0.01 kg) and mixed with 0, 5 and 10% w/w sugar concentration and each was replicated three times. Stainless steel trays (300 mm x 440 mm) were layered with light density polyethylene plastics to create easy removal of samples after drying. A one kg of marula fruit pulp was spread evenly using a stainless steel spoon. The trays with fruit pulp were inserted in a drying trolley carrier then loaded into the drying chamber.

#### **4.2.3 Marula Fruit Leather Preparation: The Drying Procedure**

The drying experiments were carried out in a commercial scale forced convection dryer (AD3000 Agri-Dryer, Dryers for Africa, Limestone Hill, SA). Where, the relative humidity (RH %) and speed (m/s) were kept constant at  $15\pm 2\%$  and 0.3 m/s, respectively. In order to validate the drying conditions inside the dryer, the relative humidity and air temperature were also recorded using a data logger (Hobo U23 Pro v2, Onset Computer Cooperation, Bourne, USA). The drying runs were conducted at temperatures of 50, 60 and 70°C. For each temperature three independent triplicates for each sugar treatment during drying were done. The fruit pulp weight/ or moisture loss, determined by the AOAC (1996) method, was measured at a one-hour interval during the drying process. The fruit samples were dried up until there was a  $\geq 1\%$  change in consecutive measurement readings. The marula fruit leather were obtained and were immediately packed in high density polyethylene bags, heat sealed to prevent further moisture loss, and stored at 5 °C for further analysis.

#### **4.2.4 Marula fruit leather textural attributes**

The textural attributes were determined based on two analyses 1) Texture Analysis Profile (TPA) where, hardness and chewiness were assessed and 2) Tensile test, where tensile strength was determined. TPA and tensile tests of fruit leathers were performed using a Texture Analyzer (TAXT2, Stable Micro Systems Ltd, Godalming, Surrey, United Kingdom). Texture Expert<sup>®</sup> software supplied with the equipment was used for extracting the texture parameters from the data recorded. Before tests were performed, the packed fruit leathers were taken out from the refrigerator (5 °C) and equilibrated at standard room temperature (25 °C) for about 20 minutes.

#### **4.2.5 Texture Analysis Profile (TPA)**

The marula fruit leather samples were cut into square shapes of 3 × 3 cm (length × width). At least twenty replicates for each sample of fruit leather were done. Each sample was placed at the centre of the TPA instrument platform, with a P/75 (75 mm diameter) aluminium compression cylinder plate. The texture profile analysis involved compressing each sample twice and it resulted into compression-decompression cycles which provided force-time graphs as shown in Figure 4.2.5.1. The TPA measurements were based on the following settings: Preferred Speed (1.00 m/s); Test Speed (5 mm/s); Pre-test Speed (1 mm/s); Post-test Speed (5.0 mm/s); Target mode (Strain); Strain percentage (30%); Time (0.5 seconds); Trigger Force (5.0g); Tare mode (Auto). The test configuration settings were as follows: Sample shape (Rectangle); Sample width (30 mm); Sample length (30 mm); Strain height (1.5-2.3 range); Temperature 1 and 2 (20 °C) and relative humidity (RH) was kept at 50%. The thickness was measured for each individual replicate using a digital Vernier calliper (3-Point digital vernier calliper, Gulaqi, China). Hardness, chewiness and gumminess were extracted from the compression-decompression cycles according to Szczesniak (1987), as/and determined using



the equations 4.2.5.1 & 4.2.5.2, (based on Figure 4.2.5.1 below): Force required to attain a given deformation:

$$\text{Hardness} = P_1 \quad (4.2.5.1)$$

$$\text{Chewiness} = P_1 \times \frac{C_1 \cdot C_2}{B_1 \cdot B_2} \times \frac{X}{Y} \quad (4.2.5.2)$$

According to Szczesniak (1987), the parameter gumminess only applies to semi-solid products and is mutually exclusive with chewiness since a certain product cannot be both semi-solid and solid at the same time. Hence, the study based TPA analyses of samples on hardness and chewiness.

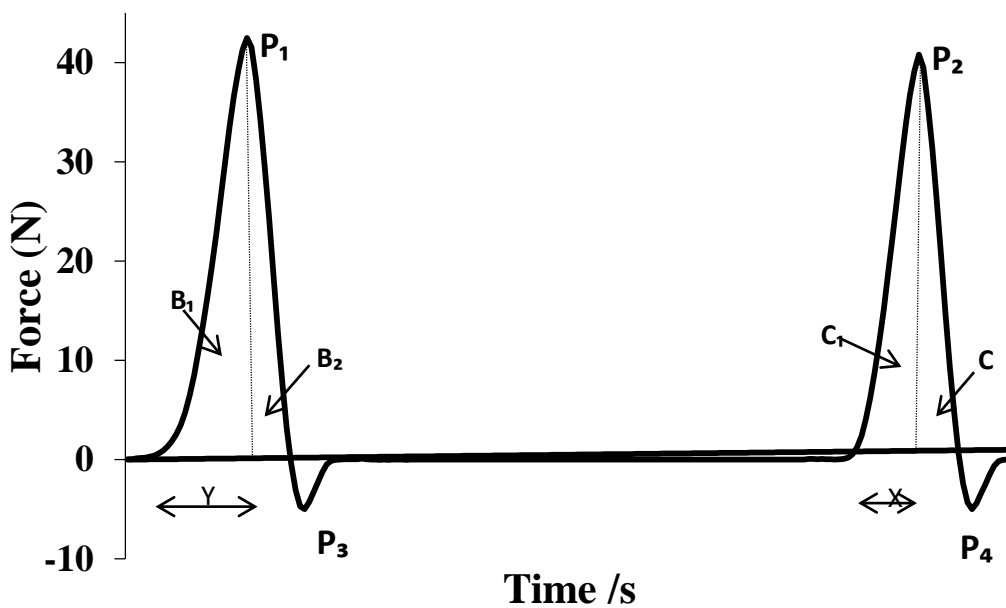


Figure 4.2.5.1: A typical instrumental TPA compression-decompression cycles of force (N) against time (s) for marula fruit leather taken from Texture Expert ® software output of the study. Where: P<sub>1</sub>: Peak force of the first compression; P<sub>2</sub>: Peak force of the second compression; P<sub>3</sub>: Peak force of the first decompression; P<sub>4</sub>: Peak force of the second decompression; X: Distance from the start of second peak to its peak; Y: Distance from the start of first

compression; B<sub>1</sub>-B<sub>2</sub>: Network of the first cycle; C<sub>1</sub>-C<sub>2</sub>: Network of the second cycle). Adapted from: Singh et al. (2013).

#### **4.2.6 Tensile test**

After equilibration at room temperature, the samples were cut into uniform strips of approximately 1.0 x 8.0cm and replicated twenty times. A tension probe, which clamped the sample on upper and bottom sides, was used to stretch each sample. The tensile test settings were based on the following specific conditions: Test speed (0.5 m/s); Test mode (tension); Distance (20 mm); Height (40 mm); Total sample height (80 mm). The Trigger type was set on Auto force; Trigger force (30 g); Break sensitivity (1000 g); Break detect (return); Tare mode (auto). The tensile strength of the marula fruits was determined from the resultant force-time curves.

#### **4.2.7 Consumer Sensory Evaluation of Marula Fruit Leathers**

According to Moskowitz (1997) and Gacula and Rutenbeck (2006), about 40-100 panellists for a sensory evaluation are sufficient to provide reliable results that could be used to draw differences in the sensory qualities and overall liking of a given product. A 9-point hedonic scale is used as a measuring tool. The dried marula fruit leathers were thus evaluated using 60 untrained panellists. Students used for the evaluation were recruited from the University of Mpumalanga and Ehlanzeni FET College in Mpumalanga Province, Nelspruit, South Africa.

The panellists were briefly introduced to consumer sensory evaluation testing. The marula fruit leather samples (3 x 3cm) were evaluated for colour, texture (i.e. hardness and chewiness), taste, flavour and overall acceptability using a 9-point hedonic scale (please see index). The samples were rated as: 1-Dislike extremely, 2-Dislike very much, 3-Dislike moderately; 4-Dislike slightly, 5-Neither like/dislike, 6-Like slight, 7-Like slightly, 8-Like very much and 9-Like extremely (Peryam and Pilgrim, 1957, Lawless and Heymann, 1999, Lawless and

Heymann, 2010). The panellists were distributed with three random digit coded samples. Three samples were served for tasting in a randomised order.

Before and in between the tasting, the panellists were instructed to eat a carrot in order to minimise any residual effects between samples tasted and to cleanse their palates. The panellists were also asked to evaluate and rank each of the samples according to their willingness to buy (1: Yes and 2: No), that is, whether they would buy a particular sample tasted for their consumption if they came across in the market (Hough et al., 2003). The sensory tests were done in a well aerated, temperature controlled ( $25 \pm 2$  °C) hall, illuminated with natural light and with minimised interaction between panellists.

#### **4.2.8 Statistical Data Analysis**

The data obtained from the sensory evaluation was analysed utilising a one-way factorial analysis of variance (ANOVA) using SPSS version 23 (Institute Inc., Cary, N.C) statistical software. The differences among the mean values of attributes were determined by the Duncan's multiple range tests with a 95% confident interval. Correlation between the sensory attributes was also assessed based on Spearman's rank correlation.

### **4.3 Results and Discussion**

#### **4.3.1 Texture profile analysis (TPA) properties of marula fruit leathers**

Shown in Table 4.3.1.1 are results of the effect of drying temperature and sugar concentration on the textural attributes of marula fruit leathers.

Table 4.3.1.1: Effect of drying temperature and added sugar concentration on the textural parameters of marula pulp dried at 50, 60 and 70 °C, with added sugar contents of 0, 5, and 10% w/w.

Drying Temperature (°C)	Sugar Concentration (%)	Hardness (g)	Chewiness	Tensile strength
50	0	2674.8 ± 350.4 <sup>a</sup>	1337.5 ± 155.6 <sup>a</sup>	1337.5 ± 155.6 <sup>a</sup>
	5	5148.9 ± 522.4 <sup>d</sup>	2507.4 ± 247.4 <sup>d</sup>	2507.4 ± 247.4 <sup>d</sup>
	10	6247.9 ± 726.3 <sup>g</sup>	3189.1 ± 561.7 <sup>g</sup>	3189.1 ± 561.7 <sup>g</sup>
60	0	4914.4 ± 751.7 <sup>b</sup>	2211.1 ± 175.8 <sup>b</sup>	2211.1 ± 175.8 <sup>b</sup>
	5	6123.1 ± 989.5 <sup>e</sup>	3958.9 ± 508.2 <sup>e</sup>	3958.9 ± 508.2 <sup>e</sup>
	10	7030.2 ± 1264.9 <sup>h</sup>	4266.4 ± 419.8 <sup>h</sup>	4266.4 ± 419.8 <sup>h</sup>
70	0	6107.9 ± 910.9 <sup>c</sup>	2900.3 ± 777.3 <sup>c</sup>	2900.3 ± 777.3 <sup>c</sup>
	5	7326.8 ± 356.9 <sup>f</sup>	4395.4 ± 669.2 <sup>f</sup>	4395.4 ± 669.2 <sup>f</sup>
	10	7137.1 ± 1186.6 <sup>i</sup>	3610.0 ± 467.8 <sup>i</sup>	3610.1 ± 467.8 <sup>i</sup>

Values with same letter in each column are not significantly ( $p \leq 0.05$ ) different. At least twenty tests were done for each measurement. Values with means are standard deviation.

The Texture Profile Analysis (TPA) was used to evaluate the texture of marula fruit leather products because it imitate the repeated biting or chewing of the samples (Szczesniak, 2002). The instrumental analysis of texture provides an indication of products textural characteristics (Anton and Luciano, 2007). TPA has been used to determine different arrays on the texture attributes of fruit leathers (Al-Hinai et al., 2013). Amongst many, it gives impressions of hardness and chewiness of products in a dried state (Argyropoulos et al., 2011).

According to Abdel (2012) texture is measured objectively and expressed as a function of mass, time and distance. It has been stated that, during the processing of dried fruits, in this case fruit leathers, texture of the final product can be affected by several factors such as the remaining moisture content after drying, drying temperature and time the product underwent under processing conditions (Azeredo et al., 2006) and also can be affected by nature of different additives introduced during the preparation process (Irwandi and Che Man, 1996, Vijayanand et al., 2000, Gujral and Khanna, 2002). Moreover, the process of drying may lead to some undesirable textural changes of the final product and these changes are mainly influenced by various physiological events related to biochemical constituents, water content, tissue and cell wall components among other factors (Ramos et al., 2003, Guiné and Barroca, 2011).

Hardness is one of the texture parameters utilised to determine case hardening in dried fruits (Chong et al., 2008) . It is regarded as a force required to compress the food product between the molar teeth, tongue and palate (Ansari et al., 2014). Chewiness is defined as the length of time required to masticate the food sample under the application of constant rate of force in order to reduce it to a manner suitable for swallowing (Vatthanakul et al., 2010). Chewiness of dried fruits is a major consideration when it comes to consumers as it affects the oral cavity mouth feel (Szczeniak, 2002).

The TPA derived hardness and chewiness of marula fruit leathers were significantly ( $p \leq 0.05$ ) affected by drying temperature and sugar concentration and are shown in Table 4.3.1.1. From the results, hardness and chewiness of fruit leathers were significantly ( $p \leq 0.05$ ) affected by both drying temperature and added sugar concentration. The attributes significantly ( $p \leq 0.05$ ) increased increase with sugar concentration and temperature for samples dried at 50 °C. However, at 70 °C, the increase with sugar concentration occurred only from 0 to 5%, and then decreased thereafter at 10%.

The variations in drying processes affect the mechanical, nutritional and sensory qualities of the dried product (Bonazzi and Dumoulin, 2011). Moreover, these quality changings are time and drying temperature related and both will affect various reaction rates dependent on the water activity of the dried product (Bonazzi and Dumoulin, 2011). Increase in hardness during drying of various fruit leathers has been reported to be associated with lower moisture contents depending on the drying temperature and drying time (Irwandi et al., 1998, Vijayanand et al., 2000, Gujral and Khanna, 2002).

Hardness and chewiness of oyster mushrooms were reported to increase with increasing temperature (Kotwaliwale et al., 2007). The increase in hardness was suggested to have occurred as a result of rapid moisture removal during drying which might have caused a collapse of capillary voids inside the product, whereas the increase in chewiness was attributed to the fact that chewiness is a function of hardness, hence increased. During red pepper drying, hardness was observed to increase with increasing temperature, and this was attributed to changes in plant cell wall that might have occurred during processing (Vega-Gálvez et al., 2008). Chong et al. (2008) hot air dried chempedak (at 50, 60 and 70 °C) and reported hardness of dried product to increase with increasing temperature. In the same study, chewiness was also observed to increase with increasing temperature. The increase in both these attribute was therefore associated with long drying durations under processing conditions. Hardness of African wild medlar (dried at 60 and 80 °C) increased with increasing drying temperature and drying time Chiau et al. (2013), and this was suggested to be a result of reduced water content at higher drying temperatures. Although these cases demonstrated similar changes in hardness to those in the present study, they dealt with whole/non-pulped fruit components.

Hardness and chewiness of Grape molasses treated with starch concentrations (5, 7.5 and 10%) dried at (60, 70 and 80 °C) were reported to increase with increasing drying temperature (Goksel et al., 2013). This system was similar to the one in the present study due to the semi-

solid nature of molasses. The hardness and chewiness in that study were attributed to have occurred from moisture migration from the samples as temperature increased. As for the result obtained in this study, since the marula fruit were pulped it means that there were no capillary voids present. Therefore, in the present study, the variations in hardness and consequently, the chewiness of marula fruit leather were probably due to the loss of moisture related to increase in temperature (more energy to evaporate the water and facilitate diffusion within the samples). Similar research findings have also shown that added hydrocolloids lead to increase in hardness and chewiness during drying of fruit leather (Vijayanand et al., 2000, Gujral and Khanna, 2002, Huang and Hsieh, 2005, Vatthanakul et al., 2010, Al-Hinai et al., 2013). In pineapple fruit leathers, hardness was reported to increase with increasing pectin concentrations (from 0.5, 1.0 and 1.5%) and it was suggested that this was due to pectin producing a firm gel structures resulting to tough textured products (Phimpharian et al., 2011). African medlar was also reported to exhibit increments in hardness for samples treated with sucrose and maltodextrin i.e. hardness increased from 1N to 3N when sucrose was added and from 1N to 9N when maltodextrin was added (Chiau et al., 2013). The possible explanation given was that this may have resulted from an incomplete solubilisation of sucrose and maltodextrin particles with the pulp and this heterogeneity behaviour contributed to harder dried products.

During drying of pear fruit leather, Huang and Hsieh (2005) reported that higher pectin concentrations resulted into higher hardness and higher chewiness of final product. The possible explanation given was that pectin molecules formed hydrogen bonding with each other and formed cross-links which may have enhanced the fruit leathers ability to resist deformations from the texture analyser probe and this may have rendered the samples to result into higher hardness and chewiness. Similar observation and explanation for hardness and chewiness was reported by Al-Hinai et al. (2013) during the development of date-tamarind fruit leather treated with pectin and other different hydrocolloids (i.e. starch, maltodextrin, and

guar gum). They observed that, following pectin, the addition of starch concentrations resulted into higher values of hardness and chewiness of date-tamarind leather and this was attributed to gel formation resulting from gelatinized starch content.

Hardness and chewiness were also reported by Goksel et al. (2013) to increase with starch concentration, and it was suggested that the increase in starch concentration mainly results into harder gel firmness, which happens as a result of starch undergoing retrogradation (referring to changes occurring from gelatinized starch (Fredriksson et al., 1998, Gudmundsson, 1994)) and this gel firmness was mainly caused by starch gelatinization ( i.e. starch granules swelling to form gel particles (Fredriksson et al., 1998, Gudmundsson, 1994), amylose gelation and amylopectin crystallization. As for the findings in the present research that showed increase in hardness and chewiness, the observations probably resulted from a combination of the following factors to various extents: Formation of firm gel structures promoted by sugar interactions with other micro-molecules in the leather, hydrogen bonding of sugar with other micro-molecules in the leather due to the incomplete solubilisation of sugar due to moisture loss.

On the other hand, it has been reported that dried fruits containing higher levels of sugar would chemically bond more moisture compared to samples with no added sugar and as a result those fruits would have higher water activity, which probably will soften the product (Lemus-Mondaca et al., 2009). The findings of this study were similar to those that Diamante and Dong (2015) reported for gold kiwifruit leathers. They observed that the puncturing force/ or hardness of gold kiwifruit leather was lower at the middle (i.e. when 7.5% sugar) and lower at high (i.e. when 15% sugar) levels of sugar concentration regardless of the drying temperature. The possible explanation given was that this was due to the occurrence of the optimum interaction effects, which they referred to as a quadratic effect, between sugar and samples and temperature.



During pear fruit leather, Huang and Hsieh (2005) reported hardness and chewiness of pear fruit leather (at 70 °C) to decrease with increase in corn syrup level (0 and 8%) when compared with pectin and the possible explanation was that corn syrup has the ability to retain moisture, thus enhanced the products' softness and resulted in lower values of hardness and chewiness. Hardness of Apple-blackcurrant fruit leather treated with 20, 30 and 40% apple juice concentrations was observed to decrease with increasing apple juice concentration and it was suggested that higher levels of apple juice contributed in increasing the amounts of sugar in the fruit leather, which probably softened the product (Diamante et al., 2013). The decrease in hardness and chewiness of marula fruit leather at higher temperature (i.e. 70 °C) and sugar concentration (10% w/w sugar) can mean that the interaction of sugar and temperature was beyond the optimum, which probably leads to softer fruit leather.

The observations in the present study were in agreement with those reported by other researchers for other more conventional products. Changes in hardness and chewing of marula fruit leather were due to moisture removal from the fruit leather as temperature was increased. In addition, the increase in hardness and chewiness with addition of sugar probably resulted from hydrogen bonding of sugar molecules with each other and with other macro-molecules in the fruit leathers to form cross-linked network that enhanced the fruit leathers' ability to resist the deformations caused by the texture analyser probe, therefore resulting in higher values of hardness and chewiness obtained in the Texture Profile Analysis. As for the observed decrease in hardness and chewiness at 70 °C with 10% w/w sugar, this means that an optimum interaction effect between sugar and temperature on the water activity of the fruit leathers was reached, and that the addition of 10% w/w sugar was significant in resulting into a higher water activity (retaining moisture) and making the fruit leather softer and thus resulted into decrease hardness and chewiness.

### **4.3.2 Tensile Strength of Marula Fruit Leathers**

The tensile strength attribute is regarded as the maximum stress a food material is able to sustain without failure or before breaking (Anton and Luciano, 2007). It is a measure used to describe possible variations on the products' mechanical properties that occur during drying due to the products' chemical structures and to indicate dried products' quality (Bourne, 1980, Bourne, 2002, Mayor and Sereno, 2004). According to Waldron et al. (1997), factors that may influence materials' mechanical properties during the drying process include moisture composition, and cell adhesion and their mode of rupture among other factors.

The variations in the tensile strength as affected by drying temperature and sugar level are depicted in Table 4.3.1.1 above. The tensile strength of the fruit leathers increased with increasing drying temperature (Table 4.3.1.1 above). It also increased with increasing levels of sugar concentration; however, at 70 °C 10% w/w sugar, it decreased (see Table 4.3.1.1 above).

Similar observations were made by Krokida et al. (2000b) during the drying of several agricultural produce (apple, banana, carrot and potato). The authors observed that all the materials' stress failure increased with the drying process. This behaviour was said to be as a result of the crystallisation of the cellulose cell wall components at critical moisture content which resulted in to difficult failure of the materials. Osmo-convective dried apple and banana samples, infused in glucose solutions, were reported to resemble more resistance to rupture (i.e. higher values of stress failure) than the untreated samples (Krokida et al., 2000a). The possible explanation given to this was that it was due to the plasticization of the structure and reduction of elasticity caused by sugar uptake during osmotic pre-treatment by the samples.

The stress failure of pumpkin were reported to increase with increasing temperature (Mayor et al., 2007). This was attributed with the collapse and deformation of cell walls and decrease in turgor pressure in cells of the samples. As for the result of this research, the increase in tensile

strength of fruit leathers with temperature can be associated with moisture loss associated with high drying temperature and drying time with may have resulted in to a collapse of cell and tissue structures in the samples.

The tensile strength of gold kiwifruit leather was reported to increase with increasing pectin (i.e. 1, 2 and 3%) and increasing glucose syrup (i.e. 10, 15 and 20%) (Vatthanakul et al., 2010). This was attributed to the fact that pectin plays a role in providing the structural properties of in many foods, in particular fruits products. So the more pectin was added the higher the tensile strength and was suggested that the percentages of pectin and glucose syrup used were significant for retaining moisture in the fruit leather.

Mango leather that were cabinet dried and added with sucrose at levels of 0%, 4.5% and 9%, and it was observed (without explanation) that at concentrations of 4.5% and 9% the mango leathers showed a decrease in extensibility compared to the untreated (Gujral and Khanna, 2002). Chiralt et al. (2001), hot air dried kiwifruit and mango treated with sucrose solutions, and reported that failure stress decreased for treated samples compared to the untreated samples. The authors suggested that the occurrence of this behaviour might be due to the protectant effect (referred to as cryoprotectant effect) created by sucrose to the samples.

Mayor et al. (2007), also observed that at higher levels of sucrose solution (60% sucrose), pumpkin sample resembled more ability to resist failure (i.e. stress failure slightly decrease). This was suggested to be due to fibre compactions during drying. It was also suggested that this could have been an indicator of a prevailing cell- debonding mechanism during failure in dehydrated samples. The observed decrease in the tensile strength of marula fruit leather at 10%, 70 °C, can be associated to the optimum interaction of sugar and temperature which resulted into softer products, hence the tensile strength of fruit leathers decreased.

The observed increase in tensile strength of the fruit leathers with temperatures in this research was due to the moisture content loss linked with higher temperatures and drying time, collapse of cells and tissues of the samples. As for the decrease in tensile strength at 10% w/w sugar concentrations, this can mean an interaction between sugar and temperature had reached the optimum and that the 10% w/w addition of sugar was significant in resulting into softer products, which consequently decrease the stress failure of the dried samples.

#### **4.3.3 Marula Fruit Leather Consumer Sensory Acceptability Testing**

Sensory analysis such as consumer sensory evaluation is mainly used by food manufacturers, processors and industries to study the effects of ingredients and processing variables on the perceived sensory attributes of various food products (Sidel and Stone, 1993, Torres et al., 2015). It provides food manufacturers with proper understanding of the products' quality, direction for products improvement and a chance to better evaluated the products reformulations from a consumers view point (Lawless and Heymann, 2010).

Consumer sensory evaluation is thus a testing tool utilised to quantify the degree of liking or disliking of the product (Lawless and Heymann, 1999, Hein et al., 2008). The degree of products' acceptability is often evaluated by employing the hedonic scale, which is used to rate the products' sensory characteristics such as texture, flavour, colour and aroma (Prakash et al., 2004, Phimpfarian et al., 2011). This method of product evaluation is very effective in newly developed products, such as marula fruit leather, as it allows for the quantification of the products acceptance regarding its sensory quality attributes (Meilgaard et al., 1999, Besbes et al., 2009). As for the present research, marula fruit leather is a new developed natural product, therefore conducting a sensory test is of paramount importance as it will allow for the characterisation of the products sensory properties and help determined the consumers' preference that will drive the products acceptance and purchasing intent.

The effects of drying temperature and added sugar concentration on the sensory attributes of the marula fruit leathers are shown below in Table 4.3.3.1 and 4.3.3.2, respectively. The drying temperature and sugar concentration significantly affected ( $p \leq 0.05$ ) the marula leather sensory attributes; overall acceptability and the willingness to buy the fruit leathers (Table 4.3.3.1 and Table 4.3.3.2 below).

Table 4.3.3.1: Effect of Temperature on the Consumer Sensory Evaluation Parameters of Marula Fruit Leathers dried at 50, 60 and 70 °C.

Temperature/°C	Colour	Hardness	Chewiness	Taste	Flavour	Overall Acceptability	Willingness to Buy
50	6.22 (0.216) <sup>a</sup>	5.78 (0.216) <sup>a</sup>	5.89 (0.220) <sup>a</sup>	5.68 (0.235) <sup>a</sup>	6.69 (0.195) <sup>a</sup>	6.18 (0.199) <sup>a</sup>	1.65 (0.045) <sup>a</sup>
60	5.76 (0.230) <sup>ab</sup>	4.81 (0.239) <sup>b</sup>	5.03 (0.261) <sup>b</sup>	5.45 (0.266) <sup>a</sup>	5.85 (0.246) <sup>b</sup>	5.69 (0.252) <sup>b</sup>	1.51 (0.051) <sup>b</sup>
70	5.45 (0.283) <sup>b</sup>	4.80 (0.285) <sup>b</sup>	4.91 (0.297) <sup>b</sup>	5.25 (0.295) <sup>a</sup>	5.68 (0.283) <sup>b</sup>	5.73 (0.273) <sup>b</sup>	1.51 (0.051) <sup>b</sup>

Values in brackets are standard errors of means. Means with the same letter within the same column are not significantly different ( $p \geq 0.05$ )

Table 4.3.3.2: Effect of added sugar concentration (%) on the Consumer Sensory Evaluation Parameters of Marula Fruit Leathers with 0, 5, and 10% w/w added sugar.

Sugar %	Colour	Hardness	Chewiness	Taste	Flavour	Overall Acceptability	Willingness to buy
0	4.88 (0.273) <sup>b</sup>	3.62 (0.226) <sup>c</sup>	3.74 (0.236) <sup>c</sup>	4.15 (0.257) <sup>c</sup>	5.08 (0.258) <sup>c</sup>	4.45 (0.220) <sup>c</sup>	1.25 (0.044) <sup>a</sup>
5	6.04 (0.218) <sup>a</sup>	5.28 (0.229) <sup>b</sup>	5.55 (0.243) <sup>b</sup>	5.71 (0.242) <sup>b</sup>	6.19 (0.226) <sup>b</sup>	6.11 (0.216) <sup>b</sup>	1.65 (0.046) <sup>a</sup>
10	6.50 (0.216) <sup>a</sup>	6.48 (0.213) <sup>a</sup>	6.52 (0.228) <sup>a</sup>	6.46 (0.245) <sup>a</sup>	6.96 (0.213) <sup>a</sup>	6.97 (0.219) <sup>a</sup>	1.75 (0.042) <sup>a</sup>

Values in brackets are standard errors of means. Values with the same letter within the same column are not significantly different ( $p \geq 0.05$ ).

The mean sensory attribute, overall acceptability and willingness to buy scores, of the marula leather dried at 50 °C, were significantly ( $p \leq 0.05$ ) higher than those of the leathers processed at 60 and 70 °C. The willingness-to-buy and overall acceptability are aggregate parameters which summarize the sensory attribute scores of the samples. The panellists were willing to buy the samples dried at 50 °C more than those dried at 60 and 70 °C (Table 4.3.3.1). The marula fruit leathers dried at 50 °C were also significantly ( $p \leq 0.05$ ) more highly rated in terms of the sensory attributes (colour, hardness, chewiness, taste and flavour). These results indicated that 50 °C was the most suitable drying temperature for marula fruit leather.

According to Durance and Wang (2002), low drying air temperature conditions (50 °C) are efficient for food material preservation since they can significantly reduce nutritional, chemical composition and sensory attribute alterations of dried products. Hot air dried pomegranate arils dried at 50 °C, resulted into higher sensory attribute scores in terms of colour, aroma, sweetness and liking acceptability compared to 60 and 70 °C dried samples (Calín-Sánchez et al., 2013). This was attributed to proper stability of sugar and organic acids which were promoted or favoured by low drying conditions.

According to Fundira et al. (2002) marula pulp is characterised with high volatile composition which can directly affect its product sensory qualities, which in turn will influence perceptions towards its sensory attributes. Therefore, in the present research, the lower temperature (50 °C) probably led to higher sensory attribute scores through better preservation and/or stabilization of the sugars, organic acids and volatile components, compared to 60 and 70 °C.

The sensory attribute (colour, hardness, chewiness, taste and flavour) scores, significantly ( $p \leq 0.05$ ) increased as sugar concentration increased (Table 4.3.3.2). The marula fruit leathers

overall acceptability and willingness-to-buy scores also significantly ( $p \leq 0.05$ ) increased with sugar content (see Table 4.3.3.2).

The taste of fruit leathers is mostly contributed to the amount of sugar contained in the fresh pulp (Ashaye et al., 2005). Thus, increasing sugar amounts during preparation may either reduce or improve on the taste (sweetness and flavour) ratings of the end product, however, this may vary during processing and depends on the type of fruits used (Ashaye et al., 2005, Jain and Nema, 2007). According to Marsh et al. (2006), sugar that is added to pulps (kiwifruit and banana) induces the pulps perception by the testers and leads to better liking scores probably due increase of desirable interactions between sugar and other pulps components in the testers mouth. In the present research, the higher added sugar (10%) addition of sugar probably enhanced the flavours and this possible a more suitable interaction between sugars and other marula pulp components hence leading to a more desirable and balanced interaction in panellists mouth.

Increasing drying temperature conditions lowered the sensory acceptability of the fruit leathers with respect to colour, hardness, chewiness, taste, flavour and overall acceptability and willingness to buy the fruit leathers. Increasing the levels of sugar concentrations improved on the colour, hardness, chewiness, taste, flavour and overall acceptability and willingness of sensory panel to buy the fruit leathers. Marula fruit leathers containing 10% w/w sugar dried at 50 °C were found to be the most acceptable and most willingly to be bought by the sensory panel.



#### **4.3.4 Correlations between Sensory Evaluation Parameters and Treatments**

##### **(Temperature and Sugar Content)**

The Spearman's rank correlation coefficient is mostly used to assess the correlations using the ranking dependence between variables (Singh et al., 2013) . According to Szczesniak et al. (1963) and Huang and Hsieh (2005) finding a correlation between attributes is a convenient way of reducing cost, time and labour during the development of new products. In this study, Spearman's rank correlation coefficient was used to evaluate the relationships there exist between the sensory perception in order to identify the most important attributes that affect consumers' responses towards the marula fruit leathers.

The correlation between the attributes of the fruit leathers dried at different temperatures and sugar concentrations is shown in Table 4.3.4.1 below. Temperature was apparently (with low values) negatively correlated with all the attributes, while sugar positively correlated (with higher coefficients) with the attributes of the marula fruit leathers.

These observations probably were due to the effects explained above (see section on texture analysis above). The validity of the observations made in the present study was supported by the fact that age, gender and frequency of buying, that were potential underlying variables, had low and statistically insignificant ( $p \geq 0.05$ ) coefficients. The overall acceptability and willingness-to-buy were more correlated with mouth-feel (chewiness and hardness) and taste-flavour attributes, than with the colour (Table 4.3.4.1).

Added sugar positively correlated with all the sensory attributes tested by the panellists in addition to the overall acceptability and the willingness-to-buy. These results imply that sugar probably plays a more important role in the acceptability of marula fruit leathers than the drying

temperature. The reduction in drying temperature and addition of sugar can therefore enhance the sensory attributes and also induce the likelihood acceptance of the marula fruit leathers.

Table 4.3.4.1: Correlation matrix of marula fruit leather organoleptic attributes at 50, 60, and 70 °C, at sugar concentrations of 0, 5, and 10% w/w

	Temperature °C	Sugar/ %	Colour	Hardness	Chewiness	Taste	Flavour	Overall Acceptability	Willingness to Buy	Buying Frequency	Gender	Age
Temperature °C	1.000	-0.036	-0.127	-0.162	-0.155	-0.066	-0.171	-0.079	-0.121	0.011	0.010	0.010
Sugar %	-0.036	1.000	0.263	0.453	0.422	0.345	0.306	0.414	0.400	-0.010	>0.001	-0.001
Colour	-0.127	0.263	1.000	0.543	0.542	0.620	0.54	0.470	0.440	-0.050	-0.054	0.048
Hardness	-0.162	0.453	0.543	1.000	0.778	0.612	0.57	0.601	0.600	-0.040	-0.095	0.100
Chewiness	-0.155	0.422	0.542	0.778	1.000	0.682	0.618	0.645	0.621	-0.024	-0.052	0.115
Taste	-0.066	0.345	0.620	0.612	0.682	1.000	0.712	0.699	0.616	-0.007	-0.056	0.050
Flavour	-0.171	0.306	0.540	0.570	0.618	0.712	1.000	0.716	0.606	-0.020	-0.030	0.047
Overall Acceptability	-0.079	0.414	0.470	0.601	0.645	0.699	0.716	1.000	0.729	-0.073	-0.065	0.015
Willingness to Buy	-0.121	0.400	0.440	0.600	0.621	0.616	0.606	0.729	1.000	-0.063	-0.062	0.046
Buying Frequency	0.011	-0.010	-0.050	-0.040	-0.024	-0.007	-0.02	-0.073	-0.063	1.000	0.229	0.171
Gender	0.010	>0.001	-0.054	-0.095	-0.052	-0.056	-0.03	-0.065	-0.062	0.229	1.000	0.060
Age	0.010	-0.0010	0.048	0.100	0.115	0.050	0.047	0.015	0.046	0.171	0.060	1.000

<sup>a</sup>Spearman's rank correlation coefficient

#### **4.4 Conclusion**

Drying temperature and sugar concentration were the most important variable treatments of the research that significantly ( $p \leq 0.05$ ) affected the texture attributes and consumers perception of the fruit leathers. The addition of sugar was observed to be the most important ingredient that significantly affected the textural properties since its addition induced softer texture products and increased the sensory acceptability of the fruit leathers.

The reduction in drying temperature and addition of sugar can enhance both the texture and consumer sensory attributes of the marula fruit leathers and also induce the likelihood of acceptance of the marula fruit leathers. In this study age also appeared to be an important factor in the acceptance of the product, as younger generation would be willing to buy marula fruit products compared to the older generation. This indicates that the marula fruit leathers could be used as a medium for nutritional interventions that target younger generations such as micro-nutrient fortification.

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## **Chapter 5: General Discussion, Conclusion and Future Research Recommendations**

### **5.1 General Discussion and Conclusion**

Over the years, indigenous fruits such as the marula fruit have been acknowledged by the rural society as a valuable food security resource. The fruits' highly nutritive nature, distinctive tropical flavour and its multipurpose characteristic has necessitated efforts by the local and commercial industries to optimise its utilisation through processing into various products highly appreciated both locally and internationally. Therefore, it was imperative to develop and diversify on the fruits' technological processing aspects in order to optimise its preservation techniques and utilisation by producing other possible value-added by-products.

In this study, marula fruit leathers were successfully developed using a method of hot air drying. To date, no work has been reported on the drying of marula fruit, thus it was imperative to investigate and document the lesser known, on the heat and mass transfer processes governing the process of drying marula fruit. The main objective of this study was to investigate the effect of different drying temperature and the effect of the incorporated ingredient, i.e. sugar, on the drying behaviour, physiochemical (colour and texture) attributes and consumer sensory acceptability of the developed marula fruit leather.

The effects of different drying temperature and sugar concentration on the drying characteristics and colour attributes were studied and reported in Chapter 3. The results obtained in this study showed that a rise in temperature and sugar will increase the conductivity of heat and moisture transfer rate from the material. The results also showed that increasing sugar will require more drying of the material and this was shown by the increase in activation energy as sugar was increased. During the evaluation of colour attributes, the results showed that the increase in temperature during the processing of marula fruit leather will result into intense coloured fruit leathers while adding more sugar will minimise that occurrence. This

was shown by the increase in Chroma, Yellowness Index and Browning Index with rising temperature and a decrease in these attributes with the addition of sugar. This chapter formed the basis of this study and emphasised the importance of measuring the drying process and incorporated ingredient in achieving a quality improved product.

The effect of drying temperature and sugar concentration on the texture properties and consumer sensory acceptability of the marula fruit leather product were investigated and reported in Chapter 4. The result obtained in this chapter showed that controlling temperature during drying is very critical. These results also showed that adding additives such as sugar plays a critical role during the processing of marula fruit leathers. The results obtained indicated that the rise in temperature and sugar significantly influenced the texture properties and consumers acceptance of the product. The results also showed that marula fruit leathers prepared with high concentration of sugar, were softer products and this was shown by the instrumental texture analysis results which revealed a decrease in hardness, chewiness and tensile strength of marula fruit leather prepared with 10% w/w added sugar. This showed manipulating additive will result into a certain character of the end product.

The results from Spearman's Correlation of the treatments and sensory attributes tested for sensory evaluation revealed that temperature was negatively correlated with all the consumer sensory attributes tested. This was shown by a decrease in overall acceptability and willingness to buy the fruit leather by panellists. Moreover, sugar positively correlated with all the sensory attributes of interest. This was shown by the increased in the overall acceptability and willingness to buy the fruit leathers. The addition on sugar seem to have improve on the texture attributes, colour properties, taste and flavour, the overall acceptability and willingness to buy the marula fruit leathers. The sensory evaluation results showed that reducing temperature and increasing sugar significantly influenced the sensory attributes tested and enhance the liking of

the fruit leather by the panellists. This was shown by the high scores of preference to the colour, hardness, chewiness, taste, flavour, overall acceptability and willingness to buy of fruit leathers prepared at 50 °C with 10% w/w sugar. From this chapter, the drying temperature (50 °C) and 10% w/w sugar addition was recommended for drying marula fruit leathers and for producing a more preferred product by consumers.

In conclusion, the results obtained from this entire study indicated that introducing a new variety of marula fruits (i.e. marula fruit leather) to the market should be accompanied by critical product quality characteristics assessment demanded by consumers. These results could assist in optimising the utilization of marula fruits to its full potential. The development of such nutritious snack will not only optimise the postharvest handling of marula fruits, but also impart value to other appreciated indigenous fruits.

## **5.2 Future Research Recommendations**










- An investigation of the shelf life of marula fruit leathers is required in order to help understand the stability of the product and to identify optimal suitable packaging and storage conditions.
- Fruit leathers are considered healthy nutritious snack. Given that marula fruits contain high Vitamin C content, future studies will need to investigate the amount of Vitamin C retained in the final product after drying. This will help with better control of the drying process.
- Improving the sensory attributes of marula fruit leathers is required. Preparing the fruit leathers by mixing the fruits pulp with a variety of ingredients, preservatives or other types of fruits could result into an enriched fruit leather with interesting physiochemical properties and enhance consumers' preferences. However, this will require further investigation and evaluation.

## Appendix










### Consumer Sensory Evaluation Questionnaire use for the Study

Welcome to the marula fruit leather sensory evaluation. You have been given 3 different coded samples to taste. Please taste the samples from left to right. Before and in between the tasting, please eat a carrot provided.










How much do **you like or dislike** the sample in terms of the **provided properties**. Please use the **rating scale (1-9)** to evaluate the samples. Please **tick (√)** your level of **like/dislike**.

Sample code:									
<b>Rating Scale (1-9)</b>	1-Dislike Extremely	2-Dislike very much	3-Dislike moderately	4-Dislike slightly	5-Neither like/dislike	6-Like slight	7-Like slightly	8-like very much	9- Like extremely
<b>Colour</b>									
<b>Texture/hardness</b>									
<b>Chewiness</b>									
<b>Sweet-sour taste</b>									
<b>Marula fruit flavour</b>									
<b>Overall liking/Acceptability</b>									

Would you buy this sample? Please (√)  
 Yes:  
 No:

Sample code:									
<b>Rating Scale (1-9)</b>	1-Dislike Extremely	2-Dislike very much	3-Dislike moderately	4-Dislike slightly	5-Neither like/dislike	6-Like slight	7-Like slightly	8-like very much	9- Like extremely
<b>Colour</b>									
<b>Texture/hardness</b>									
<b>Chewiness</b>									
<b>Sweet-sour taste</b>									
<b>Marula fruit flavour</b>									
<b>Overall liking/Acceptability</b>									

Would you buy this sample? Please (√)  
 Yes:  
 No:

Sample code:									
<b>Rating Scale (1-9)</b>	1-Dislike Extremely	2-Dislike very much	3-Dislike moderately	4-Dislike slightly	5-Neither like/dislike	6-Like slight	7-Like slightly	8-like very much	9- Like extremely
<b>Colour</b>									
<b>Texture/hardness</b>									
<b>Chewiness</b>									
<b>Sweet-sour taste</b>									
<b>Marula fruit flavour</b>									
<b>Overall liking/Acceptability</b>									

Would you buy this sample? Please tick (✓)  
 Yes:  
 No:

**Please provide the following information. Please circle**

Gender: Male / Female

Age range:      ≤20      21-30      31-40      41-50      ≥50

Which sample did you like the most? (Please specify with the sample code): \_\_\_\_

Do you like eating dried fruits or any other snack (either be sweets, chocolates, cookies, etc.):      Yes / No

How often you buy dried fruits or any snack (sweets, chocolate, cookies etc.):    Every-day (\_\_\_): Once a week (\_\_\_): Once a month (\_\_\_): Rarely buy (\_\_\_): Not at all (\_\_\_) (Please tick)

Cellphone #: \_\_\_\_\_ (only for follow up and quality control)

Any comments on colour, flavour or anything else \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

Would you like to be included on the next sensory evaluation: Yes/No (Please circle)

**Thank you very much for your time and participation**

