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DRYING AND SENSORY CHARACTERISTICS OF MANGO (*Mangifera indica* L.)

MASTER'S THESIS

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Declaration

I hereby declare that I have done this thesis entitled "DRYING AND SENSORY CHARACTERISTICS OF MANGO (*Mangifera indica* L.)" independently, all texts in this thesis are original, and all the sources have been quoted and acknowledged by means of complete references and according to Citation rules of the FTA.

In Prague April 2023

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MODUROTOLUWA EMMANUEL OJO

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Abstract

Mango (*Mangifera indica* L.) is a commercially important fruit which is growing in popularity worldwide, particularly in regions not suited for local production. There is a need for proper processing of this product to reduce postharvest loss and preserve quality of fruit during transport. The aim of this research was to investigate the influence of two types of drying methods, namely hot-air drying and lyophilisation, on the drying behaviour of mango and to evaluate the influence of drying behaviour on sensory properties. Four drying experiments with varying parameters of hot-air drying (H1, H2, H3) and lyophilisation (L) were carried out on ripe mango samples. These samples were also tested for colour change, moisture content, water activity and texture. Results showed that all drying methods attained a moisture content of less than 20 % and a water activity rate of less than 0.6; favourable organoleptic qualities suitable for long-term storage. Sensory evaluation by semi-trained panellists revealed no statistically significant difference in the taste and general likeability of all dried samples, with a slight preference for the freeze-dried samples.

Key words: heat drying, freeze drying, lyophilisation, sensory evaluation, dried mango

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STDEV:	Standard deviation
dE:	Delta E
FCP:	Free Choice Profile
QDA:	Quantitative Descriptive Analysis
FPA:	Flavour Profile Analysis
TPA:	Texture Profile Analysis
TIA:	Time Intensity Analysis
CIE	Internation commission on illuminaiion
OVD	Convection oven drying
MVD	Modified ventilation greenhouse solar drying

1. INTRODUCTION AND LITERATURE REVIEW

1.1. ROLE OF FRUITS IN THE HUMAN DIET

A Fruit can be defined as the seed enclosing part of a flowering plant or tree which can be eaten as food (Encyclopedia Britannica 2023). It is also commonly referred to as the mature ovary of a plant or the succulent edible portion of woody plants. Another definition can be the edible and fleshy seed-associated structures of certain plants which could be sweet (such as apples, oranges, mangoes, berries, and banana), or non-sweet (such as lemon and olives) in their raw forms. While it is true that fruits contain an abundance of nutrients majorly vitamins and minerals, no single fruit however provides all the nutrients an individual needs to be healthy (Amao 2018).

The human diet has gone through remarkable changes throughout the course of history. The earliest hominids were mostly hunters-gatherers, who consumed a diet composed of wild game, fish, nuts, fruits, and vegetables. Slowly around 10,000 to 7000 years ago the practice of agriculture began to develop, and humans began to subsist more on plants and animals (Cordain et al. 2005; Milton 2003). The increased consumption of plants is an important feature of this development. Plants are essential to the human diet and provide nutrients such as carbohydrates, protein, vitamins, and various minerals (Liu 2003). Proteins play a vital role in the human diet, and early humans likely obtained most of their protein from animal sources. However, as the human diet has evolved, plant-based sources of protein have become more important. Legumes, for example, are a good source of protein and are widely consumed in many parts of the world. Soybeans are also a popular source of protein and are often used as a substitute for meat (Craig et al. 2009; Liu 2003). Another essential nutrient is Fat, it has played an important role in the human diet throughout history. Early humans likely obtained most of their fat from animal sources, such as meat and dairy products. However, as the human diet has evolved, plant-based sources of fat have become more important. Nuts, seeds, and vegetable oils are all good sources of fat, and are widely consumed in many parts of the world (Tuso et al. 2013; Schwingshackl & Hoffmann 2014).

The role of Sugar in the human diet has changed significantly over time. Early humans likely consumed only small amounts of sugar, primarily in the form of honey and fruits. However, today sugar is widely consumed in the form of processed foods and sweetened beverages. Several health issues, including as obesity, diabetes, and heart

disease, have been related to excessive sugar consumption. (Hu et al. 2014). Carbohydrate food sources provided a reliable source of energy and calories, allowing humans to settle in one place and form complex societies. However, the overconsumption of carbohydrates has also been linked to numerous health problems, including obesity, diabetes, and heart disease (Mozaffarian et al. 2011).

The industrialisation of food production in the 20th century brought about the mass production of processed and convenience foods, leading to a significant increase in the consumption of refined sugars, unhealthy fats, and artificial additives. This shift has been linked to the rise in chronic diseases, such as obesity, type 2 diabetes, and cardiovascular disease (Fung et al. 2008). As our understanding of nutrition has improved, the importance of vitamins, minerals, and other micronutrients has become increasingly apparent (Cordain 2012). These essential nutrients are necessary for many physiological functions, and deficiencies can lead to a range of health problems. As a result, many governments and health organisations have implemented dietary guidelines that emphasise the importance of consuming a balanced and varied diet (WHO 2013).

According to the Food and Agriculture Organization of the United Nations (FAO), global fruit production has been increasing steadily in the last decade, from 648.8 million tons in 2010 to 781.2 million tons in 2019 (FAO 2020). This increase in production is due to the growing demand for fruits in both developed and developing countries. The top ten fruit-producing countries in the world are China, India, Brazil, the United States, Mexico, Indonesia, Turkey, the Philippines, Egypt, and Iran. The average per capita consumption of fruit worldwide was estimated to be about 78 kg in 2017, up from 73.6 kg in 2010 (FAOSTAT 2020). However, this consumption varies greatly across regions, with some regions having much lower fruit consumption rates than others. For example, the average per capita consumption of fruit in Africa was 35.2 kg in 2017, while in Europe, it was 157.3 kg. In developing countries, the consumption of fruit is influenced by a variety of factors, including income, availability, and cultural practices. According to the FAO (2014), the per capita consumption of fruit in developing countries is much lower than in developed countries, with some countries having very low levels of fruit consumption. One of the primary reasons for the low levels of fruit consumption in developing countries is the limited availability of fresh fruit. Many developing countries lack the infrastructure and resources to grow, store, and transport fresh fruit to urban areas. As a result, people

living in these areas have limited access to fresh fruit and may rely on processed or canned fruit, which may not provide the same nutritional benefits as fresh fruit.

Another factor that influences fruit consumption in developing countries is cultural practices. In some cultures, fruit is not a traditional part of the diet, and people may not be accustomed to eating it regularly. Additionally, in many developing countries, fruit is viewed as a luxury item, and only the wealthy can afford to consume it regularly (FAO 2014). There is a tonne of peer-reviewed research that have proven the enormous benefits of incorporating fruit consumption into the human daily diet. Some of these research works have been able to show how adequate fruit consumption can affect gastro-intestinal health, risk factors for the development of non-communicable diseases (such as diabetes, cancer, cardiovascular diseases), and even weight management. For instance, according to a study of cancer incidence and mortality produced by the International Agency for Research on Cancer, it was estimated that there would be 18.1 million new cancer cases and 9.6 million cancer deaths in the year 2018 alone (Bray et al. 2018).

Early case-controlled studies on cancer reported that higher intake of fruits and vegetables were associated with a lower risk of several types of cancer (Key et al. 2020). Certain epidemiological studies have long demonstrated a strong association with increased fruit and vegetable consumption and decreased risk of chronic diseases such as cardiovascular disease, Type 2 diabetes, and cancer (Aune et al. 2017). According to a study of Klimenko (2018) in the Journal Nutrients, a diet rich in fruits, vegetables, and other high-fibre, plant-based foods improved gut bacteria diversity within two weeks. In this study, researchers assessed gut bacteria composition in 248 participants over a two-week dietary intervention that increased fibre intake. Those who consumed more fruits, vegetables, and grains improved gut bacterial diversity when compared to participants who did not change their diet. High-fibre diets increased the bacteria associated with anti-inflammatory compounds linked to improved glucose tolerance and metabolism. In particular, a higher intake of blueberries, grapes, apples, bananas, and grapefruit was individually linked to a considerably decreased incidence of Type 2 Diabetes Mellitus (T2DM) in 3 groups of American men and women. (Nicola et al. 2021).

Furthermore, adherence to the Australian Dietary Guidelines recommendations for fruit consumption (minimum of 2 servings of fruit per day for adults) was associated with a 32% lower risk of T2DM over 12 years in the Australian Diabetes, Obesity and Lifestyle Study (Dow et al. 2019). And yet another study reported that a one-serving

increase of daily fruit intake was associated with a highly statistically significant 0.24 kg reduction of body weight per 4-year period and did not report associations with other measures of adiposity (Guyenet 2019).

1.1.1. MANGO (*Mangifera indica* L.)

The mango is a popular fruit crop produced from the *Mangifera indica* L. tree. It is said to originate from the region of present-day India (Mukherjee & Litz 2009). Although the mango originated from Asia, it was spread by humans through travel and can now be found in tropical and subtropical regions around the world. Due to its unique taste and texture, the mango is fast becoming a global favourite and demand for this fruit is on the increase (Eurostat 2021). World mango production comprises of over a hundred countries that produce over 34.3 million tonnes of fruit annually. Eighty percent of this production is based in the top nine producing nations that also consume up to 90% of their production domestically. 1 to 2 percent of fruit is traded internationally in markets in the European Community, USA, Arabian, Peninsula and Asia.

The European climate is generally not suited to the production of mangoes, and this translates into increased importation of mangoes to satisfy the upsurge in demand; 89% of the mangoes consumed in Europe are sourced from developing countries (CBI 2021). These imports must be properly preserved during transport to prevent contamination and spoiling while also maintaining the qualities which appeal to consumers. Furthermore, a lot of developing nations face the challenges of food wastage and postharvest losses due to a myriad of factors, such as a lack of adequate storage and processing facilities. In some cases, postharvest losses throughout the entire production cycle were found to be as high as 34 % (Sab et al. 2017). There is a need to increase the adoption of food processing methods to salvage the high rate of food wastage. Various postharvest preservation methods have been employed to prevent spoilage and preserve the quality of the fruit, to varying degrees. More research is needed to evaluate these methods to determine what approaches are most effective in prolonging the shelf life and preserving sensory quality for the consumers.

1.1.1.1 BOTANY OF THE MANGO

The mango (commonly known as *Mangifera indica* L.) is a species of flowering plant in the Kingdom Plantae, the Magnoliophyta Division, the Magnoliopsida Class, the Rosidae sub-class, and belongs to the Tracheophytes, Angiosperms, Eudicots Clade, the Sapindales Order, the Anacardiaceae family, the *Mangifera* Genus and the *Indica* species (Morton 1987). Descriptively, in terms of its distinct genetic populations, the mango is classified into the Indian and Southeast Asian types. It is usually a large tree whose leaves are mainly shiny and dark green as seen in Figure 1.

Figure 1: Mango plant and fruit (Encyclopaedia Britannica 2023)

Typically, Mango trees live for 100 years and produce fruits up till the last stage of their life cycle. According to a study by the University of Wisconsin- La Crosse, the oldest living mango tree is 300 years old and can be founded in East Khandesh, India, and still produces fruits. In addition, Mango trees that are planted from seeds take about 8 years to produce fruit, while mango trees planted from saplings take about 5 years to produce fruits (Diczbalis et al. 1997). The growth habit of the Mango tree makes it ideal for specific landscape specimens and shade. The mango trees are erect and grow fast with well-supplied heat, with a broad, upright, and rounded canopy that is usually a slender crown as seen in Figure 2. The mango tree is large up to about 20 metres and a taproot with a depth of 6 metres into the soil. Also, the feeder root of the mango tree is profuse,

wide spreading with many anchor roots of several feet penetration (Johnson & Robinson 1997).

Figure 2: Mango tree canopy (Encyclopaedia of Life 2018)

In addition to the above, the height of the mango tree is usually medium to large, about 10 to 40 meters. Additionally, the mango tree is evergreen with a symmetrical, rounded canopy ranging from low and dense to upright and open. The bark is commonly dark grey to black, as well as smooth and superficially cracked or fissured, peeling off in irregular thick pieces (Maxwell & Maxwell 1984). The foliage of mango leaves is usually dark green in the upper part and pale in the lower part. The leaves are alternate, variable in shape, and with no stipules. The full-grown mango leaves have a length and breadth between 12 cm – 45 cm and 2 cm -12 cm. The mango leaves contain a sufficient deposit of mangiferin (xanthone). The root of the mango tree is a long unbranched long taproot with about 6-8 meters and sufficient superficial feeder roots developed at the trunk base. It also has a fibrous root system which extends with an effective root system of 1.2 meters in depth and lateral spread of 7.5 meters (Samson 1986).

Mango flowers usually have matured terminal branches with pyramidal flower panicles that provide pollen and can be bisexual and set fruit. The pollination is by flies, wasps, and bees. Also, pollen cannot be shed in high humidity or rain. Fertilisation is ineffective when night temperatures are below 22.8°C. In addition, Mangoes are monoecious and self-fertile (Sharrard et al. 1997). As shown in Figure 3 below, the inflorescence is a widely branched and broadly conical panicle which can measure up to 60cm (Ramirez & Davenport 2016). It is estimated to contain between 1000 to 6000 individual flowers by panicle (Mukherjee 1953). The panicle contains both perfect and staminate flowers.

Figure 3: Mango Inflorescence (International Tropical Fruits Network 2022)

The fruits are usually irregularly egg-shaped and slightly compressed large fleshy drupes (Tharanatan et al. 2007). They usually vary in shape, size, colour, fiber, taste, and flavour. The flesh is peach-like and juicy and may vary in quality.

1.1.1.2 Mango Cultivars

Generally, there are severall known mango cultivars numbering hundreds, with most commercial cultivars belonging to *Mangifera indica.* Also, others are prominent in India, Australia, Asia, USA (mostly in Florida), and Africa (Litz 2009). It is said that at least 350 are propagated in commercial nurseries. Figure 4 belows some of the popular varieties of mango.

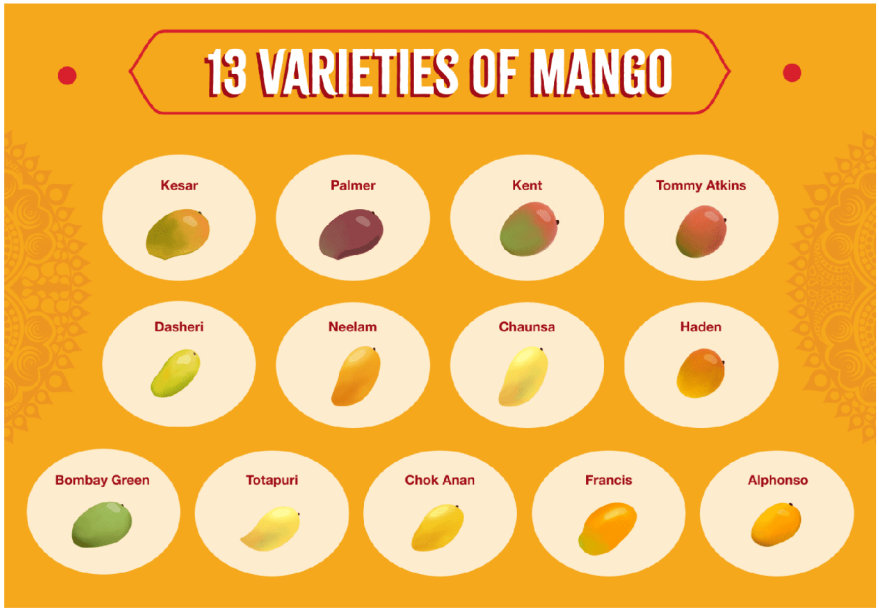

Figure 4: Picture showing 13 varieties of mango (Sukhi's Gourmet Foods 2021)

For proper context, according to The Mango Factory (2023), key mango cultivars in key producing countries include;

i. Australia: Kensington Pride, Banana, Earlygold, Glenn, Haden, Irwin, Keitt, Kent, Zill
ii. Bangladesh: Aswina, Fazli, Gopal Bhog, Himsagar,Khirsapati, Langra, Kishan Bhog, Kohinoor, Kua Pahari, Mohan Bhog
iii. Brazil: Bourbon, Carlota, Coracao, Espada, Itamaraca, Maco, Magoada, Rosa, Tommy Atkins
iv. China: Baiyu, Guixiang, Huangpi, Huangyu, Macheco, Sannian, Yuexi No. 1
v. Costa Rica: Haden, Irwin, Keitt, Mora, Tommy Atkins
vi. Ecuador: Haden, Keitt, Kent, Tommy Atkins

vii. Egypt: Alphonso, Bullocks Heart, Hindi Be Sennara, Langra, Mabrouka, Pairie, Taimour, Zebda

viii. Guatemala: Haden, Kent, Tommy Atkins

ix. Haiti: Francine, Madame Francis

x. India: Alphonso, Banganapalli, Mumbai, Bombay Green, Cha[OBJ] (a, Dashehari, Fazli, Fernandian, Himsagar, Kesar, Kishen Bhog, Langra, Mallika, Mankurad, Mulgoa, Neelum, Pairi, Samar Behisht Chausa, Suvarnarekha, Totapuri, Vanraj, Zardalu, Amrapali, Bangalora, Gulabkhas

xi. Indonesia: Arumanis, Dodol, Gedong, Golek, Madu, Manalagi, Cengkir, Wangi

xii. Israel: Haden,Tommy Atkins,Keitt, Maya, Nimrod, Kent, Palmer

xiii. Kenya: Boubo,Ngowe,Batawi

xiv. Malaysia: Arumanis, Kuala Selangor 2, Golek, Apple Rumani, Malgoa, Apple Mango, Maha-65, Tok Boon

xv. Mali: Amelie,Kent

xvi. Mexico: Haden, Irwin, Kent, Manila, Palmer, Sensation, Tommy Atkins, Van Dyke

xvii. Myanmar: Aug Din, Ma Chit Su, Sein Ta Lone, Shwe Hin Tha

xviii. Pakistan: Anwar Ratol, Baganapalli, Chausa, Dashehari, Gulab Khas, Langra, Siroli, Sindhri, Suvarnarekha, Zafran

xix. Peru: Haden, Keitt, Kent, Tommy Atkins

xx. Philippines: Carabao, Manila Super, Pico, Binoboy, Carabao, Dudul, Pahutan, Senorita

xxi. Singapore: Apple Mango, Arumanis, Golek, Kaem Yao, Mangga Dadol

xxii. South Africa: Fascell, Haden, Keitt, Kent, Sensation, Tommy Atkins, Zill

xxiii. Sri Lanka: Karutha Colomban, Willard, Vellai Colomban, Petti amba, Malwana amba, Parrot Mango and Peterpasand, Dapara, Hingurakgoda

xxiv. Thailand: Nam Doc Mai, Ngar Charn, Okrong, Rad, Choke Anand, Kao Keaw, Keow Savoey, Pimsenmum

xxv. USA: Keitt, Kent, Tommy Atkins

xxvi. Venezuela: Haden Keitt Kent Tommy Atkins.

1.1.1.3 Nutritional Content of Mango Fruit

Mango fruit has high nutritional value and health benefits due to its important components. Mango components can be grouped into macronutrients (carbohydrates, proteins, amino acids, lipids, fatty, and organic acids), micronutrients (vitamins and minerals), and phytochemicals (phenolic, polyphenol, pigments, and volatile constituents). Mango fruit also contains structural carbohydrates such as pectin and cellulose. The major amino acids include lysine, leucine, cysteine, valine, arginine, phenylalanine, and methionine. The lipid composition increases during ripening, particularly the omega-3 and omega-6 fatty acids. The most important pigments of mango fruit include chlorophylls (*a* and *b*) and carotenoids. The most important organic acids include malic and citric acids, and they confer the fruit acidity. During development and maturity stages important biochemical, physiological, and structural changes occur affecting mainly the nutritional and phytochemical composition, producing softening, and modifying aroma, flavour, and antioxidant capacity. In addition, postharvest handling practices influence total content of carotenoids, phenolic compounds, vitamin C, antioxidant capacity, and organoleptic properties (Maldonado et al. 2019).

The energy value for 100 g of the pulp ranges from 60 kcal to 190 kcal (250–795 kJ), making it an important fruit for the human diet. The nutritional, non-nutritional, and water contents of mango fruit vary depending on the cultivar and several pre-harvest and postharvest factors. For example, according to the United States Department of Agriculture (USDA) data of nutrient report, the mature mango pulp of Haden, Kent, Keitt, and/or Tommy Atkins varieties contains 83.4 g of water per 100 g of fresh fruit, while the cultivar Azúcar from Colombia contain 79.3 g (Corrales-Bernal et al. 2014).

1.2. FRUIT DRYING

One of the most serious challenges affecting growers of fruits and vegetables is how to prevent their products from spoiling and thereby becoming unfit for consumption (Fellows 2016). There are various methods of accomplishing this, such as canning or freezing. However, one of the most suitable methods of preserving most fruits and vegetables is through drying to remove most of the water content. Drying is a significant way to tackle postharvest losses (Abe-Inge et al. 2018; Farhana et al. 2018). It is one of the oldest preservation techniques known to man, it removes the moisture from the food so that microbial growth is inhibited. (Saravacos & Kostaropoulos 2016). Drying also slows down the action of enzymes (naturally occurring substances which cause foods to ripen) but does not inactivate them (Fellows 2016).

1.2.1 Dried Fruit Products

Dried fruit is fruit from which most of the original water content has been removed either naturally, through sun drying, or with the use of specialised dryers or dehydrators. Dried fruit has a long tradition of use dating back to the fourth millennium BC in Mesopotamia, and is prized because of its sweet taste, nutritive value, and long shelf life. Traditional, conventional dried fruits such as dates, figs, prunes, raisins, apricots, apples, and pears have no added sugar or juice and are formed by the removal of water. WHO classifies traditional dried fruits as “fruit”, and like fresh fruit the sugars content is not defined as “free sugars” (Swan et al. 2018) In contrast, some dried fruits such as blueberries, cranberries, cherries, strawberries and mangoes are usually infused with sugar syrup or fruit juices prior to drying, although these fruits can also be dried without any infusion, which adds to consumer confusion. Some types of dried fruits are brighter in colour compared with natural sun-dried fruits, as sulphur dioxide may be added. Other types of dried fruit include “candy” fruits such as pineapples and papaya, which have a high content of added sugar but are not necessarily labelled as such. Processed, dried-fruit snacks may contain added sugars, or may be made from macerated or pureed fruit that is then dried. There are several reasons for adding sugar and or/sugar syrups to dried fruit. In some cases, it increases palatability by adding sweetness (e.g., cranberries), whereas addition to dried fruit that is already sweetened helps the fruit to remain soft throughout its shelf life since sugar and sugar syrups act as natural

humectants. Sugar and sugar syrups also have a preservative function, by helping to reduce the water activity within the fruit (Goldfein & Slavin 2015).

Consumption of dried fruit is difficult to estimate because of multiple uses, for example, in baked goods, breakfast cereals and cereal bars, as well as a food in its own right. Retail sales data suggest that consumption of dried fruit as a snack has increased and use in baking has decreased, but this does not reflect use in manufactured products. Trends include an increase in sales of unsweetened naturally dried and freeze-dried fruit (Michele et al. 2019). Individual consumption of dried fruit alone as a snack is also on average very low, with only about 11% of the UK population consuming dried fruit in any one day. Data from the 2016 Health Survey for England (HSE 2017) show that reported consumption of dried fruit is lowest among 11- to 24-year-olds and highest among over 65-year-olds with dried fruit contributing around 0.1 portions/day compared with around two portions of fresh fruit (including juice)/day. On average over the whole population, this equates to about a teaspoon (3–6 g)/day (PHE 2018). The content of nutrients in traditional dried fruits remains similar to the equivalent fresh fruit, though more concentrated. Traditional dried fruits are therefore good sources of several micronutrients asides from vitamin C (EU 2013).

Dried fruits are relatively cheap and easy to store, and for that reason, they become essential components of food, beverages, and recipes. This healthy alternative to sweet snacks can be a valuable source of antioxidants and micronutrients, containing vitamins, folate, potassium, magnesium, and also fibre, whereas these products are low in total fat, saturated fatty acids, and sodium (Magdalena & Beata 2020). The researchers found that people who ate dried fruit were generally healthier than those who did not, and on days when people ate dried fruit, they consumed greater amounts of some key nutrients than on days when they skipped. However, they also found that people consumed more total calories on days when they ate dried fruit (Valerie et al. 2020). Dried fruits are generally perceived, by both consumers and researchers, as a less attractive but shelf-stable equivalent to fresh fruits and constitute a small but significant proportion of modern diets (Mossine et al. 2020). The shelf life of dried products is almost unlimited, and the cost of transportation, handling and storage are considerably lower than that of other methods of preservation (Wang et al. 2019). However, drying methods can alter the physicochemical properties and nutritive qualities of the dried products despite the improved shelf-life.

Pre-treatments are usually done before the fruit is dried so that adverse changes occur during drying and subsequent storage are reduced (Adepoju & Osunde 2017).

1.2.1.1 DRIED MANGO PRODUCTS

According to CBI (2021), dried mango is the product prepared from sound and mature ripe fruit of varieties of *Mangifera* spp., processed by drying. Mango can be dried by the sun or by other recognised methods of dehydration. According to product specifications, dried mango can be produced as natural or sweetened. These categories contain additional subcategories such as type of cut (cubes, slices, cheeks, etc.), use of preservatives (sulphites) and processing method. Figure 5 below shows some examples of dry mango products.

Figure 5: Dried mango fruit slices (Gin Gin & Dry 2022)

The EU market for mangos is growing quickly, with an average annual change of 7% in value (CBI 2011). Virtually all imports from outside Europe come from developing countries. In the next five years, the European market for dried mango is likely to continue to increase, but with a somewhat lower annual growth rate of 6-9%.

The main drivers behind the forecasted grow will be the healthy snacking trend, new product launches containing dried mango and the general popularity of mango flavour. In 2020, according to industry estimations, the imported quantity of dried mango reached 7

thousand tonnes. It is estimated that conventional dried mangoes account for around 70% (about 4,900 tonnes), organic dried mangoes for around 25% (1,750 tonnes) and sweetened dried mango for the remaining 5% (350 tonnes).

1.2.2. QUALITY OF DRIED FRUIT PRODUCTS

Consumer demand has increased for processed products that keep more of their original characteristics. In industrial terms, this requires the development of operations that minimise the adverse effects of processing. The effect of food processing on finished product quality ultimately determines the usefulness and commercial viability of that unit process operation. Major quality parameters associated with dried food products are the colour, visual appeal, shape of product, flavour, microbial load, retention of nutrients, porosity bulk density, texture, rehydration properties, water activity and chemical stability, preservatives, and freedom from pests, insects and other contaminants, as well as freedom from taints and off-odour (Perrera 2005).

Every drying method has its unique characteristics. The freeze-drying method is one of the best drying treatments because it preserves the natural colour, maximum nutrients, original flavour, and aroma (Kumar & Sagar 2014). Freeze drying is reported as the best method in terms of preservation of nutrients and colour quality of fruits but it is also the most expensive method. Conventional oven drying is one of the economical and controlled ways of fruit drying, but at a higher temperature, it may damage the colour quality and leads to the loss of heat labile nutrients (Ali et al. 2016).

1.2.2.1 MOISTURE CONTENT, WATER ACTIVITY (a_w)

Moisture content and water activity are important factors for evaluating the quality and safety of fruits. These parameters play a crucial role in defining the storage life of fruits.

The term moisture content simply means the weight of water contained in a certain object or material. It is commonly expressed as a percentage. The moisture content of a fruit refers to the water content of the fruit and varies depending on several factors such as the nature of the fruit, ripeness of fruit at harvest and postharvest handling. Fruits contain a high percentage of water, with some fruits containing as much as 95% water (Kader 2002). This is an essential factor in determining the quality and shelf life of fruits, as it affects the texture, flavour, and appearance of fruits. High moisture content can result in soft and mushy fruits, while low moisture content can cause fruits to become tough and dry. Properly dried fruits will have 80-90% of their water removed (Afolabi 2014). This will limit the conditions for the growth of microorganisms and reduce the deterioration of other qualities of dried produce. Several methods can be used to measure the moisture content of a material, including the Karl Fischer titration and Loss on drying methods (IFT 2009).

Water activity is a measure of the free or unbound water available for microbial growth and chemical reactions. It is expressed as the ratio of the vapor pressure of water in a sample to the vapor pressure of pure water at the same temperature (Beuchat 1987). Water activity affects the potential for microbial spoilage, enzymatic reactions and other phenomena such as oxidation and non-enzymatic browning. Fruits with a water activity of less than 0.6 are generally considered safe from microbial spoilage, while those with a water activity greater than 0.8 are at high risk for microbial growth (Kader 2002).

The values for moisture content and water activity for a given medium are directly correlated as higher moisture content results in higher water activity. Water activity can be measured using water activity analysis instruments such as those manufactured by Novasina AG. Decagon etc (IFT 2009)

1.2.2.2 COLOUR

The initial quality parameter assessed by customers is the surface colour of the food. It is also important in the approval of food, even before tasting. It was determined that the drying techniques had a considerable impact on the mango sample's colour (Nazmi et al. 2017). The colour parameters in sensory evaluation are designated by $\mathbf{L}^*$ values (lightness), $\mathbf{a}^*$ value (greenness/redness) and the $\mathbf{b}^*$ values (blueness and yellowness) (Vega-Galvez et al. 2012). Researchers report on the colour attributes of dried and fresh mango showed that all $\mathbf{L}^*$ colour attributes of dried mango declined against the fresh samples, although $\mathbf{L}^*$ properties were greater in freeze dried samples compared to the dried samples. As $\mathbf{L}^*$ increases, $\mathbf{a}^*$ values showed significant increases which may be due to enzymatic browning, and $\mathbf{b}^*$ was highest in all the freeze dried samples (Nazmi et al. 2017). Drying slices of 4 mm thick at 60 °C, 30% Relative Humidity, 1 m/s for 5 hours, proved very good at conserving the colour of fresh mango slices. The statistical analyses revealed numerous significant effects between the pre- and postharvest factors and the color alterations occurring during drying, even if their impact was low (Diop et al. 2021). The formular for calculating the rate of colour change is shown below (1) (CIE 1976).

$$\Delta E^*_{ab} = \sqrt{(L^*_2 - L^*_1)^2 + (a^*_2 - a^*_1)^2 + (b^*_2 - b^*_1)^2} \quad (1)$$

Where ΔE^*_{ab} (Delta E) is the colour difference between two colours in CIELAB space

L_2, a_2 and b_2 are the second colour measurements of sample.

L_1, a_1 and b_1 are the initial colour measurements of sample.

Colour changes in mango fruit samples caused by drying technique may be closely related to pigment degradation, principally degradation of carotenoids and formation of brown pigments by non-enzymatic and enzymatic reaction (Albanese et al. 2013). Present findings show pretreatments to be a suitable method for the colour and vitamin C preservation of dried mango fruits (Dereje & Abera 2020).

1.2.2.3 TEXTURE

Another crucial factor for food acceptance is texture, particularly for dried goods. Food tissues are stressed during drying, resulting in cracks and deformations, which weaken the tissues as a result (Lewicki & Pawlak 2003). The International Standards Organization (ISO) defines food texture as "all the rheological and structure (geometrical and surface) attributes of a food product perceptible by means of mechanical, tactile, and where appropriate, visual and auditory receptors" in their standard vocabulary for sensory analysis (ISO, 2008).

Consumer approval and market value are strongly influenced by the texture of food materials. Textural qualities are important from the perspectives of quality control and food safety (Wilhelm et al. 2004). In the fresh and processed food industries, texture is a crucial quality indicator used to gauge consumer approval (Cardello 1996). Important characteristics for evaluating texture include springiness, cohesion, adhesiveness, and gumminess. One of the important textural properties of a dried food product is its hardness (Wang et al. 2018). It is the main sensory quality attributes affecting food acceptance (Ikoko & Kuri 2007) since it can be related to the force performed by mastication that takes part during eating.

Food's textural qualities can be assessed using descriptive sensory or instrumental methods (Chen & Opara 2013). Sensory evaluation tests are ultimately used to determine how a food's textural qualities are measured. Since interactions between food biopolymers like proteins, polysaccharides, and lipids have a significant impact on texture, which is inextricably linked to food structures at the micro- and macrolevels, instrumental methods designed to measure rheological and/or mechanical properties may be used to establish parameters that relate to pertinent sensory textural characteristics (Chen & Opara 2013).

Some of the instrumental techniques used to analyse the texture of dried food products are compression, tension, bending, and cutting tests (Bourne 2002). A product's hardness and durability are assessed using compression tests, whilst its chewiness and stretchability are assessed using tension testing. Cutting tests are used to assess a product's brittleness and fracture qualities whereas bending tests assess a product's stiffness and flexibility.

The Texture Profile Analysis (TPA) approach is one of the techniques frequently employed in texture analysis. In TPA, a sample is compressed twice, once to a specific

distance and once to a specific force. Hardness, cohesiveness, springiness, chewiness, gumminess, and fracturability are among the characteristics that TPA measures.

1.3. SENSORY ANALYSIS

Since its advent in the 1940s, sensory assessment has been established as an exciting, dynamic and continually evolving discipline that is now renowned as a scientific field in its own right (Sharif et al. 2017). Sensory evaluation is a scientific discipline used to evoke, measure, analyse, and interpret reaction to those characteristics of food material as they are perceived by the senses of sight, smell, taste, touch, and hearing (sound) (Jain & Gupta 2005). It is the scientific measurement of food quality based on sensory characteristics as perceived by the five senses. Like every other scientific method of taking measurements, sensory evaluation is concerned with precision, accuracy and sensitivity, and with avoiding false-positive results. Reliable sensory evaluation is based on the skill of the sensory analyst in optimising four factors; definition of the problem, test design, instrumentation, and interpretation of the results (Meilgaard et al. 2007).

There has been tremendous change in the role of sensory evaluation over the years. In the early stages of product development, sensory testing can help to pinpoint the imperative sensory characteristics driving acceptability. It can be useful to ascertain target consumers, product competitors and assess the new ideas. Nowadays, chemical and physical properties of the product driving sensory attributes are ascertained by combining data obtained from sensory and instrumental testing. Sensory evaluation can determine the impact of scaling up pilot samples to large-scale manufacture. Sensory evaluation provides assurances that inferior products are not released into the market. In most of the cases, sensory evaluation is used to estimate shelf life of the food products as sensory characteristics of the product depreciate ahead of microbial quality. Customer evaluation is extensively employed in the investigation arena. It explores new technologies for product development and understanding the consumer behaviour (Sharif et al. 2017). Contrary to sensory gadgets, psychological or physiological factors can easily affect human decisions. In order to diminish or eradicate such biasness, panellists should pick right protocols and experimental design.

1.3.1. METHODS OF SENSORY ANALYSIS

1.3.1.1 Discriminative Tests:

These tests are designed to determine if a difference exists between food products (Valentin et al. 2012). Panellists should endeavour to have a fundamental idea about the product to be tested for easy choice. Each panellist is required to make a choice among the given food products. Discriminative tests at some point may be used for different purposes (e.g. determining sample differences/similarities and quantity of degree of difference/similarities) (Stone 2012). To perform these tests, the recommended panellists should be about 10-50. Discriminative tests include **triangular test, duo-trio test and paired-comparison test**.

The triangular test normally has three samples involved when determining the overall difference between two products. Out of the three samples, two are similar and one is dissimilar. The samples must be coded with individual three-digit numbers. The taster is required to select the sample which is different from others. In these tests the chance of choosing the required sample correctly is greater. It is recommended that no more than six samples be evaluated at one testing session because the method is liable to fatigue of panellists. The tests require fewer tasters, at least 4-8 tasters are considered enough to carry single testing (Singh-Ackbarali & Maharaj 2014).

Duo Trio test determines whether a sensory difference exists between two samples. There is always a reference sample and two test samples; of the two test samples, one sample is identical to the reference, and the other one is the test sample. The panel members are asked to identify the sample that is similar to reference sample. Duo-trio tests are sometimes used instead of triangle tests to compare unknown differences between samples; however, they are considered less efficient than triangle tests. At least 7-10 evaluators are recommended (Purcell 2017).

Paired Comparison Tests are applied when a difference in chemical composition of the sample which requires a sensory assessment is well known. Two differently coded samples are presented to each panellist at the same time and the task is to choose the sample that is perceived higher in the specified sensory attribute (Yang & May 2017). Tasters are asked to judge the samples by comparing them without needing to rate the magnitude of the difference, for example, “are the two samples identical or different?” or “which of the two samples sugary?” Compared to triangular test, paired comparison test

is less tedious and frequently used for strongly flavoured or complex products. At least 7-10 panellists as for duo-trio are recommended in this test (Lawless & Heymann 2010).

1.3.1.2 Descriptive Tests

In these tests, sensory attributes of products are characterised in order of their appearances and relative intensities are assigned (Mihafu et al. 2020). They provide more detailed profiles of a product by identifying the different characteristics within the product and quantifying them. Descriptive tests are more comprehensive and sophisticated as compared to discriminative tests (Pimental et al. 2015). They provide the basis for mapping product similarities and variances and determining those sensory characteristics that are important to acceptance. It is normally performed by 6 to 15 meticulously selected and trained panellists. Panellists are trained to evaluate products similar to how any instrument would give a reading. Descriptive tests include Free Choice Profile (FCP), Quantitative Descriptive Analysis (QDA), Flavour Profile Analysis (FPA), Texture Profile Analysis (TPA) and Time Intensity Analysis (TIA) (Meilagaard et al. 2014).

In the Free Choice Profile method, there is no prior training of the panellists, each judge decides his/her own list of attributes to label the product. The judge should constantly be trained and the response computerised, then a time-intensity curve obtained for the determined attribute. Analysis of variance is used to analyse three parameters from the curve, namely maximum intensity, the point at which maximum is reached, and the first point at which no more perception occurs (Cruz et al. 2010).

The Quantitative Descriptive Analysis consists of progressive survey of sensory terms for a product generated by a trained sensory panellist using nontechnical language. Trained judges normally reach a consensus on the relative discrepancies between the samples (Mihafu et al. 2020). QDA and FCP have the same purpose of determining the intensities of all product attributes and also defining the complete sensory profile.

The Flavour Profile Analysis is useful for identifying sample taste and odour. It is a technique that provides a written record of noticeable aroma of a product, flavour and aftertaste components. Panellists characterise individual aroma and flavour in the order perceived and assign a constant rating scale. Normally 4-6 panellists are suggested. They independently examine the product and record their impression in terms of aroma, flavour

and aftertaste. Finally, a report is presented to a panel leader in an open discussion (Curren et al. 2014).

The Texture Profile Analysis has been widely applied to test solid and semisolid food products. Usually, it involves a panel of 6-9 members; textural attributes and other evaluation procedures are established unanimously by panel members before carrying out the evaluation of the products in question (Mihafu et al. 2020). TPA is convenient for rapid evaluation of food texture which is normally measured only by humans. In some experiments, liquid samples that cannot keep their shape but flow under gravity are poured into a cup and subjected to uniaxial compression.

Then the parameters obtained from uniaxial compression are then discussed without considering the physical meaning of these parameters namely hardness, cohesiveness, and adhesiveness (Mihafu et al. 2020).

The Time Intensity Analysis is used to estimate the change in intensity of a determined characteristic with time. It has the main role of determining the intensity of any descriptor term in a product with time. TIA and FCP are among the descriptive sensory tests mostly used in scientific studies and by the food companies (Purcell 2017).

1.3.1.3 Affective/ Consumer Acceptance Tests

Affective methods are also called subjective methods. These are very useful for evaluating food acceptability or preference (which product is liked or preferred). Normally large number of respondents is required (50-150 panellists considered adequate). Panellists are not trained but selected based on previous use of product, economic social level and geographical area (Mihafu et al. 2020).

1.3.1.4 Preference Ranking

In this technique, three or more samples are rank ordered with one sample being preferred over the other. This type of test supplies information about people's likes and dislikes of a product and determines how various samples differ based on a single distinguishing attribute. In consumer analysis, the panellists are asked to rank the coded samples according to their preference (Yang & May 2017).

1.3.1.5 Hedonic Rating Scale

This is among of the widely used sensory evaluation methods that measure consumers' level of liking of food products (Mihafu et al. 2020). In practice there are 9-point Hedonic scale, 7-point Hedonic scale and 5-point Hedonic scale. The 9-point Hedonic scale range from "like extremely'' to "dislike extremely''. Practically, not fewer than five points are recommended (Singham et al. 2015). The scales can be structured or unstructured.

1.4. DRYING METHODS

Drying is a term used for the process of removal of liquid by evaporation from a solid, to improve quality and increase shelf life. Mechanical methods of separating a liquid from a solid are not considered drying. A major portion of energy consumption during drying is for the evaporation of liquid water into its vapour. The water may be contained in the solid in various forms like free moisture or bound form which directly affects the drying rate (Datta 2015). In drying, warm temperatures cause the moisture to evaporate, low humidity allows moisture to move quickly from the food to the air and the air current speeds up drying by moving the surrounding moist air away from the food. There are several drying methods used in food production each of which affects its appearance, rehydration properties, and nutrients differently. This chapter will be discussing 2 categories of drying used in food processing, the heat drying and freeze-drying methods.

1.4.1 Heat Drying Fundamentals

The heat drying process involves the principle of heat and mass transfer (Bamire & Oke 2003). The moist food is heated to an appropriate temperature either by conduction or convection using external drying medium usually hot air or steam or by radiation (Datta 2015). The moisture gets vaporised and diffuses into the environment. Moisture is removed from food through two pathways.

i. Vaporisation of moisture from the surface of the material
ii. Movement of moisture from the interior of the food to its surface due to diffusion, cell contraction and vapour pressure gradient.

The rate of moisture removal from food during heat drying is related to the moisture content, relative humidity, and temperature of the air (Fellows 2016). Air temperature is directly correlated with its moisture-holding capacity. This means that more moisture can be removed from the material being dried as the temperature of the air increases. However, the rate of moisture removal also depends on the relative humidity

of the air. If the air is already saturated with moisture, then additional moisture cannot be removed from the material being dried.

Several factors such as the temperature differential between the heat source and the produce being dried, the surface area, and thickness of produce all affect how quickly heat is transferred during drying. (Ozbek & Dadali 2007). By increasing the temperature differential between the heat source and the item being dried or by expanding the material's surface area, the rate of heat transfer can be sped up. Because moisture must pass through thicker materials to reach the surface where it can evaporate, thicker materials take longer to dry.

There are several heat drying methods commonly used in food processing, this includes sun drying, tray drying, spray drying, solar drying, oven drying, drum drying and belt drying (Izli et al. 2017). Each process has its own benefits and disadvantages. Figure 6 below shows the oven dryer which was used in this research

Fig 6: Oven dryer used for the mango drying experiments (Author 2023)

Some advantages of heat drying include the following:

1. Increased Shelf-Life: By removing moisture, which prevents the growth of bacteria that might cause deterioration, heat drying can increase the shelf-life of food goods. (Mathlouthi 2001). Therefore it is a widely used technique for food preservation.

2. Cost-effectiveness: Compared to other drying techniques like freeze-drying, heat drying is frequently less expensive. This is so that the procedure uses less energy and less expensive equipment for heat drying. Figure 7 shows a drying rack used for sun drying.

3. Reduced Transportation Costs: Because heat-dried goods weigh less than fresh goods, transportation costs are reduced. Because of this, it is a common way for importing food into far-off markets (Owolarafe et al. 2007).

4. High Throughput: Heat drying is a common technique for industrial-scale production because it can quickly handle huge volumes of materials.

Figure 7: Sliced tomatoes on drying racks in open sun drying (Mavis et al. 2018)

Due to the high temperatures associated with heat drying, it may result in some adverse effects in dried food products,

1. Loss of Nutrients: Heat drying can cause the loss of vitamins and minerals in food goods (Praveenkumar et al. 2006). The final product may be less nutrient-dense than fresh products as a result.
2. Quality Loss: Heat drying can cause food products to lose quality, including modifications to colour, flavour, and texture (Smith 2011). Customers may find the finished product less appealing as a result.

1.4.2 FREEZE DRYING FUNDAMENTALS

Freeze-drying, also called lyophilisation, is a dehydration process for the long-term preservation of heat-sensitive foodstuffs and other biological materials. It is based on the phenomenon of sublimation, which minimises structural changes and preserves the bioactive compounds and flavours of the dried product (Natalia et al. 2018). Freeze-drying includes three main steps: product freezing, primary drying (removing the ice by direct sublimation under reduced pressure), and secondary drying (release of unfrozen water by desorption and diffusion) (Pramod 2019). Lyophilisation is used to preserve food and make it very lightweight.

The principle involved in freeze-drying is the transition of a solid (ice) to the gas phase, without first becoming liquid phase. It works on the principle that solids have a weak intermolecular force, hence a higher vapour pressure which converts it into directly vapour state. Sublimation of liquid can take place at temperature and pressures below triple point. The material to be dried is frozen first and then treated under a high vacuum to heat (by radiation or conduction or by both methods) so that frozen liquid sublimes leaving only dried and solid components of the original liquid. The driving force for the removal of water during lyophilisation is the concentration gradient of water vapour between the drying front and condenser (Sheena et al. 2018). Figure 8 below shows the diagram of a freeze dryer.

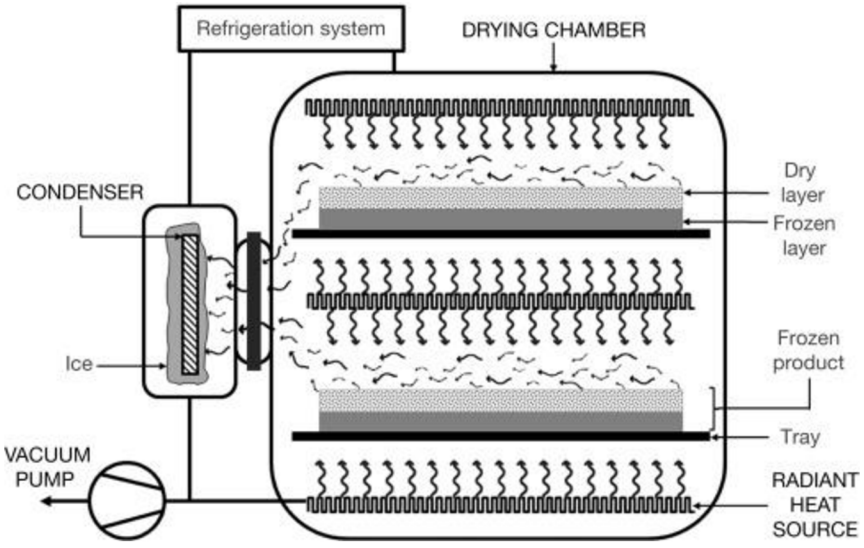

FIGURE 8: Diagram of a Freeze Dryer (Garcia-Amezquita LE et al. 2016)

The fundamental process of lyophilisation includes;

i. Freezing: The product is frozen to provide a necessary condition for low temperature drying.
i. Vacuum: After freezing, the product is placed under vacuum to enables the frozen solvent in the product to vaporise without passing through the liquid phase, a process known as sublimation. (Peter et al. 2021).
ii. Heat: Heat is applied to frozen product to accelerate sublimation.
iii. Condensation: Low temperature condenser removes the vaporised solvent from the vacuum chamber by converting it back to a solid.

Lyophilisation techniques has various important advantages compared to the heat drying methods.

i. It is an ideal drying technique for heat sensitive products (Salazar et al. 2018)
ii. Easy reconstitution significantly reduces weight and makes the products easier to transport, maintains food/biochemical and chemical reagent quality.
iii. It can enhance product stability in a dry state. (Waghmare et al. 2021)
iv. Reconstitution of the dried product facilitates use in emergency medicine and safe application in hospitals.
v. Lyophilised products sensitive to oxidation can be stoppered and sealed within an inert atmosphere (i.e., nitrogen) to minimise detrimental effects.
vi. It is not limited to products for parenteral use but can also be used for fast dissolving sublingual tablets. Tablets can have very low disintegration time and have great mouth feel due to fast melting effect. (Rey & May 2010).
vii. It is much easier to achieve sterility of the product and freedom of foreign particles than using other drying methods.

Although lyophilisation has many advantages compared to other drying and preserving techniques it has a few disadvantages as well; (Gaidhani et al. 2015)

i. It is a time-consuming process.
ii. It requires heavy cost which in turn increases the coast of the product.
iii. It requires sterile diluents for reconstitution.

2. Objectives

The main objective of this work was to investigate the drying behaviour and sensory properties of Mango (*Mangifera indica* L.). The specific objectives were to evaluate the influence of two types of drying methods on the drying behaviour, to compare the drying behaviour with respect to the used drying technology and to evaluate the influence on sensory properties.

3. Material and methods

These experiments were conducted at the Faculty of Tropical AgriSciences, Czech University of Life Sciences Prague, Czech Republic. The drying and sensory experiments took place in the summer of 2022, while the texture experiments took place in January 2023.

3.1. Fruit samples

The fruit samples used in this experiment were ripe mangoes of the Tommy Atkins variety purchased from a local Kaufland supermarket. These mangoes were washed, peeled and cut to a width of 5mm with a rectangular dimension of 60 mm by 40 mm using a slicer (GRAEF Vivo D-59757, Germany).

3.2 Drying Procedure

The drying of fresh-cut samples of mango was carried out in a heat drier (BINDER RS 422/485 Germany) and lyophilizer (Virtus Genevac SP Scientific, Model- ADP-B2XL-EVA-X, USA).

3.2.1. Heat drying

The heat drying experiments were conducted at varying parameters. The parameters were chosen after the evaluation of test samples to maintain an optimum percentage of moisture content of not less than 10% and not more than 20% (Nyangena et al. 2019; Oppong et al. 2019). They are codenamed H1, H2 and H3 and are shown in Table 1 below.

Table 1: Heat Drying experiments and their parameters.

Trial	Time (hrs)	Temperature (°C)	Relative Humidity (%)
H1	18	45	30
H2	14	55	30
H3	10	65	30

After colour measurements, the mango samples were placed in the heat drier. The three reference samples were placed on weighing balances (Fx-300i, Korea) in the heat drier and their weight was measured at 10-minute intervals throughout the drying period. The dryer was attached to a Dell Vostro 15 3000 computer, and RSMulti data recording software (WinCTplus, A &D Company Ltd, Japan) was used to record the weight readings of the reference samples. After the completion of the allotted drying time, the samples were evacuated from the drying chamber and kept in a desiccator to allow them to return to room temperature, then the samples were collected, and vacuum sealed in labelled plastic bags which were stored at room temperature.

3.2.2 Freeze drying

The freeze-drying experiment was carried out once for 75 hours and at a pressure of 700 mTorr. After colour measurements, the mango samples were placed in the lyophilisation chamber and probes were inserted into the three reference samples to monitor temperature change. Care was taken to first line the glass door to the chamber with lube for adhesion and then frost sealing was carried out.

When the condensation chamber attained a temperature of - 50°C then pre-freezing of samples took place, and the probes were monitored to ensure they attained a temperature of - 20°C. Subsequently, thermal treatment followed for 35 minutes and then the chamber was evacuated. After the conclusion of the drying process, the lyophilisation chamber finished at room temperature and the reference samples were separated for further tests. Thereafter other samples were collected, and vacuum sealed in a labelled plastic bag which was stored at room temperature.

3.3 Organoleptic properties and sensory analysis

3.3.1. Colour Measurement

For each drying experiment, colour was measured two times; before drying and after drying, on three reference samples. The measurement was carried out ten times on each sample with a spectrophotometer (Konica Minolta Cm-600D, Japan).

According to the formula (2) (CIE 1976**)** for measuring colour change dE;

$$\Delta E^*_{ab} = \sqrt{(L^*_2 - L^*_1)^2 + (a^*_2 - a^*_1)^2 + (b^*_2 - b^*_1)^2} \quad (2)$$

Where ΔE^*_{ab} (dE) is the color difference between two colours in CIELAB space

L* is the lightness value (0 black - 100 white),

a* is the greenness/redness value (-60 green - +60 red)

b* is the blueness/yellowness value (-60 blue - +60 yellow)

L$^*_2$**, a**$^*_2$ and **b**$^*_2$ are the colour measurements of dried sample.

L$^*_1$**, a**$^*_1$ and **b**$^*_1$ are the initial colour measurements of fresh sample.

3.3.2. Moisture content and water activity (aw) measurement

After the colour measurements, the reference samples from the heat drying and freeze-drying experiments were then placed in an oven (MEMMERT UF110mplus, Germany) for drying for 24 hours at 105°C. Then samples were retrieved and placed in a desiccator to allow them to return to room temperature and then weighed again to determine dry weight. Moisture content on wet basis was measured using formula (3) (Department of Engineering, Purdue University 2022):

$$\text{Moisture content} = [\text{water weight/total weight}] \text{ X } 100\ \% \qquad (3)$$

Then 3 random samples were chosen from each experiment and their aw was measured using an aw measuring device (Novasina AG Ch-8853 Lachen LabTouch-aw, Switzerland).

3.3.3 Texture Measurement

Samples from each drying practical was subjected to texture analysis using a compression machine, as seen in Figure 9 (INSTRON 34SC-2, USA). Each sample was secured on the load cell with the aid of grips and then the cylindrical crosshead probe (diameter 12mm) was lowered to apply a compressive force to the specimen. This was repeated with varying initial and final force parameters (5N-10, 10N-30N, 30N-60N, 60N-90N, 90N-120N) until the compressive displacement of the specimen due to penetration was recorded by the machine. For each experiment, the mean maximum penetration force was recorded.

Figure 9: INSTRON Compression machine used for this experiment (Author 2023)

3.3.4 Sensory Panel

This testing took place in Summer 2022 at the Laboratory of Food Sciences, Faculty of Tropical AgriSciences, Czech University of Life Sciences Prague, Czech Republic. Twelve semi-trained participants were selected for this analysis. The samples were coded 270, 170, 435 and 845, representing H1, H2, H3 and L, respectively. One sample from each drying experiment was placed on a coded ceramic plate covered with a glass lid. The panellists were seated in individual cubicles containing the response form and writing materials and each panellist was presented with one sample at a time, in no particular order together with a cup of water and a piece of bread to cleanse out the palate between each tasting. There was no time pressure on the participants for the analysis.

Sensory analysis was carried out using an unstructured hedonic scale ranging from 0-10 and measuring 13.5 cm on the paper response form. The response form (see Appendix 1 in Appendices) included the following parameters: General appearance, Colour, Texture, Aroma, Taste, Juiciness, Dryness, General Palatability and a textbox for additional comments. With an unstructured scale ranging from left to right. E.g., 0 = extremely dislike, 100 = Extremely like.

4 Results and Discussion

4.1 Drying Performance

In Figure 12, we can see the drying rates for the reference samples from the heat-dried samples. The drying rate curve is a crucial variable in many procedures that involve removing moisture from a solid substance. During the drying process, it indicates the rate at which moisture is taken out of a material as a function of time (Mujumdar 2006). Understanding the drying rate curve is crucial for increasing the effectiveness of drying processes and has a big impact on the end product's quality. According to recent studies, the thickness of the mango slices and the drying methods utilized greatly influence the drying kinetics, colour, rehydration, and microstructure. The study (Mugodo & Workneh 2021) noted that 3mm was the ideal thickness for mango slices. Additionally, it was found that using drying techniques, such as convection oven drying (OVD) and modified ventilation greenhouse solar drying (MVD) at high temperatures (70°C), shortened drying times and enhanced product quality.

The rate at which moisture is lost from a sample while it is drying is graphically represented by the drying rate curve. The slope of the curve, which represents the rate of drying, is commonly depicted as the relationship between the material's moisture content and time. Due to the significant concentration gradient between the surface of the material and its surroundings, the drying rate is normally high at the beginning of the operation but then gradually declines as the material's moisture content drops until it achieves a constant value at the end of the drying operation (Workneh & Oke 2012). The drying curves obtained in this experiment show a similar trend to the results obtained by Adepoju et al. (2017) and Omda et al. (2008).

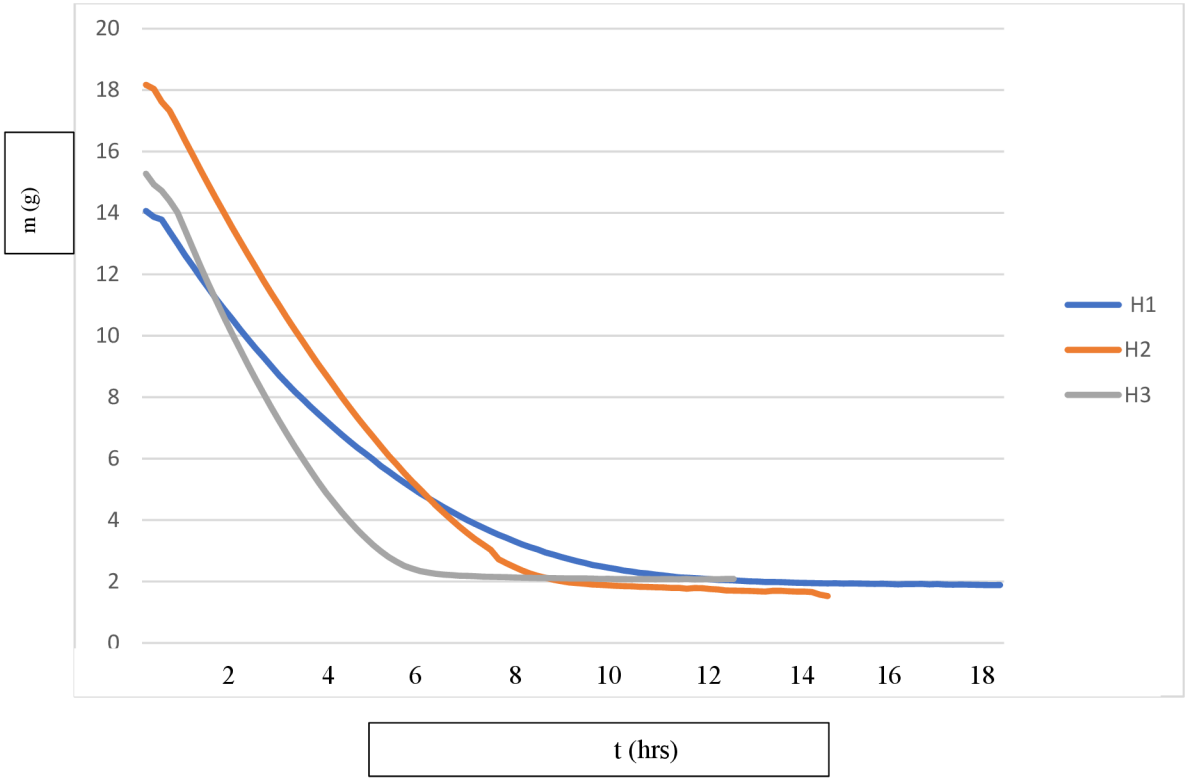

Figure 10: Drying curve for heat samples H1, H2 and H3

4.2 Organoleptic Properties and sensory analysis

4.2.1 Colour measurement

The preservation of natural colour in dried food products is crucial since a consumer's first impression is often based on the appearance of the product (Zellner & Durlach 2003). Colour, along with size, shape, and other factors, contributes to appearance and serves as an important suggestive criterion for sensory evaluation. Most colour changes that occur during drying are due to browning reactions, which can be brought on by both enzymatic and non-enzymatic processes. Fruits and vegetables experience enzymatic browning due to the oxidation of phenolic compounds, which begins the production of the brown pigments known as o-quinones (Calin-Sanchez et al. 2020). Contrarily, non-enzymatic browning is caused by many non-enzymatic processes such as Maillard, caramelisation, and ascorbic acid oxidation and is regulated by water activity, temperature, pH, and the makeup of the final product. Pre-treatments such as the application of sulphites, can be used to inhibit this reaction (Ahmed et al. 2011). However, no pre-treatments were applied to the dried samples used in this study.

The results presented in Table 2 show that the L^* values for H1, H2 and H3 declined against the fresh samples while that of L increased against the fresh samples. The same trend was noticed for a and b values with L showing a negative correlation to other samples when compared to their initial ratings. This does not agree with a previous study which showed a uniform decline against fresh samples from all dried products. (Nazmi et al. 2017).

Table 2: CIE L.a.b colour measurement

		L^* Mean	L^* STDEV	a^* Mean	a^* STDEV	b^* Mean	b^* STDEV
Before drying	**H1**	76.98	1.37	5	0.36	43.81	3.29
	H2	66.51	1.9	5.54	0.72	44.49	3.43
	H3	69.2	1.75	6.9	0.75	58.09	3.83
	L	71.69	1.83	6.74	0.61	48.58	3..6
After drying	**H1**	76.33	0.67	11.96	0.6	63.9	1.5
	H2	65.4	0.79	9.08	0.29	55.6	0.76
	H3	65.46	1.87	9.27	0.56	41.46	2.88
	L	82.69	1.58	6.61	0.85	37.91	2.2

According to the Delta E scale (CIE 1976), colour difference values can be interpreted with the following guide (less or equal to 1.0 - not perceptible by human eyes, 1 -2 - perceptible through close observation, 2-10 - perceptible at a glance, 11- 49 - colours are more similar than opposite, 100 - colours are exactly opposite). A study by Salazar et al. (2017) noted that dE between fresh and dried fruit samples is generally greater than 12. In her study, values of dE between fresh and lyophilized samples ranged from 4.39 to 22.59. Also, similar research by Chong et al. (2013) on dried mango products showed a range of 5-30.

Data from Table 3 indicates that the difference between the colour of fresh fruit and the final colour of all dried samples was perceptible to observers, but it was more similar than opposite. Sample H2 showed the lowest colour change, and this does not agree with the findings of Akoy (2014), who indicated that drying mango slices at 80°C was optimal for lower colour changes. While L was expected to show the lowest colour changes due to the freeze-drying technique, as observed by Izli et al. (2017), this was not so here.

Table 3: Colour change dE for all samples

	Mean dE	STDEV dE
H1	21.31	2.51
H2	11.83	3.78
H3	17.31	7.08
L	13.45	8.67

4.2.2 Moisture content and water activity

Moisture content and water activity for all samples are presented in Table 4. All samples have an acceptable level of moisture content ranging from 13.29 % to 17.5 % for long-term storage with L showing the lowest levels. All samples also display an adequate level of water activity required for long-term storage as studies have shown that microorganisms like bacteria require a_w greater than 0.8 to grow while yeast and mould require a_w of 0.6 and above to grow (Owureku et al. 2018).

The sample L posseses the lowest levels of moisture content and water activity which is most suited for long-term storage. While this level of moisture content can be replicated or surpassed by heating fruit samples for longer periods or higher temperatures, it is possible that this will adversely affect the texture and organoleptic properties of the dried fruit. This is a major reason why the freeze-dried method is regarded as one of the most suitable methods for producing products with low moisture content while retaining similar properties with fresh fruit (Calin-Sanchez et al. 2020).

Table 4: Moisture content and aw for all samples

	Moisture content (%) (Mean, STDEV)	Aw (mean, STDEV)
H1	17.5±0.42	0.494±0.03
H2	16.39±1.47	0.398±0.005
H3	15.95±1.39	0.382±0.01
L	13.29±0.91	0.346±0.04

4.2.3. Sensory Evaluation

From Table 5 we can see that Fruit samples H1 and H2 were judged to have the best general appearance, while L had the worst general appearance. We can also observe that H2, which had the lowest dE ratings shows the highest colour likeability. Overall, all heat-dried samples show favourable colour values compared to L even though L showed a lower dE than H1 and H3. This may indicate panellist familiarity and preference for the appearance of heat-dried products. Heat drying methods affect the quality of the final product, causing a change in flavour, colour, texture and nutrients compared to the fresh fruit. Innovative technologies such as the integrated solar oven drying method have shown a reduction in the loss of nutrients in dried samples compared to oven drying as is presented in the study of Yitayew & Fenta (2021).

According to Berk (2013) freeze-dried products on the other hand have been seen to retain the flavour and nutritional qualities similar to natural fruit, but the lack of pretreatment methods in this practical may be a factor for the relatively low aroma rating of L seen here. Using Pretreatment techniques such as lemon juice on freeze-dried samples have been seen to show better colour acceptance than heat-dried and control samples altogether (Dereje & Abera 2020).

As expected, for Juiciness, we see that L has the highest levels amongst all samples, due to the freeze-drying method retaining most of the properties found in the fresh foods. In terms of Aroma, we can see that H1 is the most preferred sample followed by L. Certain studies have showed that the colour of analysed samples can influence the perception of its flavour (Zellner & Durlach 2003) and we can infer that these may have influenced the judgement of the panellists in this evaluation. When we observe Taste, General Likability and Texture, we can see that L shows higher preference, however, there is no significant difference between all samples in these categories. Furthermore, we see that the H1 sample scores highly in General appearance, Colour, Taste and Aroma, this supports the study of Dereje & Abera (2020) that show heat-drying methods can produce samples equally acceptable to consumers as freeze-dried samples.

Table 5: Results from ANOVA post hoc tukey test on Sensory evaluation responses

	General appearance	Colour	Aroma	Texture	Juiciness	Taste	General Likeability
H1							
	67.93 ± 16.62[a]	65.98 ± 21.84[ab]	65.57± 26.94[a]	59.57± 30.77[a]	37.03 ± 21.42[a]	71.39 ± 26.18[a]	67.87 ± 22.21[a]
H2							
	64.20 ± 19.52[ab]	74.14 ± 19.63[a]	48.77± 11.68[ab]	41.90 ±12.75[a]	34.29 ± 23.22[a]	53.88 ± 23.53[a]	52.20 ± 21.05[a]
H3							
	59.51 ± 13.95[ab]	68.20 ± 16.27[ab]	41.51± 22.16[b]	39.80 ±20.77[a]	24.28 ± 17.39[a]	56.42 ± 25.08[a]	51.52 ± 16.69[a]
L							
	46.54 ± 15.49[b]	47.51 ± 22.39[b]	54.88± 20.44[ab]	57.30 ± 23.24[a]	70.86 ± 14.02[b]	75.49 ± 15.56[a]	70.06 ± 17.02[a]

Values in same column with similar alphabets as superscripts are not significantly different at $p < 0.05$

4.2.4 Texture Analysis

Table 6 below shows a dataset containing values for Compressive displacement at maximum force total, maximum force total and Energy at maximum force total for all samples, generated from the texture compression machine. The empty cells in the table below indicate that the sample had attained penetration and further texture analysis was not required.

Sensory evaluation indicated in table 5 that there was no significant difference between all four samples in terms of texture, but instrumental analysis below shows that samples H1 and L undergo the highest amount of maximum force before they are penetrated. Various texture analysis on dried food products indicate that higher juiciness values are negatively correlated with values for firmness and crunchiness (Farcuh et al. 2020). But this was not observed in this experiment as sample L with the highest juiciness rating is seen to withstand the most amount of force of any sample before penetration.

Table 6: Results of Texture analysis on all samples

	Compressive displacement at Maximum Force TOTAL (mm)				**Maximum Force TOTAL (N)**				**Energy at Maximum Force TOTAL (J)**			
Range of Force applied (N)	**H1**	**H2**	**H3**	**L**	**H1**	**H2**	**H3**	**L**	**H1**	**H2**	**H3**	**L**
5-10	1.63[a]	1.24[a]	0.55[a]	1.19[a]	11.33[a]	11.35[a]	9.4[a]	11.44[a]	0.01[a]	0.007[a]	0.003[a]	0.007[a]
10-30	2.66[a]	2[a]	1.48[a]	1.83[a]	31.5[a]	30.34[a]	26.52[a]	31.63[a]	0.01[a]	0.025[a]	0.025[a]	0.027[a]
30-60	3.17[a]	1.92[a]	0.96[a]	1.75[a]	53[a]	44.83[a]	31.84[a]	41.86[a]	0.1[a]	0.046[a]	0.014[a]	0.038[a]
60-90	3.92[a]			1.97[a]	44.85[a]			47.64[a]	0.113[a]			0.045[a]
90-120				1.94[a]				89.59[a]				0.067[a]

Values in same row with similar alphabets as superscripts are not significantly different at $p < 0.05$

5. Conclusion

The drying behaviour of Mango (*Mangifera indica* L.) was investigated using heat-drying and freeze-drying methods with various parameters H1, H2, H3 and L. In addition to these, the samples were measured for moisture content, colour, water activity and texture. Sensory evaluation was also carried out by a group of semi-trained panellists. Results from drying behaviour showed a colour difference ranging from 11.83 to 21.31, with the freeze-dried sample not showing the lowest values, contrary to other research. The moisture content range of all dried samples was 13.29 % to 17.5 % and water activity for all samples was from 0.346 to 0.494 with the freeze-dried Sample L producing the most suitable values for long-term storage. Sensory evaluation indicated that all samples possessed favourable sensory qualities and were generally acceptable to the consumers, heat- dried sample H1 was most preferred in terms of General appearance, Texture and Aroma. While the freeze-dried sample L was most preferred in terms of juiciness. All samples were generally acceptable to the consumers as there was no significant difference in the values of all samples for that field, with a slight preference for L. More studies need to be carried out in this field to explore more parameter for heat-drying and freeze-drying food products. I recommend that the Freeze-dried technology will be suitable for markets in advanced economies able to afford the costs of using this technology, and which will appreciate the sensory qualities of the product; while the heat-drying process, as evidenced by H1 is comparable in quality and therefore is an affordable option for production in less developed regions. These will be important for food manufacturers in developing regions where proper postharvest technologies need to be adopted to reduce waste and increase production, and utilizing the freeze-dried technology may prove too costly or ineffective.

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APPENDICES

Appendix I: Unstructured sensory evaluation form provided to the panellists to rate the dried mango samples using the continuous scale method.

Task: Please evaluate carefully the samples before you. Rate the samples by indicating your preference on the scale between the two horizontal points "Extremely like and Extremely dislike" .

Mark on the scale with your pen to show your rating of the samples.

It is recommended to take a sip of water in between samples to ensure proper evaluation. If you want to provide more feedback, a box for additional comment is provided for each sample.

Sample 270

General appearance

Extremely Dislike Extremely Like

Colour

Extremely Dislike Extremely Like

Texture

Extremely Dislike Extremely Like

Aroma

Extremely Dislike Extremely Like

Taste

Extremely dislike Extremely Like

Juiciness

Extremely dislike Extremely Like

Dryness

Extremely dislike Extremely Like

General Palatability

Extremely dislike Extremely Like

Additional comments	