OPTIMIZATION OF PROCESSING PARAMETERS IN THE PRODUCTION OF MANGO FLAKES

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This dissertation is my original work and has not been submitted for the award of a degree in any other University

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DEDICATION

To my family, my parents and siblings, for always checking up on me and giving me the motivation and courage to continue with my education journey, I always thank God for granting me the grace to have such a caring family. You have always been my source of strength and resilience. May God bless you in abundance.

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ABREVIATIONS AND ACRONYMS

AAS	Atomic Absorption Spectrophotometer
ANOVA	Analysis of Variance
AOAC	Association of Official Analytical Chemists
CCD	Central Composite Designs
CFU	Colony-forming Unit
GMP	Good Manufacturing Practices
HACCP	Hazard Analysis and Critical Control Points
ISO	International Organization for Standardization
KEBS	Kenya Bureau of Standards
PDA	Potato Dextrose Agar
RSM	Response Surface Methodology
SPSS	Statistical Package for Social Scientists
TCA	Trichloroacetic Acid
TSS	Total Soluble Solids
TTA	Total Titratable Acidity

OPERATIONAL DEFINITIONS

Calories	The amount of heat needed to raise a quantity of water by one degree Celsius of temperature. It is normally used to express the energy composition of food.
Economic potential	The potential of a food commodity to provide economic development and growth and creation of surplus value
Food value	The measure of a well-balanced ratio of the essential nutrient carbohydrates, fat, protein, minerals, and vitamins in items of food or diet in relation to the nutrient requirements of their consumer.
Fortification	Enriching food with micronutrients by manufacturers to reduce micronutrient deficiencies.
Gelatinization	The process of converting into a gelatinous form or a jelly under heat treatment.
HACCP system	A management system which ensures the safety of food through control of the chemical, biological and physical undesirable components in food.
Micronutrient deficiencies	Insufficiency of one or more of the micronutrients required for optimal human health. They include both vitamin deficiencies and mineral deficiencies**,**
Nutraceutical value	The composition of food products that is less than the pharmaceuticals and more than food.
Optimization	Determination of the most effective processing parameters.
Organoleptic losses	Sensory deterioration in terms of mouth feel appearance, aroma bouquet, and taste.
Pasteurization	A process in which packaged and non-packaged foods are treated with mild heat, usually to less than 100 °C, to eliminate pathogens and extend shelf life.
Physicochemical parameters	Physical and chemical properties of food include mechanical, thermal, water activity, and properties. The chemical properties are acidity, flavoronents, enzymes and, pigments.

Shelf stability	The ability of a food sample to be stored at room temperature for a long time without going bad.
Utilization	Putting a commodity to its best effective use.

ABSTRACT

Mango fruit (Mangifera indica. L) is a common fruit seasonally produced in large volumes in Kenya. However, post-harvest losses which can be attributed to a lack of enough modern processing technology have been a bottleneck in the maximization of the fruit's economic and nutritional potential. Mango flakes are one of the products that can be produced from mango fruits. Further enrichment of mango flakes with locally produced green grams has been viewed to have the potential to enhance their nutrition profile. The study was designed to optimize the processing parameters in the production of mungbean-enriched mango flakes.

A randomized block design was used to determine the consumer acceptability of drum-dried mango flakes. A total of 15 treatments were obtained using sugar variations of 0%, 2%, and 4%, and starch at 0%, 10%, and 20%. 30% of cooked mungbean paste was incorporated into the formulations. Process variables were determined by varying pressure of steam (0.8 BAR, and 1.6 BAR) and speed of drum drying (2.2 rpm and 7.6 rpm). Sensory analysis was done using a 7-pointer hedonic scale. Response Surface Methodology (RSM) of Design Expert 13 software, was used to optimize mango flakes production procedures by adjusting factorial variables. Moreover, bacteriological status analysis for yeasts and molds was determined using dextrose potato agar. A completely randomized design was used to compare means between variables and test for significance. A total of 16 samples were taken through microbial analyses with respect to the type of packaging material, storage temperature, and mango varieties. Physicochemical and nutritional analysis was done using predetermined AOAC procedures. Results indicated that formulations that were incorporated with 20% starch, and 0% sugar, and dried at 7.57 rpm for 5 minutes and 2 seconds at a constant gauge pressure of 0.8 BAR were the most preferred with a mean overall sensory score of 5.79. Homogeneity of variances was observed between different formulations for overall acceptability (P=0.192). The average yeast and mold counts were 2.8 log10cfu/g within the eight-month storage duration, with 98.4% of the samples compliant with Kenya Bureau Standards (KEBS), and East African Standards for dried mango products. Packaging material and storage temperatures did not play a role in influencing the rate of microbial growth with one-way ANOVA analysis indicating P-values of 0.064 and 0.851 respectively for statistical differences. Mungbean-enriched mango flakes showed average ash, beta carotene, vitamin C, crude fiber, protein, and moisture content of 0.21±1.50 g/100 g, 0.21±1.50 g/100 g, 15.75±13.22 μg/100 g, 22.17±5.81 mg/100 g, 0.63±0.17 g/100 g and 15.57±1.50 g/100 g respectively. Magnesium was the predominant mineral with an average of 44.16±2.52 mg/100g. Significant differences were noted in ash, and fiber composition in mango flakes processed from different mango varieties as well as those drum-

dried at different steaming pressure. The study concludes that the incorporation of cooked green grams paste enhances the protein, beta carotene, and mineral profiles of mango flakes. However, high-pressure treatment combined with an inappropriate ratio of ingredients negatively impacts the composition of mango flakes by reducing the content of volatile components. It is therefore important to encourage the reduction of high-temperature exposure of mango-based products during treatment by using low-pressure production mechanisms.

CHAPTER ONE: INTRODUCTION

1.1 BACKGROUND INFORMATION

The mango fruit (*Mangifera indica*. L) is a common fruit produced in tropical regions. According to (Mitra, 2016) mango farming is estimated to be taking place in over 100 countries worldwide with an estimated production volume standing at 40 metric tons. Its production is characterized by both small-scale and large-scale farming. In Kenya, mangoes are considered one of the high-production potential fruits which can survive a wide range of ecological zones. Mangoes can grow in semi-humid areas as well as in semi-arid regions (Mitra, 2016). The economic impact of mangoes production has not only improved livelihoods among the farmers but also has been a big boost in the expansion of the food industry. However, despite the positive impact of mangoes, its utilization has not been fully exploited.

Post-harvest losses which can be attributed to a lack of enough modern processing technology have been a bottleneck in the maximization of the fruit’s economic and nutritional potential. Another challenge is its seasonal availability and that is beside its high perishability. Mango harvesting in the Central and Eastern parts of the country is at its peak between December and March while in the Coastal region, mangoes are in plenty between November and December (Muriithi *et al*., 2016). Lack of enough knowledge of the appropriate mango varieties for the different ecological zones is another drawback in the optimization of its production volume in Kenya. The latter can be attributed to a lack of enough dissemination of mango varieties that were introduced from foreign countries such as Australia, Florida, and Israel. This is because the new commercial mango varieties were introduced in the 1980s from the above-mentioned countries but farmers were not sufficiently trained on the proper agroecological zones for the specific new varieties.

Mangoes possess good nutritional content such as carotenoids, minerals, and antioxidants (Yamato *et al.*, 2020). Even though value addition is important in realizing its nutritional and economic potential, some of the processing methods used for the production of various mango products lead to nutritional losses. One of the factors that can lead to these losses is exposure to high temperatures. Optimization of heat treatment plays a major role in the determination of the quality of different mango products.

Mango flakes are one of the products that can be produced from mango fruits. When compared to other mango products such as juice, puree, and concentrates, mango flakes can stay for a long without spoilage due to reduced water activity. Flake production through drum drying has shown to be effective in that it has high nutrient retention as well as its benefits in terms of cost-effectiveness (Yamato *et al.*, 2020).

Value addition through mango flakes production has been shown to increase the stability of mangoes. Research has shown that the stability of dried products can be attributed to reduced water activity (Yamato *et al.*, 2020). The production process through drum drying, and the addition of different additives at a 3% dry basis (corn starch or maltodextrin 10DE), was evaluated and results show that it is indeed effective. The estimated shelf life, based on the obtained isotherms, showed that a package with a high barrier to water vapor is also effective. According to results from previous studies, the product with maltodextrin showed a more hygroscopic behavior and higher instability during storage in comparison with the product with corn starch.

1.2 STATEMENT OF THE PROBLEM

Mango production in Kenya has been characterized by seasonal harvesting periods. Seasonality deprives people of its nutritional availability when the fruit is off-season. Post-harvest losses incurred by farmers during harvesting periods that can be attributed to underutilization of the fruit have been a big issue that has not been addressed sufficiently. High price tags slapped for the acquisition of the fruit in the market when they are off-season reduce its intake by reducing its economic accessibility. The economic gain from the fruit in terms of revenue is minimal when the mangoes are in season. This can be related to the lack of a good market structure that leads to low market pricing of the fruits from December to March for the Central and Eastern parts of Kenya, and November to December for the case of the Coastal region when the fruits are in season. Mango farmers at this stage are forced to settle for cheaper prices.

Mango fruits have a short shelf life. They are one of the most perishable tropical fruits due to their high-water content when ripe. Under ambient conditions, ripe mangoes can stay fresh for 4 - 9 days. When stored under cold conditions, the fruits can stay fresh for 2 to 3 weeks (Maina *et al.*, 2019). Their shelf stability is worse when they have to be frequently transported from one area to another.

Lack of enough knowledge and facilities has been an area of concern. In the rural areas where small-scale farming of the crop is done, farmers still languish in poverty despite their efforts to commercialize the crop. Farmers have not been trained in value addition. It is for this reason that their main focus has been on the mango fruit itself and less on other products that can be produced from the mango fruit. The result of this is revenue generation that does not reflect the fruit’s economic potential.

Another gap that has been exposed in the mango value chain is the nutritional degradation during the value addition process. The physicochemical and nutritional content of dried mango products may not be the same as that of fresh mango fruits. Sun drying is one way of improving the shelf stability of mango by-products. However, as much as the method is effective, the exposure of the drying products to the ambient environment and the prolonged time factor are some of the drawbacks of this method. High-temperature treatment of fruits above 65℃ leads to loss of unstable compounds and nutrients such as antioxidants and beta carotene. Fruit products treated at high temperatures change their nutritional components and may not be very cost-friendly (Yamato *et al.*, 2020). Apart from the nutritional losses, exposure to high temperatures for a long time can negatively affect their aroma, color, and palatability in general (Izli *et al.*, 2017). Development of a shelf-stable and nutritious mango flakes using local varieties is yet to be realized. The study will produce shelf-stable and market-acceptable mango flakes while taking into consideration the retention of the nutritional and physicochemical properties of the mango fruit.

1.3 JUSTIFICATION OF THE STUDY

According to Sarkar & Chakraborty (2018), only 2% of the produced mangoes undergo processing while about 20%- 30% go to waste. These losses are a representation of the annual underutilization of the fruit. Because mango fruits have a moisture content of 81.7% (Sarkar & Chakraborty, 2018), lack of processing exposes them to fast physicochemical deterioration.

The price of mangoes during the on-season period is extremely low. It is during this period that buyers portray an opportunistic attitude due to the informal nature of the mango market (Martin, 1986). Farmers are, therefore, not able to get fair prices for the mangoes that come twice a year. Satisfaction in terms of economic returns can, therefore, be achieved by value addition through the production of diversified mango products of high economic value. It is through this approach that income generation by mango farmers can be improved through the production of optimally processed mango flakes. Information from this research will provide measures for economies of scale commercialization through low-cost, effective production and efficient processing practices.

The beneficiaries of this study will be the small-scale farmers who are the backbone of the mango value chain through the generation of more income from the more diversified mango products. Processors will also get informed on the optimal processing conditions for enhancement of the quality of the product. Shelf-stable stable mango flakes will be beneficial to consumers since they will acquire products with a longer shelf life.

1.4 AIM OF THE STUDY

The study aims to contribute towards improvement of the of utilization of mango fruits through the production of diversified mango products while at the same time reducing the rate of wastage brought about by the seasonality nature of mango production.

1.5 PURPOSE OF THE STUDY

The purpose of the study is to generate data that can be used in developing quality standards to be used in the processing of consumer-acceptable mango flakes.

1.6 STUDY OBJECTIVES

1.6.1 Overall objective

To optimize processing parameters in the production of mango flakes.

1.6.2 Specific objectives

i. To establish optimization process and product factors for the production of sensory-acceptable mango flakes.

ii. To determine the physicochemical and nutritional stability of optimally produced mungbean-enriched mango flakes from different mango varieties.

iii. To evaluate the shelf stability of drum-dried mango flakes under different storage conditions and temperatures.

1.8 HYPOTHESES

1. There is no difference in the sensory-acceptability of mango flakes produced under different process and product factors.
2. There is no difference in the physicochemical and nutritional composition of optimally produced mungbean-enriched mango flakes from different mango varieties.
3. There is no change in shelf-stability of mango flakes when subjected to different storage conditions and temperature.

CHAPTER TWO: LITERATURE REVIEW

2.1 MANGO FARMING IN KENYA

Mango farming in Kenya is vital economically as it plays a big role in income generation while also creating employment opportunities especially in the rural areas. Its production in Kenya is mainly done on a small scale basis (Midingoyi *et al.*, 2019). It is estimated that by 2019, about 47,000 ha of land was put under utilization for the purpose of mango growing. Its subsequent production volume stood at 580,000 tones (Gitahi *et al.*, 2016). Production is estimated to have significantly increased since then and it is projected to increase even more in the coming years. When exported, mangoes generate revenue. Although many varieties of the fruit were introduced in Kenya centuries ago, there are three mango varieties that are mostly grown in Kenya; *Ngowe*, *Apple* and *Kent* (Gitahi *et al.*, 2016).

Despite of the efforts made to put the fruit into improved utilization and reduce postharvest losses, the fruit's perishability remains a roadblock in achieving this target. Lack of efficient facilities that can store mangoes during their glut season especially in the rural areas remain a big challenge. An alternative which can be a remedy to mitigating this problem is production of mango products with a longer shelf life. This can only be achieved through equipping local farmers on value addition through processing. Capacity building by training has however, proved to be costly (Friday, 2013). Furthermore, export of mango fruits has been minimal due to the lack of processing facilities. According to a report that was published in 2013, the volume of mangoes that were exported worldwide stood at four percent of the total production volume (Edward, 2017).

2.2 MANGO UTILIZATION IN KENYA

Mango and mango products play a substantial role in the food safety sector. For its effective utilization, about 20% of the mangoes are converted into different forms through processing. These transformations are in the following forms; nectar, juices, slices, leather and puree (Ravani & Joshi, 2013). It is from these forms that gives a survival margin to the mangoes during their on-season periods in terms of shelf- life. Apart from the fleshy parts of the mangoes, the other parts which can be put into utilization include the mango peels and seeds. Mango peels and kernel are rich in carotenoids, polyphenols, dietary fibers, tocopherols and phytosterols. Apart from the above-mentioned bioactive compounds, mango peels in particular have shown to possess antioxidant properties (Ravani & Joshi, 2013). Utilization of the peels and seeds plays an important in reducing wastes resulted from the processing of mango fruits. For the purpose of nutritional stability and to protect the physicochemical profiles of mangoes, dehydrated mango products have been recommended by scientists. According to (Sarkar & Chakraborty, 2018), when mango pulp is formulated with other components such as soy flour, sugar, pectin, coconut powder and some preservatives on a dry matter basis, the end product becomes less perishable while also serving the purpose of prolonged shelf life.

2.3 HEALTH BENEFITS OF MANGOES

Aside from the economic contribution of mangoes, they are highly nutritious and can be a remedy in reducing macronutrient and micronutrient deficiencies when utilized well. The rise in the popularity of mango and mango products is further due to its pharmaceutical and nutraceutical value. *Mangiferin*, which is an common polyphenol in mango has been regarded as a remedy in combating degenerative diseases such as cancer and heart diseases (Masibo & Qian, 2008). The polyphenols in the mangoes however, are not limited to the mango pulp as they vary in different mango parts such as peels, seeds and pulp. Mango pulp which is the main processed product of the fleshy part of ripe mangoes, is rich in vitamins and proximate components. For example, 100g of mango pulp contains 3894 IU of vitamin A, 27.7 mg of vitamin C and 1.8 g dietary fiber (Martin M & Qian H, 2009). Table 2.1summarizes the micronutrients and macronutrient components in 100 g of mango pulp

Table 2.1: Food value for 100 g of mango

Component	Amount (per 100g)
Vitamin A (carotene), mg	0.135–1.872 12
Calories (Kcals)	62.1–63.7
Water, g	78.9–82.8
Protein, g	0.36–0.40
Fat, g	0.30–0.53
Carbohydrates, g	16.20–17.18
Fiber, g	0.85–1.06
Ash, g	0.34–0.52
Calcium, mg	6.1–12.8

Source; Adopted from (Martin Masibo & Qian He, 2009)

Mangoes are also a relatively good source of proteins. A 100 g of mango pulp constitutes about 0.4g of protein. When broken down into its building blocks, mangoes contain essential amino acids which include valine, leucine and lysine in the ratio of 4.3: 6.9: 5.8 respectively.

2.4 PHYSICO-CHEMICAL PROFILES OF MANGOES AT DIFFERENT RIPENING STAGES

Ripening of stages play a role in the physical and chemical properties of the mangoes. This not only gives an overview of the nutritional components at the different stages; it also tells how storage can influence their nutritional profiles. Different varieties of the fruit have varying ripening periods in terms of nutritional characteristics, flavor and storage behaviour (Okoth *et al.*, 2013). Apple fruit records the highest vitamin C content of 109.35 mg/100g in its unripe stage. Its total titratable acidity (TTA) is extremely low at 0.04%. Total Soluble Solids (TSS) was found to be the highest at >19.5 ^{0}Brix during its ripe stage. The moisture content of *Apple* fruit was lowest at 79.96% when ripe (Okoth *et al.* 2013).

2.4.1 PHYSICO-CHEMICAL CHANGES OF MANGO FRUITS DURING RIPENING

During ripening, there are a number of physical, sensory and chemical changes that occur to the profiles of mango fruits. The fruit's color and firmness changes takes place in an inward-outside direction (Ngamchuachit *et al.,* 2016). The changes are however subject to the mango varieties. For example, according to USDA, the water content of Kent, Keitt, Tommy Atkins, and Haden varieties is 83.4 g per 100g while that of Azucar have a water content of 79.3g per 100g. Lipid composition of mangoes improves with time especially the omega-6 and omega-3 fatty acids (Maldonado-Celis *et al.,* 2019). During different ripening stages, the firmness of the fruit decreases. This decrease is attributed to the conversion of pectin into soluble forms causing the softening of the fruit. Apart from the reduction in firmness of the fruit, the conversion of pectin improves the Total Soluble Solids profile of the mangoes. Titratable Acidity changes are recorded inversely during ripening. The changes occur concurrently with the PH of the fruits. These changes are as a result of the conversion of the organic acids in the fruit into sugars (Rooban *et al.,* 2016). An increase in sugar profile of mangoes during ripening is also a result of hydrolysis of starch to glucose during maturation. Amino acids content in mangoes increases with advancements in maturation period. However, the protein profiles of mangoes are only in trace quantities as earlier reported. As opposed to the other micronutrients ripening trends, vitamin A and C content in mango fruits reduces with maturation (Maldonado-Celis *et al.*, 2019). The deterioration of vitamin C content is attributed to metabolic pathways taking place during this period. The table below shows a summary of the changes in mango profiles during ripening

Table 2.2: Changes in mango profiles during ripening

Stage	Firmness (Kg/cm^2)	Total soluble solids (Brix)	Titratable Acidity (%)	pH
Immature	43.8±2.19	9.2 ± 0.46	26 ± 1.30	3.3 ± 0.16
Mature	34.4 ± 2.06	11.2 ± 0.67	24 ± 1.44	3.9 ± 0.23
Quarter Ripen	28.4 ± 1.98	13.3 ± 0.93	17 ± 1.19	4.8 ± 0.33
Half Ripen	22.4 ± 1.12	15.1 ± 0.75	16 ± 0.80	5.9 ± 0.29
Full Ripen	18.5 ± 1.11	19.1 ± 0.95	14 ± 0.84	6.8 ± 0.40

Source: Hoque *et al*., (2017)

2.5 MANGO PROCESSING

Mangoes can hardly be transported over long distances or exported due to their high perishability. It is for this reason that processing comes into play. Although the primary goal of processing is to add value in terms of nutrient content and overall acceptability of the mango products, achieving a shelf stability is important as it makes the products available over a longer period of time. There are several forms in which mangoes can be processed into. These forms include mango puree, leather, pickles, chitney, nectar, canned slices and other industrially related products (Dyab *et al.,* 2016). These forms can easily be transported and stored as compared to the natural mango fruits. An advanced form of mango processing is the development of mango dried powder. Advancements in processing technologies enable mango powders to have a natural color and pigment. The dried powder is advantageous over the fruit juices which are commonly found in the market in the sense that it requires less storage attention. The juices are also of a shorter shelf life as compared to the juices and nectar (Dyab *et al.*, 2016). Processing of mango waste products, which constitute of 35% to 60% of the fruit (Dorta *et al.,* 2012), has played an important role in environmental conservation. In the past, only the edible parts of mangoes would be utilized while the rest of the fruit would be discarded. New developments have emerged and there has been an interest in the wastes from peels and seeds. These products which were initially discarded are now being utilized as cheaper options as nutraceutical ingredients in the subtropical and tropical food processing industries (Jahurul *et al.,* 2015).

Thermal processing is a common practice in the processing of mangoes to reduce microbial spoilage and prolong shelf life. However, this treatment may not be very efficient as it contributes to nutritional and organoleptic losses in the products (Kaushik *et al.,* 2014)

2.5.1 The dynamics of flakes processing

Fitriani *et al.* (2019) described flakes as one of the cereal breakfast snacks that is mainly characterized by its crunchy texture and its reduced water content. To enhance its nutritional composition during its production, two or more ingredients are mixed to make a composite mixture. In its production as described by one of the authors, a product formulation of the ingredients was mixed in a pre-determined ratio. Vanilla and sugar are added at a 2% each while also a mixture is formed. The flakes dough that was formed is flattened using a roller, molded and dried in an oven drier (Carvalho *et al.*,2012). For the purpose of optimizing the best temperature treatment, the flakes are put for three hours at varied temperatures of 40^0C, 60^0C and 80^0C.

2.5.2 Mango flakes processing

Mangoes have an excellent aroma, flavour and has a high therapeutic value. For the purpose of market acceptability of mango products, it is important to ensure these attributes are maintained over a long period of time. Mango flakes which are a dried by-product of mangoes can achieve durability, storage and transportation stability. Addition of wheat flour to mango pulp helps in retention of physicochemical components such as ascorbic acid, moisture content, total soluble solids, PH and titratable acidity. According to a study conducted by (Ahmed, 2015), addition of sorghum and wheat flour helped in the retention of vitamin C profile of mango flakes by about 90%-98% at a temperature of 30^0C for up to 6 months.

Drum drying is a cheap option for drying of mango flakes. Another way of obtaining dry powder is through spray drying. This technique utilizes hot gas to dry slurry solutions or liquid. However, through drum drying, high nutrient retention is achieved. The method also has other advantages such as cost effectiveness, easy to clean, high flexibility, energy efficiency and it is easy to operate (Yamato *et al.,* 2020). There are other additives which can be used during drum drying of mango flakes. These include maltodextrins, starches, gums, and pectin. In addition to the low molecular weight contained in the mentioned additives, they also are rich in sugars. These attributes are useful in avoiding stickiness, increasing the T g of the dried product and generally contribute to the stability of the final product (Yamato *et al.,* 2020).

One commonly practiced mode of drying especially for fruits and vegetables is the hot air drying. Although it is a relatively fast method of drying, this technique can be detrimental to the color, flavour and the nutrients of the product. Microwave drying is another method of dehydration that can be utilized in the production of mango flakes (Kumar, 2019) The effectiveness of this method is from its ability to achieve kinetic energy from electromagnetic energy. Since this method mainly focuses on the water molecules in a product, the energy builds up in the product increases the drying rate of the product thus saving energy. This is because energy generated cannot be transferred due to the nature of the method. The two biggest draw backs in this technique is the textual damage that are resulted from energy generated and overheating of the product surfaces (Izli *et al.,* 2017).

2.5.3 Fortification

Food fortification has been defined by the Regulatory Monitoring of National Food Fortification Program as incorporation of essential minerals and vitamins during processing to enhance its nutritional composition of the end product. According to Kruger *et al.,* (2020) cases of undernutrition have been increasing worldwide over the years. The same report indicates that globally 88% of the countries experience more than one form of malnutrition. Fortification is one of the approaches that have been used to improve micronutrients intake. The world today focuses on different approaches to improve food quality, processing capacity and storage as well as adoption of education for the sake of food acceptance. Fortification plays an important role in reducing micronutrient deficiencies while also taking into consideration the cost effectiveness of the food. With the growing world populations and the ever-increasing agricultural productions and industrially processed food products, the shift has been on the exploration of new processing approaches.

Fortification of fruits and cereals has been helpful even in combating what was initially considered as wastes. Results from studies have indicated that the agro wastes contain valuable nutrients which can be utilized through incorporating into other food products (Lai *et al.,* 2017). New trends such as the Food-to-Food Fortification (FtFF) are emerging which aim at achieving bioavailability of micronutrients. Other forms of fortification include biofortification, conventional and dietary modification. Apart from improving self-reliance and sustainability, these strategies create market opportunities and self-reliance of food products that are produced locally (Kruger *et al.*, 2020). Much however, need to be done to deeply evaluate the effectiveness of the approaches in achieving the bioavailability of micronutrients.

2.5.4 Shelf life of flakes

The extremely low water content of flakes determines their shelf stability. In the case of breakfast flakes, for example, the product can stay up to one year without undergoing physical deterioration (Azanha & Faria, 2005). The bottleneck in ensuring the stability of flakes is the ability of the product to gain moisture from the environment which consequently affects their consumer acceptability. The period which flakes can stay however, varies depending on a number of factors. The type of packaging material is one of those factors. (Galić *et al.,* 2009).

Textural and change in flavour changes with time when the product is not properly stored.

2.6 PHYSICO-CHEMICAL CHANGES DURING PROCESSING AND STORAGE

Lack of proper handling of mangoes prior to processing can lead to 20%- 30% losses (Rathore *et al.,* 2007). Spoilage due to anthracnose and stem end can also compromise the fruit's storage potential. Processing techniques and different storage conditions affect the volatile and phenolic compositions of mango and mango products. Phenolics are responsible for the quality of mangoes. Phenolics compounds present in the fruit such as gallic acid, sinapic acid, ellagic acid and quercetin are responsible for enhancing the taste and visual appearance of the mango products (Zhao *et al.,* 2016). Organoleptic attributes such as taste, aroma and color are also affected by these exposures. A study report by (El-Nemr *et al.,* 1988) showed that heat treatment of mango juice at 85^0C for 10 minutes resulted to reduction of all volatile fractions due to evaporation. Volatile compounds such as 5-methyl furfural, acetyl furan, β- terpineol, butyl-3-hydroxyl butanoate and terpinene-4-ol were found in the heated juice which were not present in the fresh juice. The development of these compounds is related to degradation of the ascorbic acid which was in the fresh juice (El-Nemr *et al.,* 1988). Mango juices which were stored under room temperatures also displayed development of ethyl fatty acids and a decrease in oxygenated compounds as well as hydrocarbons. These changes altered the general appearance and quality of the juice. Exposure of mango puree to heat causes inactivation of polyphenol oxidase and at the same time affect the stability of beta carotene (Vijayanand *et al.,* 2015). Concentrating mango pulp in hot air cabinet dryer at about 70^0C and 16^0brix- 28^0brix results to maximum beta carotene retention. However, a 16 minute heat treatment of mango puree by pasteurization for a temperature range of between 85^0C and 93^0C results to 15.4% loss of vitamin A. (Rathore *et al.,* 2007) reported a significant increase in total soluble solids (TSS) with storage time (10%- 25.27%). Titratable acidity on the other hand significantly had an inverse trend as compared to the TSS. The average TTA reduction for the 15-day storage. was 15.67%.

2.7 MANAGEMENT OF MANGO BY-PRODUCTS

Mango processing is an important player leading to the expansion of the food industry all over the world. The mango agroindustry sector is projected to expand even more in the coming years due to the ever-increasing technologies and industrialization. However, the massive industrial processing gives rise to high volumes of bio wastes ranging from the mango peels, to the kernels and the discarded mangoes. As stated earlier in this chapter, mango by products make about 35%- 60% of the mango fruit depending on the size of the fruit. These wastes not only pose a public health threat but also disadvantageous economically. Different approaches have been initiated to put the non-edible mango parts underutilization through measures such as bio utilization and using them for livestock feeding (Wall-Medrano *et al.,* 2020). Industrial innovations are still needed to tap the bio efficiency of the mango by products. According to a report by (Wall-Medrano *et al.,* 2020), mango peels are a rich source of dietary fiber, some phenolic compounds and carotenoids. These aspects can be helpful in the nutraceutical manufacture of drugs which are a remedy for cardiovascular diseases, diabetes type 2 and cancer. On the other hand, mango seed has been reported to be a rich source of protein, macromolecules and vegetable oil. The seeds also have antibiotic potential which can be a cheaper option in the nutraceutical industries. Another study conducted by (Aslam *et al.,* 2014), showed that mango peel powder contained a high level of antioxidants activity and crude fiber. Mango kernel powder was characterized by high levels of total phenolics, total ash and protein. When the mango kernel powder and mango peel powder were incorporated in biscuit by 5% and 10% respectively, the nutritional content and acceptance of the biscuits were significantly enhanced.

In an attempt to reduce waste of mango by- products, scientists have been looking for ways to use bio waste to produce ethanol (Boyce, 2014). This can be a cheaper energy alternative to the fluctuating fuel prices. The hemicelluloses and celluloses present in mango peels especially that can be hydrolyzed into sugars that can eventually be fermented. In addition, waste management, exploration on alternative biomass can help in reduction atmospheric pollution caused by petrol fuel.

2.8 MARKET STRUCTURE OF MANGO PRODUCTS

Agricultural produce plays an important role in the economic growth of a country. One sub-sector involved is the fruits and vegetables which accounts for about 10% of urban consumed foods and even a plays a bigger role in the rural food consumption (Interface *et al.,* 2009). The structure of mango marketing in Kenya is characterized by small scale channels (Davis *et al.,* 2017). According to (Curir, 2012) 98% of the mangoes produced in Kenya are consumed locally and only 2% is exported. The local prices are however, extremely low especially when the mangoes are in season. Gate prices may be as low as Ksh 2 to Ksh 9 per piece while the wholesale prices may range between Ksh 15 to Ksh 70 for crates that contain about 70- 600 mango pieces (Pollire, 2022). Most of the gate buyers are local traders, middlemen processors and on a small-scale processor. One big weakness of the mango chain is lack of collaboration between players that is resulted from lack of trust between players. Reinforcement of the above mentioned challenge is caused by lack of clear quality standards and clear price (Curir, 2012). These markets are one of the players that lead to the farmers to hang onto.

There is no clearly defined marketing board for mangoes in Kenya. The market is fully liberalized with the government only playing regulatory role. In a liberalized system, the sellers lack bargaining power hence end up being exploited by the buyers. Another roadblock resulted from this liberalization is the inability of the mango farmers to access high value markets for their produce. The end result of this is farmers looking for one channel where they sell the majority of their products. (Davis *et al.*, 2017) . With this done, price satisfaction becomes a big a challenge to achieve.

Establishing high value standard products such as pulps and juices is beyond the capacity of the small scalers. (MPOC, 2020). Capacity building in terms of processing training is therefore necessary if utilization is to be scaled up. Little has been done on linking external players such as women-led entrepreneurs to the formal mango processing firms.

2.9 GOOD MANUFACTURING PRACTICES (GMP)

The food manufacturing industry is always at the forefront when it comes to the global business face. (Rajendran & Sharaai, 2020). Food consumers are sensitive to ethical considerations in terms of the production elements used in food industries (energy and water). The safety of the production process is as well an issue that is of great concern. Quality assurance is a necessity when an industry or a firm has to produce a food product or is in any way involved in handling of food products. Good Manufacturing Practices is part of the quality assurance that ensures that there is uniformity in the products produced and that the products are controlled for the appropriate standards as stipulated by the relevant marketing authorities of a given country (Ngwa, 2017). Adoption of There has been a call by manufacturers and other interested parties to ensure that these practices are made 'open ended.' This stipulates that assessment of good manufacturing practices should not only focus on the end product but should also focus on implementation and compliance for the whole process in the production line. GMPs are important since they enhance customer acceptance for products while also increasing the efficiency of the processing and production processes. One drawback commonly experienced in most of processing plants for fruits is the lack of enough information and knowledge for the implementation of the GMPs due to lack of International Organization for Standardization (ISO) and Hazard Control and Critical Control Point (HACCP) systems (Ngwa, 2017). GMP can be extrapolated to quality of fruit products such as mango pulp. Quality can be explained in three different ways (De Farias Silva *et al.*, 2015). The first approach is analyzing the quality and physicochemical characteristics of the mango pulp compared to other food products. The second point of concern is the nutritional content and how it influences benefits on food for consumers. Lastly, the quality standards of the food with respect to workers, tradition and the environment.

Due to the ever-growing market of processed foods, microbial food safety has been on the limelight. Another catalyst is the recent outbreaks of foodborne illnesses. Different stakeholders such as public health agencies, and research organizations have been working closely with food industries to achieve microbiology food safety (Heredia *et al.*, 2008).

2.9.1 Hygiene and sanitation

Foodborne illnesses are major cause of morbidity and mortality worldwide. According to (Abdul-Mutalib *et al.*, 2012), 18% of children under the age of five die annually due to diarrheal conditions globally. Poor food handling and neglection to follow good hygiene and sanitation practices lead to an increase in transmission of these foodborne illnesses. The common bacteria that cause foodborne illnesses include *Staphylococcus aureus* and *Escherichia coli.* Food handlers play the role of a vector in transferring these bacteria to food and eventually to the consumers of the handled food (Abdul-Mutalib *et al.*, 2012). Training of food handlers on good practices has been shown to be effective in reducing cases of food poisoning resulted from food industries. This intervention may, however, not be very effective because of the ethnic and diversified education background in the workforce. Instilling new ideas in the workers may also be a challenge due to the cultural differences and perceptions (Hurst, 2019). Governments have been involved in regulation of food businesses to curb the risk that comes with skip tracing the HACCP systems. (Egan *et al.,* 2007).

Food contact surfaces and environments also are crucial points in determining the safety of the food product produced in an industry. Processing environments not only affect the shelf life of the products, they can also affect their physicochemical quality (Moore & Griffith, 2002). Cleaning regimes in these environments aim at reducing debris that may harbor microorganisms. However, cleaning alone may not be sufficient to declare an environment safe for the purpose of production. Companies are therefore encouraged to come up with methods that give assurance that food processing surfaces are safe. One of these methods is the rapid hygiene monitoring (Moore & Griffith, 2002). In this method, contamination of surfaces is assessed either indirectly by verification of disinfestation and cleaning procedures or directly by microorganisms' cultures. Chlorinated washes can also be used to achieve microbial reduction in the food contact surfaces (Hurst, 2019).

2.10 MUNGBEAN PRODUCTION IN KENYA

Mungbean (*Vigna radiata* L.) locally known as *Ndengu* is one of the legumes that is cultivated in many parts of the Arid and Semi-arid areas (ASAL). The short duration between growth and harvesting (65 to 90 days) encourages rapid farming. Climatic tolerance of green grams is the same as that of mango producing zones with warm and tropical climate favouring effective production (Kehlenbeck *et al*., 2010). Small scale farmers grow green grams mainly for human consumption. However, their utilization can further be diversified to be used as livestock forage, as well as green manure crop (Mohammed *et al.,* 2017). Although production has been on the rise, the consumption rate is higher causing a deficit which is compensated through import. It is estimated that the country's annual yield is about 0.6 tonnes per hectare compared to an estimated production potential of 1.5 ton/ha (Muchomba *et al*., 2023). Constraints leading to inability to achieve yield potential include pests and diseases, effects of climate change, land degradation, poor agronomic practices, and decline in soil health. With over 80% of the Kenyan land classified as ASAL (Mugo *et al.*, 2020), the region becomes susceptible to variability and climate change.

Although generally the average consumption rate is high, mungbean consumption zones record a low consumption rate compared to other regions (Mohammed *et al*., 2017). Coupled with lack of market information, little market promotion, and inadequate stakeholder commitment, the nutritional potential of mungbeans remain inadequately tapped.

2.10.1 Nutritional value of mungbeans

Green grams contribute towards enhancement of food security status worldwide. This class of pulses is rich in carbohydrate, protein, fat, ash and fiber with average composition of 61.8%, 22.9%, 1.2%, 3.5%, and 4.4% respectively (Elobuike *et al.*, 2021). These nutrients are essential in fighting undernutrition as well as micronutrient deficiencies. Traditionally, mungbeans are consumed independently or as compliments. However, their utilization in the production of improved food products have shown positive nutritional outcomes due to their impressive nutritional value and presence of minimal anti-nutrients (Dahiya *et al.*, 2014). Research has showed that significant bioactive compound in mungbeans such as polysaccharides, polyphenols, and peptides further ameliorate medical conditions such as hyperlipidemia, hyperglycemia, and hypertension. Consumption has further indicated positive outcomes among patients with melanogenesis, and cancer (Hou *et al.*, 2019).

2.11 GAPS IN KNOWLEDGE

Despite the high economic potential of the mango fruit, its utilization has not been sufficiently exploited. Mango farmers are stick stuck in poverty despite the high production volume of mangoes every year. Economic gains from mango fruits are relatively low due to lack of a formal market for the mango fruits and its products. Postharvest losses in mango farming is as high as 30% (S. Bakhri, 2015). Mango value addition is not common among small scale farmers in rural farmers who are the largest producers of mango. A report by Musyoka *et al* (2020) indicates that only 33.52% of mango producers practice value addition. The bottlenecks which are associated with this trend is lack of adequate storage facilities, processing technology, and lack of awareness. In attempt to scale up the economic returns from mango farming, players in the mango market chain have come up with mechanisms that aim at adding value to the mango fruits. The main focus has, however, been on mango juice. Diversification of mango products has not been given enough attention. Although there are impressive advances in mango processing, there is still room for development of high value mango products with a long shelf life such as mango flakes from local varieties which are yet to be elucidated.

CHAPTER THREE: DEVELOPMENT OF MANGO FLAKES USING RESPONSE SURFACE METHODOLOGY TO OPTIMIZE PRODUCT AND PROCESS VARIABLES

ABSTRACT

Mango fruit (***Mangifera indica L***.) is one of the tropical fruits which are produced in large volumes in Kenya. Transformation of the perishable fruit into shelf-stable nutritious products is one of the interventions that can be used to reduce losses while accruing better returns for farmers. The objective of this study was to determine the optimum processing parameters in the production of consumer-acceptable mango flakes. Fifteen treatments were obtained using sugar variations of 0%, 2%, and 4%, and starch at 0%, 10%, and 20%. Process variables were determined by varying pressure of steam (0.8 BAR, and 1.6 BAR) and speed of drum drying (2.2 rpm and 7.6 rpm). Sensory analysis was done using a 7-pointer hedonic scale while physicochemical, and proximate lab analysis was done using predetermined AOAC procedures. Response Surface Methodology (RSM) of Design Expert 13 software, was used to optimize mango flakes production procedures by adjusting settings of factorial variables. Results indicated that formulations that were incorporated with 20% starch, 0% sugar, and dried at 7.57 rpm for 5 minutes and 2 seconds at a constant gauge pressure of 0.8 BAR were the most preferred with a mean overall score of 5.79. Homogeneity of variances was observed between different formulations for overall acceptability (*P=0.192*). The predictive model of the Central Composite Design stipulated that an increase in sugar concentration reduces the sensory quality of drum-dried mango flakes. Nutritional profile of the most acceptable mango flakes was a composite of 1.9g/100g, 2.8g/100g, 0.9g/100g, and 0.5g/100g for carbohydrates, vitamin C, crude protein, and crude fat, respectively. A significant difference was observed between values for protein and vitamin C (*P=0.002*). In conclusion, the organoleptic acceptability and nutritional profiles of drum-dried mango flakes were affected by the time: pressure exposure of the puree as well as the product ratios of ingredients. The study recommends special attention on process and product variables including optimized product formulations, and processing conditions for an enhanced nutritional outcome of drum-dried mango flakes.

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3.1 INTRODUCTION

Mango fruit (*Mangifera indica. L*) is a common fruit produced in the tropical regions. According to Mitra (2016) mango farming is estimated to be taking place in over 100 countries worldwide with an estimated production volume standing at 40 metric tons. Its production is characterized by both small scale and large-scale farming. In Kenya, mangoes are considered one of the high production potential fruits which can survive a wide range of ecological zones. Mangoes can grow in semi humid areas as well as in the semi- arid regions (Mitra, 2016). In mango production, there are two important factors to be considered; a dry period to facilitate flowering, and exposure to sufficient heat for ripening with the main growing seasons in Kenya recorded between November to April, and between May to July. (Fresh Plaza, 2019). Mango production has not only improved farmers' livelihoods but has also positively impacted growth of food industries through production of mango products. Mango processing in Kenya is carried out by medium, small and micro enterprises which play an important role in boosting food security, as well as preventing reducing post-harvest losses (Owino & Ambuko, 2021). However, despite the potential of mangoes to enhance food security in developing countries, their utilization has not been fully exploited.

In Africa, it is estimated that postharvest losses account for over 50% of the produced mangoes especially during harvesting (Owino & Ambuko, 2021). Postharvest management is one of the interventions that aims at mitigating effects of these losses. Generally, postharvest management of perishable horticultural food products determine their nutritive value, sensory quality and visual standards (Nazah, 2015). All the above-mentioned factors contribute to the safety of the products. In the case of mango value chain, post-harvest losses which can be attributed to lack of enough modern processing technology has been a bottleneck in the maximization of the fruit's economic and nutritional potential. Another challenge is its seasonal availability and that is beside its high perishability. Waste products from mango processing, which are a composite of peels and seeds are among the leading agro-industrial wastes worldwide with about 123000 metric tonnes recorded every year. However, research has indicated that these wastes have the potential to industrial applications through value addition (Wall-Medrano *et al.*, 2020). Mango harvesting in Central and Eastern parts of the country is at its peak between the month of December and March while in the Coastal region, mangoes are in plenty between the month of November and December (Kehlenbeck *et al.*, 2010). Lack of knowledge on the appropriate mango varieties for the different ecological zones is another drawback in optimization of its production volume in Kenya. Currently, mango varieties available in Kenya include, Apple, *Ngowe, Keitt, Van Dyke, Sensation*, *Sabine*, *Haden*, and *Maya* (Muchiri *et al.,* 2012). The later can be attributed to inadequate dissemination of mango varieties that were introduced from foreign countries such as Australia, USA, and Israel. This is because the new commercial mango varieties were introduced in the 1980s from the above-mentioned countries but farmers were not sufficiently trained on the proper agro-ecological zones for the specific new varieties.

Mangoes possess good nutritional contents such as carotenoids, minerals and antioxidants (Yamato *et al.,* 2020). Even though value addition is important in realizing its nutritional and economic potential, some of the processing methods used for production of various mango products lead to nutritional losses (Mishra *et al.,* 2021). Effective preservation of mango pulp can be achieved using chemical preservatives such as sodium benzoate, and potassium metabisulfite at suitable concentrations. These preservatives have antimicrobial effect that can prolong the shelf life of mango puree. However, these preservatives have some negative effects on the sensory characteristics of fresh mango products as observed in mango juices (Siddiq *et al.,* 2017). Nutritive deterioration of mango products can be as a result of many factors. One of these factors is exposure to high temperatures. Optimization of heat treatment plays a major role in determination of the quality of different mango products (Lofti *et al.,* 1996).

There are diversified products that can be processed from the different varieties that are found in Kenya. These include but not limited to juices, puree, chutney, jam, dried and canned mangoes. However, in the recent past, dried mango products have continuously gained popularity among consumers. This may be associated with their shelf stability, as well as sensory appeal, making them consumable as healthy snacks. Mango flakes are one of the products that can be produced from mango fruits. When compared to other mango products such as juice, puree, and concentrates, mango flakes can stay for long without spoilage due to the reduced water activity (Kim *et al.,* 2009). Flakes production through drum drying has shown to be effective in that it has a high nutrient retention as well as its benefits in terms of cost effectiveness (Yamato *et al.,* 2020).

Optimization refers to the variation of certain production conditions and raw materials' parameters in order to minimize or maximize pre-defined criteria such as product quality or profitability (Banga *et al.,* 2003). In the production of mango flakes, the process is constrained to certain conditions to enable maximization of desirable outcomes such as their nutritional value and microbiological safety. Additionally, the optimization process has to be systematic and efficient to reduce errors that may lead to wastage. There are many states of the art methods of optimizing product processes. Response Surface Methodology is a mathematical and statistical tool that has been widely used for analyzing and modelling processes in which responses of interest are affected by independent and dependent variables (Aydar, 2018).

3.2 MATERIALS AND METHODS

3.2.1 Mangoes acquisition and preparation

Ngowe and apple mango varieties, 14.5 kgs and 17.5 kgs respectively, were bought from local markets and processed in the food processing hub at the department of Food Science, Nutrition and Technology-University of Nairobi. The mangoes were stored in open carton boxes for 24 hours at a room temperature (25℃), prior to product development. The processing involved cleaning, peeling, slicing, pulping, product formulation and drum drying. Upon pulping of the obtained mangoes and pasteurization of the pulp, formulations were made from varied ratios of starch, sugar, and mango pulp. Mango flakes were developed from two mango varieties; *Ngowe*, and Apple through drum drying.

3.2.1.1 Yield

Calculation of the total percentage yield from the pulping process was done using an adopted formula which was initially used by Aydar *et al.* (2018) in the extraction of olive oil from olive fruits. Table 3.1 summarizes the total yield from the process. The extraction formula is as follows:

$$\text{Yield}=\frac{Extracted\ pulp\ (g)}{Weight\ of\ fruits\ (g)} \times 100\%$$

Table 3.1: Yield percentage in mango processing

	Ngowe	**Apple**
Fruits weight (kg)	14.5	17.5
Pulp weight (kg)	7.0	10.0
Weight of waste(kg)	6.0	6.5
Yield (%)	43	57

3.2.2 Pasteurization and storage

Upon storage, the pulp was pasteurized in a pasteurizer at 850C for 5 minutes. It was then cooled to 65^{0}C and packaged aseptically in 5-litre sterilized bottles. The bottles were then stored in a cold room. To prevent microbial growth and retain the color of pulp, sodium metabisulfite and potassium sorbate were both added at 250 ppm.

3.2.3 Product formulation

The optimization process involved varying a number of parameters against the two mango varieties. During the formulation phase, sugar and corn starch concentrations were varied. Three samples were obtained from starch concentration variation. The subsequent concentrations were 0%, 10%, and 20% starch. Samples from sugar content variation were formulated with 0%, 2%, and 4% sugar. Formulation with corn starch was achieved by pasteurizing the mixture of pulp and starch to a gelatinization temperature of 60℃.

3.2.4 Drum drying

Pureed formulations were dried over a steam heated drum dryer (model number BK.2406.C) of an area of 0.2847 m^2 to produce sheets of drum dried mango flakes. The samples generated from sugar and corn starch alterations were processed at constant conditions of speed, pressure, and time (31.2781 rpm, 4 BAR, and 5 minutes 2 seconds respectively). Speed of drum dryer was calculated by the formula: rpm= Surface feet per minute (sfm) ÷ diameter ×3.82 ((Piyarach *et al.*, 2021).Variations were done on the speed of the drum dryer, and pressure of steam. Two samples of each of the above-mentioned parameters were derived with gauge pressure variation set at 0.8, and 1.6 (BAR). Speed was adjusted to 7.57 rpm and 4.2 rpm. The samples were given random numbers of ZBY and NFX for speed variation and FYB and BYA for gauge pressure variation. More information on the product formulations is given in Appendix 2.

3.2.5 Sensory analysis

Sensory evaluation was conducted mid-morning in a sensory room. A total of 28 panelists were recruited to participate in the evaluation using a 7-pointer hedonic scale with a lower expected limit set at 4.0 (Annex 1). Clean water was provided to each panelist to rinse their mouth between each subsequent product evaluation. Data from the evaluation was analyzed using SPSS (version 20) software and output interpreted in terms of descriptive experiments, affective testing, and difference experiments.

3.2.6 Statistical analysis

Sensory evaluation was done using SPSS statistical software version 21. Optimization of the processing parameters of mango flakes was done using the Response Surface Methodology (RSM) of the Central Composite Design (CCD) in the Design Expert 13 Software. Responses were assessed using the maximum and minimum sensory acceptability values that were achieved. The independent variables included ratio of ingredients, speed of drier, and gauge pressure whereas the response variables were the sensory scores. The minimum ($-\alpha$) and the maximum (+α) was generated from the similar studies on other products. The CCD of the Design Expert was used to compute the Centre points and the number of runs.

3.3 RESULTS

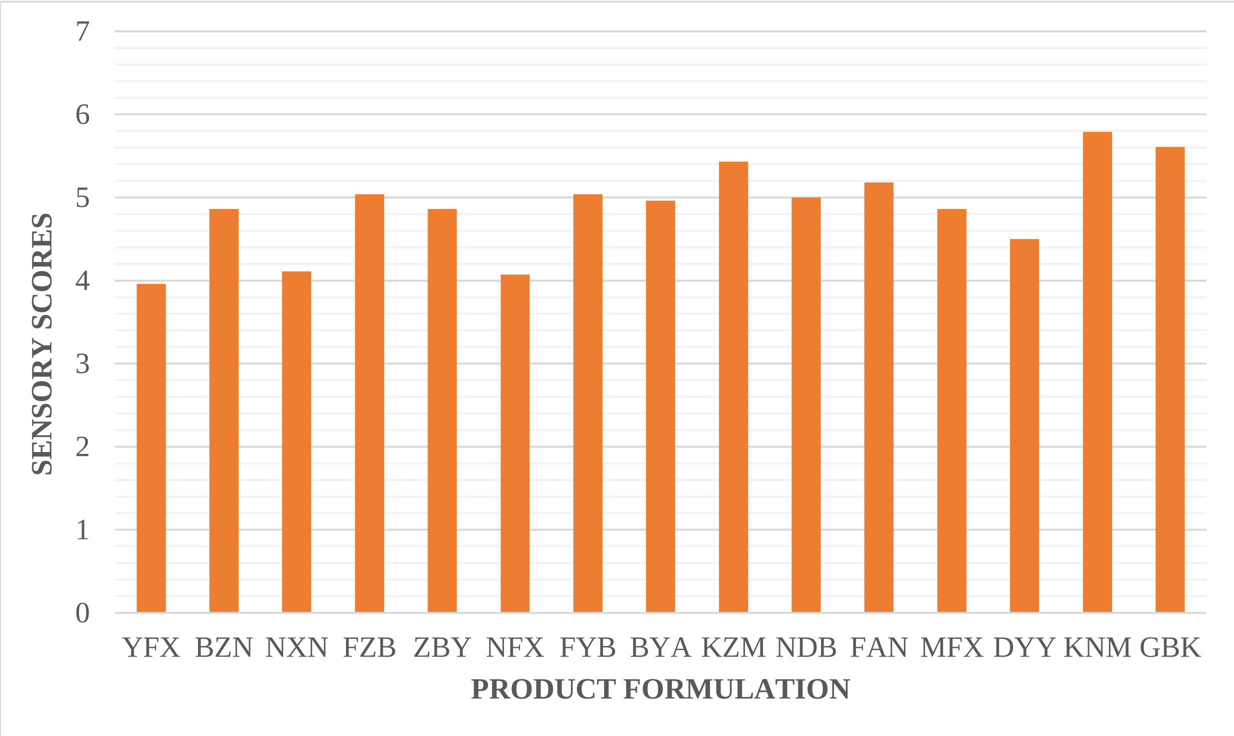
3.3.1 Age and gender of panelists

The panelists' mean age was 31.3 years. Female panelists accounted for the highest percentage (80%) compared to their male counterparts (20%).

3.3.2 Products preference for overall acceptability

Results in Table 3.2 and Figure 3.2 give the grand mean, standard deviation, and standard error values for the overall acceptability were 4.88, 1.652, and 0.081 respectively. The most acceptable product was KNM with a mean score of 5.79. This product was incorporated with 500g of pulp, 20% starch with 0% sugar, and processed at gauge pressure of 0.8 BAR.

Products FZB and FYB had equal preference with a mean score of 5.04. The same case was observed for product ZBY, and MFX which had a mean score of 4.96. Product YFX, which was the placebo of the group, was the least preferred of all.



Note: YFX= Control, BZN= Ngowe, NXN=Apple, FZB=2% sugar, FYB=4% sugar, BYA=6% sugar, KZM=8% sugar, ZBY=7.6 rpm, NFX=4.2RPM, NDB=5% starch, FAN=10% starch, MFX=15% starch, DYY= 25% starch, KNM=0.8BAR, GBK=1.6BAR

Figure 3.1: Sensory acceptability of mango flakes. The bars indicate sensory scores.

Table 3.2: Overall acceptability

Sample ID	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean	
					Lower Bound	Upper Bound
YFX	28	3.96	1.953	0.369	3.21	4.72
BZN	28	4.86	1.508	0.285	4.27	5.44
NXN	28	4.11	1.833	0.346	3.40	4.82
FZB	28	5.04	1.774	0.335	4.35	5.72
ZBY	28	4.86	1.627	0.307	4.23	5.49
NFX	28	4.07	1.804	0.341	3.37	4.77
FYB	28	5.04	1.201	0.227	4.57	5.50
BYA	28	4.96	1.374	0.260	4.43	5.50
KZM	28	5.43	1.665	0.315	4.78	6.07
NDB	28	5.00	1.700	0.321	4.34	5.66
FAN	28	5.18	1.492	0.282	4.60	5.76
MFX	28	4.86	1.433	0.271	4.30	5.41
DYY	28	4.50	1.795	0.339	3.80	5.20
KNM	28	5.79	1.397	0.264	5.24	6.33
GBK	28	5.61	1.100	0.208	5.18	6.03
Total	**420**	**4.88**	**1.652**	**0.081**	**4.72**	**5.04**

Note: YFX= Control, BZN= Ngowe, NXN=Apple, FZB=2% sugar, FYB=4% sugar, BYA=6% sugar, KZM=8% sugar, ZBY=7.6 rpm, NFX=4.2RPM, NDB=5% starch, FAN=10% starch, MFX=15% starch, DYY= 25% starch, KNM=0.8BAR, GBK=1.6BAR

3.3.3 Product preference for crunchiness

Results in Table 3.3 indicate that the grand mean for crunchiness was 4.82 with a standard deviation of 1.65. The crunchiness of product GBK was the most acceptable with a mean score of 5.71. Product YFX scored the least with a score lower than the minimum expected score of 4.0 (3.64). Levene statistical test indicated that there was homogeneity of variances between the different formulations (*P*=0.192). Generally, GBK was formulated with 500g of pulp from apple mango variety, 20% corn starch with 0% sugar. Drum drying of the product was done at 1.6-gauge pressure at constant conditions of time and temperature.

Table 3.3: Results for sample crunchiness sensory evaluation mean values

Sample ID	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean	
					Lower Bound	Upper Bound
YFX	28	3.64	1.682	0.318	2.99	4.30
BZN	28	4.89	1.474	0.279	4.32	5.46
NXN	28	4.29	1.652	0.312	3.65	4.93
FZB	28	5.07	1.741	0.329	4.40	5.75
ZBY	28	4.68	1.701	0.321	4.02	5.34
NFX	28	3.68	1.827	0.345	2.97	4.39
FYB	28	5.07	1.215	0.230	4.60	5.54
BYA	28	4.89	1.423	0.269	4.34	5.44
KZM	28	5.07	1.720	0.325	4.40	5.74
NDB	28	5.14	1.508	0.285	4.56	5.73
FAN	28	5.18	1.786	0.337	4.49	5.87
MFX	28	5.04	1.319	0.249	4.52	5.55
DYY	28	4.39	1.685	0.318	3.74	5.05
KNM	28	5.50	1.427	0.270	4.95	6.05
GBK	28	5.71	1.243	0.235	5.23	6.20
Total	**420**	**4.82**	**1.649**	**0.080**	**4.66**	**4.97**

***Note:** YFX= Control, BZN= Ngowe, NXN=Apple, FZB=2% sugar, FYB=4% sugar, BYA=6% sugar, KZM=8% sugar, ZBY=7.6 rpm, NFX=4.2RPM, NDB=5% starch, FAN=10% starch, MFX=15% starch, DYY= 25% starch, KNM=0.8BAR, GBK=1.6BAR*

3.3.4 Product preference for flavor

Results in Table 3.4 below show the mean of different formulation varied significantly (*P*=0.00). The panelists rated sample KNM significantly high with a mean score of 5.89 compared to the lowest rated product NFX which had a mean of 3.61 ($P<0.05$). The grand mean score for the group in terms of flavor was 5.02 with a standard deviation of 1.6. The general composition for product KNM was 500g of pulp from *Ngowe* variety, 20% starch with 0% sugar, and processed at gauge pressure of 0.8 BAR. On the other hand, product NFX was a composite of 500g of pulp from apple mango variety, 20% corn starch with 0% sugar. Drum drying was done at a speed of 4.2 rpm.

Table 3.4: Results for products flavor sensory evaluation as means

Sample ID	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean	
					Lower Bound	Upper Bound
YFX	28	4.86	1.693	0.320	4.20	5.51
BZN	28	5.25	1.430	0.270	4.70	5.80
NXN	28	4.54	1.688	0.319	3.88	5.19
FZB	28	5.18	1.307	0.247	4.67	5.69
ZBY	28	5.46	1.319	0.249	4.95	5.98
NFX	28	3.61	2.114	0.400	2.79	4.43
FYB	28	5.25	1.430	0.270	4.70	5.80
BYA	28	5.07	1.359	0.257	4.54	5.60
KZM	28	5.29	1.675	0.316	4.64	5.94
NDB	28	5.14	1.458	0.276	4.58	5.71
FAN	28	5.21	1.371	0.259	4.68	5.75
MFX	28	4.54	1.575	0.298	3.93	5.15
DYY	28	4.32	1.847	0.349	3.61	5.04
KNM	28	5.89	0.994	0.188	5.51	6.28
GBK	28	5.75	1.236	0.234	5.27	6.23
Total	**420**	**5.02**	**1.599**	**0.078**	**4.87**	**5.18**

Note: YFX= Control, BZN= Ngowe, NXN=Apple, FZB=2% sugar, FYB=4% sugar, BYA=6% sugar, KZM=8% sugar, ZBY=7.6 rpm, NFX=4.2RPM, NDB=5% starch, FAN=10% starch, MFX=15% starch, DYY= 25% starch, KNM=0.8BAR, GBK=1.6BAR

3.3.5 Products preference for texture

The results presented in Table 3.5 below indicates that the grand mean score for the texture parameter was 5.13 with a standard deviation of 1.64. Product KNM was the most preferred in terms of texture with an average score of 6.00. The least acceptable sample was NFX which was rated at 3.29. A significant difference was observed by the panelists between the highest ranked KNM and the lowest ranked NFX (*P*= 0.002).

Table 3.5: Results for texture sensory evaluation

Sample ID	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean	
					Lower Bound	Upper Bound
YFX	28	5.07	1.698	0.321	4.41	5.73
BZN	28	5.39	1.548	0.292	4.79	5.99
NXN	28	4.79	1.833	0.346	4.07	5.50
FZB	28	5.32	1.416	0.268	4.77	5.87
ZBY	28	5.29	1.536	0.290	4.69	5.88
NFX	28	3.29	2.034	0.384	2.50	4.07
FYB	28	5.21	1.315	0.249	4.70	5.72
BYA	28	5.50	1.072	0.202	5.08	5.92
KZM	28	5.46	1.503	0.284	4.88	6.05
NDB	28	5.25	1.430	0.270	4.70	5.80
FAN	28	5.04	1.551	0.293	4.43	5.64
MFX	28	5.00	1.866	0.353	4.28	5.72
DYY	28	4.46	1.666	0.315	3.82	5.11
KNM	28	6.00	1.247	0.236	5.52	6.48
GBK	28	5.89	1.166	0.220	5.44	6.34
Total	**420**	**5.13**	**1.642**	**0.080**	**4.97**	**5.29**

***Note:** YFX= Control, BZN= Ngowe, NXN=Apple, FZB=2% sugar, FYB=4% sugar, BYA=6% sugar, KZM=8% sugar, ZBY=7.6 rpm, NFX=4.2RPM, NDB=5% starch, FAN=10% starch, MFX=15% starch, DYY= 25% starch, KNM=0.8BAR, GBK=1.6BAR*

3.3.6 Process optimization using response surface methodology

The Central Composite Design (CCD) of the Response Surface Methodology (RSM) was utilized in simulation of the optimization process. This was achieved through design of models and experiments, evaluating the effects of factors, and identifying the optimum conditions for the flakes production. The numeric factors which were put under analysis were starch concentration, sugar concentration, speed of drum drying, and pressure of steam. The mean sensory scores for the different samples were used as the response variables. The design was taken through 30 experimental runs.

Table 3.6: Summary of fit for acceptability of mango flakes

Source	Sequential p-value	Lack of Fit p-value	Adjusted R^2	Predicted R^2	
Linear	0.2718	0.5391	0.1269	-0.3854	
2FI	**0.2465**	**0.7308**	**0.4742**		**Suggested**
Quadratic	0.7308		0.2314		**Aliased**

Analysis of variance was carried out to determine the effect of the independent variables on the dependent variables. The model F-value obtained was 1.35 which implied that the model was not significant relative to noise. There was a 50.23% chance that this large F-value was due to noise. The F-value in Table 3.7 below was less than 0.05 indicating that there were no significant model terms. The second order regression equation for the model that defines acceptability is given below:

$$Y= 5.28 - 0.6917A - 1.03B + 0.0767C + 0.5100D + 1.11AB - 0.2642AC - 0.2367AD + 0.1383BC - 0.3225BD + 0.0408CD + 0.2667A^2 + 0.0000B^2 + 0.0000C^2 - 0.0367D^2$$

Table 3.7: ANOVA results for the quadratic model

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	3.4600	10	0.3455	2.260	0.2241	**Not significant**
A-Starch concentration	0.2037	1	0.2037	1.330	0.3124	
B-Sugar concentration	0.7396	1	0.7396	4.840	0.0926	
C-Speed of drum dryer	0.0533	1	0.0533	0.349	0.5864	
D-Pressure of steam	1.9000	1	1.9000	12.43	0.0243	
AB	1.2200	1	1.2200	07.99	0.0475	
AC	0.1229	1	0.1229	0.804	0.4205	
AD	0.0896	1	0.0896	0.586	0.4865	
BC	0.0270	1	0.0270	0.176	0.6958	
BD	0.3788	1	0.3788	2.480	0.1904	
CD	0.0008	1	0.0008	0.005	0.9464	
Residual	0.6109	4	0.1527			
Lack of Fit	0.1644	2	0.0822	0.3683	0.7308	**Not significant**
Pure Error	0.4465	2	0.2232			
Cor Total	4.07	14				

3.3.7 Optimization process

The interaction of factors in this RSM model gave the region of overlaybility where the ideal conditions and parameters were applied to obtain the optimization process. In this scenario, the flexibility lies in between the yellow region for the sugar concentration formulations and the starch concentration. The minima and maxima of the plots are as shown in Figure 3.2.

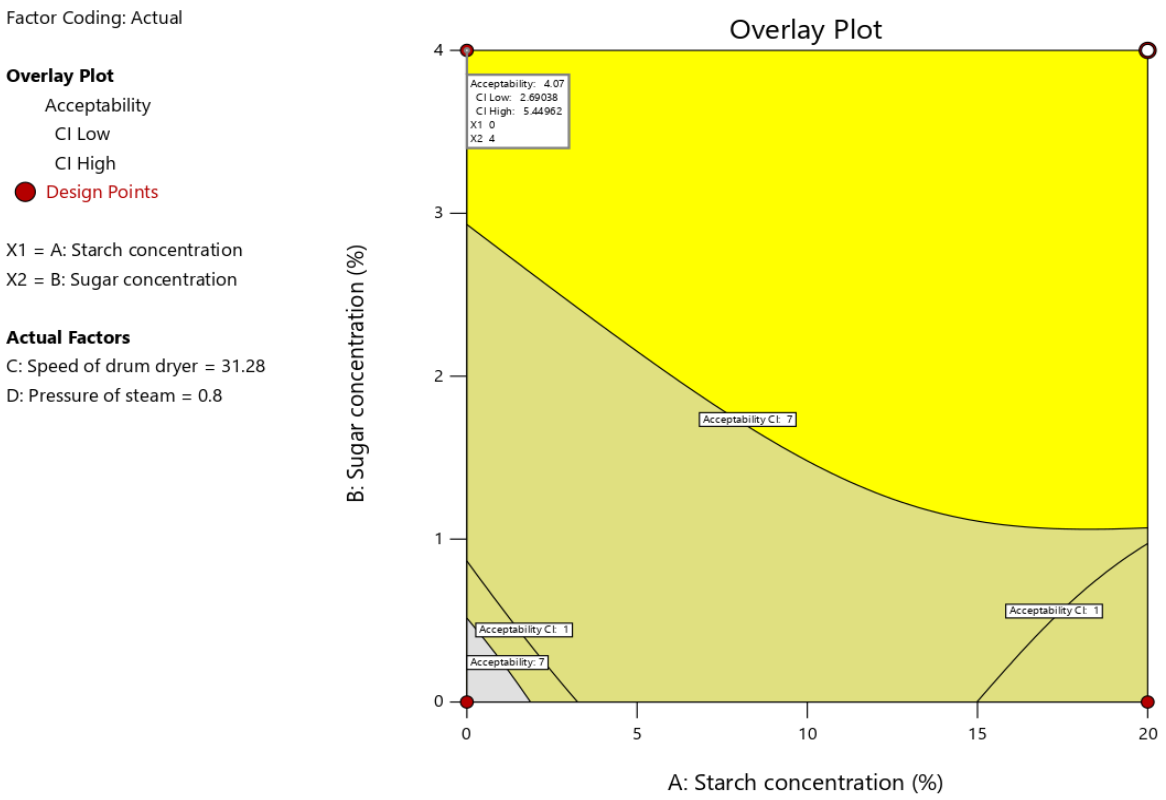


Figure 3.2: Optimization results for mango flakes production

3.3.8 Effects of changes in process factors on products acceptability

Contour graphs were used to illustrate the relationship between the factors under study. The plots in Figures 3.2 and 3.3 below show how variable starch concentration and variable sugar concentration affected the overall quality of the produced mango flakes. The minima regions showed lower concentrations of starch and sugar in the products formulations. The contour levels revealed a peak percentage of 2 in B and 10 in A. The same findings were observed for the 3D contour plots. The quality scores for the above-mentioned regions were above 4.00, which was the minimum expected sensory scores in the sensory analysis. The same design experiment was done for the variable speed of drum drying and variable gauge pressure. However, although the graphs were useful in identifying the direction to increase or reduce the specific parameters, it proved to be difficult to determine the exact level of variables adjustments.

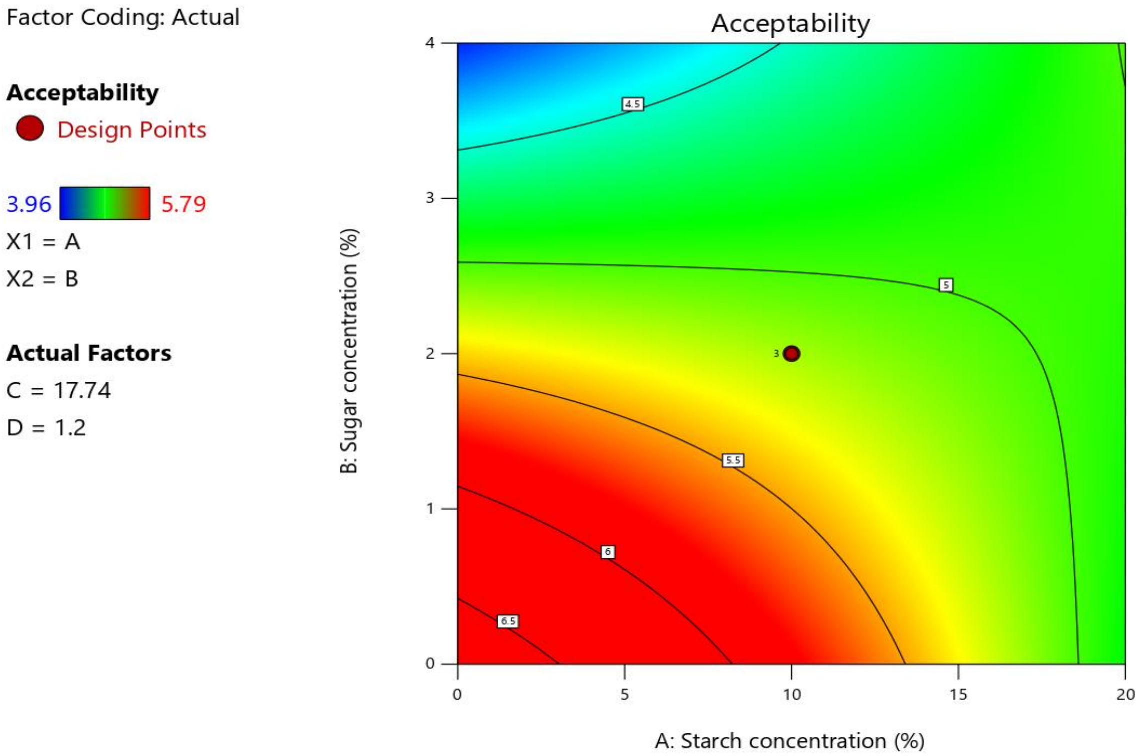


Figure 3.3: Model graph showing the acceptability regions for process conditions

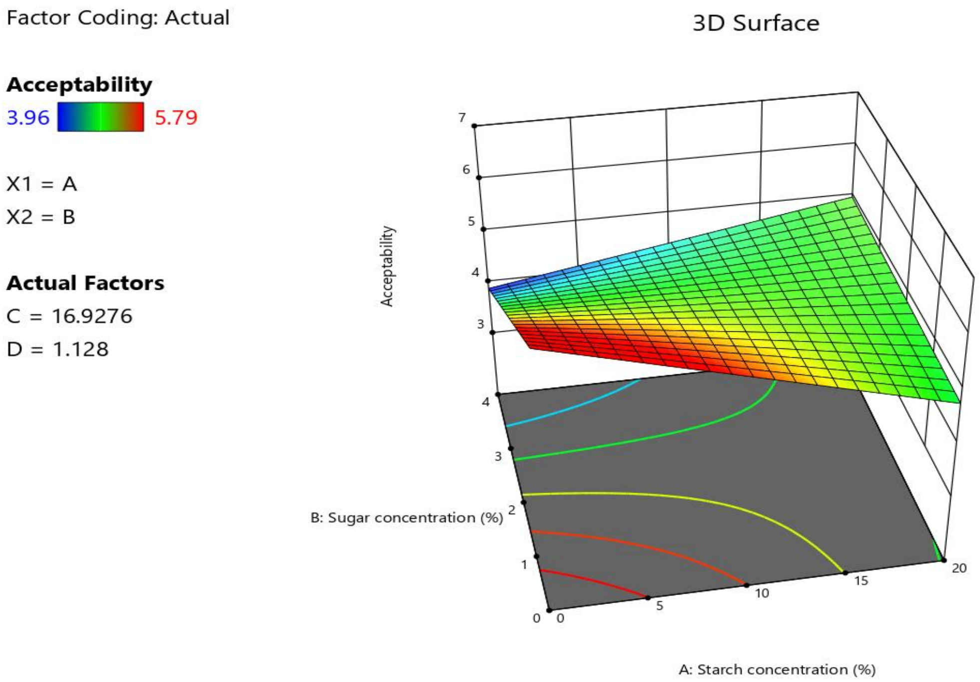


Figure 3.4: A 3D response surface plot simulating the changes in mango flakes acceptability with adjustment in process factor

3.4 DISCUSSION

The response surface model is a representation of an industrial food production system that sets production parameters (Banga *et al.,* 2003). The findings from this study revealed that concentration of sugar and starch influence the consumer acceptability of drum dried mango flakes. This finding is consistent with the outcome of a research by Mwaurah *et al.,* (2020), which associated the physicochemical characteristics of starch with its effect in dissolution with mango pulp, which ultimately affects the quality of processed mango flakes. Similarly, the current study established that an increase in sugar concentration inversely affected the quality of mango flakes due to the constitution of reducing sugars, 16-18 *w/v* (fructose, glucose and sucrose) in ripe mangoes (Lebaka *et al.,* 2021). Moreover, it has been proven that addition of sugar has an effect on the quality of fruits and vegetable products (Owade *et al.*, 2021; Torres *et al.,* 2007; Yen *et al.*, 2018).

According to this study, increasing the speed of drum dryer reduces the contact time between the pureed formulation and the drum-drying plate. As a result, heat treatment is constrained leading to low quality flakes. Despite the negative effects of heat exposure on the volatile components of mangoes, heat treatment enhances dried products quality by increasing their crunchiness (Gates, 2007; Mwaurah *et al.*, 2020). Generally, the contoured model revealed that the four production parameters (sugar, starch, drum drying speed, and pressure of steam) had significance influence on the sensory quality of drum dried mango flakes. The variation recorded by the model for the overall acceptability of the drum-dried mango flakes was 50.23%. This high variation is as a result of the close relationship between the predicted and actual values as earlier described by (Banga *et al.*, 2003). The physicochemical composition of the most acceptable mango flakes was determined and the results summarized. The results showed congruence with other studies (Yamato *et al.,* 2020) that reported a decrease in vitamin C, proteins while other value of some components such as minerals were retained (Maldonado-Celis *et al.*, 2019). These attributes can be associated with the heat treatment processes that lead to losses in volatile compounds. Additionally, a significant difference was observed between values for protein and vitamin C ($P=0.002$).

3.5 CONCLUSION

The acceptability of the mango flakes was dependent on the concentration of corn starch, speed of drum drying, gauge pressure, and the sugar content of the formulations. Generally, results from the sensory evaluation indicated that mango flakes produced from formulations of 20% starch, 0% sugar, and drum dried at speed of 7.57 rpm for 5 minutes 2 seconds at a constant pressure of 0.8 BAR were the most consumer acceptable. Additionally, the acceptability of the mango was not dependent on the mango variety. The gelatinization aspect of corn starch was used to achieve the dissolution of starch into the mango pulp. Changes in the above-mentioned factors significantly affected the sensory quality of the mango flakes.

3.6 RECOMMENDATIONS

In general, the Response Surface Methodology can be useful in optimizing industrial production processes. Aside from enhancing products quality, the model can be utilized to predict the influence one production variable can have on another. The study recommends special attention on process and product variables including optimized product formulations, and processing conditions for an enhanced nutritional outcome of drum-dried mango flakes.

CHAPTER FOUR: PHYSICOCHEMICAL AND NUTRITIONAL COMPOSITION OF MUNGBEAN-ENRICHED MANGO FLAKES PRODUCED THROUGH DRUM-DRYING

ABSTRACT

The climatic tolerance conditions of green grams is the same as those of mango-producing zones with warm and tropical climates favoring effective production. Although generally, the average consumption rate is high, mungbean-producing zones record a low consumption rate compared to other regions. The utilization of green grams in the processing of improved food products has shown positive nutritional outcomes due to their impressive nutritional value and the presence of minimal anti-nutrients. The objective of this study was to determine the physicochemical and nutritional changes in mungbean-based mango flakes during drum-drying. A completely randomized design was used to compare means of the dependent variables which were the physicochemical and nutritional compositions of the flakes produced. These values were obtained by varying the independent test factors which were variety of mangoes, pressure of steam and ripening stages. Mangoes of three different varieties, tommy, apple, and kent, were obtained from farmers in Eastern Kenya at two different ripening stages. Pulp from each of the varieties was incorporated with 30% cooked mungbean paste and 15% starch. Pressure of drum drying was varied at 0.4, 0.8, and 1.6 bar. Variations in the formulations was further made at 5%, 15%, 20%, and 25% starch concentration. Results showed that the average ash, beta carotene, vitamin C, crude fiber, protein, and moisture content in mango flakes enriched with mungbean's were 0.21±1.50 g/100 g, 0.21±1.50 g/100 g, 15.75±13.22 µg/100 g, 22.17±5.81 mg/100 g, 0.63±0.17 g/100 g and 15.57±1.50 g/100 g respectively. Magnesium was the predominant mineral with an average of 44.16±2.52 mg/100g. The assessment showed significant differences in ash, and fiber composition in mango flakes processed from different mango varieties as well as those drum-dried at different steaming pressure. A further significant variation within the process parameters for vitamin C was observed ($P<0.05$). However, no significant difference in protein content resulted from variations in the three process and product parameters (mango variety, pressure, and ripening stages) ($P>0.05$). The incorporation of cooked green grams paste enhanced the protein, beta carotene, and mineral profiles of mango flakes. The study recommends consideration of drum-drying as a processing method to make shelf-stable mango products with enhanced nutritional value. Drum-drying can further be useful in value addition and fortification of locally produced crops into nutritious products thus reducing malnutrition.

4.1 INTRODUCTION

Mango and mango products have played a substantial role in the food safety perspective. For its effective utilization, about 20% of the mangoes are converted into different forms through processing. These transformations are in the following forms; nectar, juices, slices, leather, and puree (Ravani & Joshi, 2013). It is these forms that give a survival margin to the mangoes during their on-season periods in terms of shelf-life. Mangoes possess good nutritional content such as carotenoids, minerals, and antioxidants (Yamato *et al.*, 2020). Even though value addition is important in realizing its nutritional and economic potential, some of the processing methods used for the production of various mango products lead to nutritional losses. One of the factors that can lead to these losses is exposure to high temperatures. Optimization of heat treatment plays a major role in the determination of the quality of different mango products. Flakes production through drum drying is effective in that it has high nutrient retention and is cost-effective (Ahmed, 2015). The production process through drum drying, and the addition of different additives at a 3% dry basis (corn starch or maltodextrin 10DE), was evaluated and results show that it is indeed effective (Yamato et al., 2020). The estimated shelf life, based on the obtained isotherms, showed that a package with a high barrier to water vapor is effective.

Ripening of mangoes plays a role in the physical and chemical properties of the mangoes. Different varieties of the fruit have varying ripening periods. They also vary in terms of nutritional characteristics, flavor, and storage behavior (Okoth *et al.*, 2013). During ripening, several physical, sensory, and chemical changes occur in the profiles of mango fruits. The fruit's color and firmness changes take place in an inward-outside direction (Ngamchuachit *et al.*, 2016). The changes are, however, subject to the mango varieties. For example, according to USDA (Ellong *et al*., 2015) the water content of Kent, Keitt, Tommy Atkins, and Haden varieties is 83.4 g per 100g while that of Azucar has a water content of 79.3g per 100g. As opposed to the other micronutrient ripening trends, vitamin A and C content in mango fruits reduces with maturation (Maldonado-Celis *et al.*, 2019). The decline of vitamin C content is attributed to the metabolic pathways taking place during this period.

Drum drying is a cheap option for drying mango flakes. Another way of obtaining dry powder is through spray drying. This technique utilizes hot gas to dry slurry solutions or liquid. However, through drum drying, high nutrient retention is achieved. The method also has other advantages such as cost-effectiveness, ease of cleaning, high flexibility, energy efficiency and ease of operation (Yamato *et al.*, 2020).

The utilization of mango-based products has been encouraged to improve product diversity. One such initiative is the incorporation of context-specific nutritious locally-produced crops.

Mungbean (*Vigna radiata* L.) locally known as *Ndengu* is one of the legumes that is cultivated in many parts of the Arid and Semi-arid areas (ASAL). Green grams contribute towards the enhancement of food security status worldwide. This class of pulses is rich in carbohydrates, protein, fat, ash, and fiber with an average composition of 61.8%, 22.9%, 1.2%, 3.5%, and 4.4% respectively (Elobuike *et al.,* 2021). Research has shown that significant bioactive compounds in mungbean's such as polysaccharides, polyphenols, and peptides further ameliorate medical conditions such as hyperlipidemia, hyperglycemia, and hypertension. Consumption has further indicated positive outcomes among patients with melanogenesis, and cancer (Hou *et al.*, 2019). The practicality of the development of nutritionally rich products from locally available crops lies in the effectiveness of processing mechanisms to retain essential nutrients. The objective of this study was to determine the physicochemical and nutritional changes in mungbean-enriched mango flakes during drum-drying.

4.2 MATERIALS AND METHODS

4.2.1 Research design

The physicochemical and nutritional composition was assessed based on the following process and product factors: mango varieties, the pressure of steam used for processing mango flakes, starch concentration, speed of drum-drying, and the mangoes' ripening stages. A completely randomized design at 95% confidence interval (CI) was used to compare means of the dependent variables which were the physicochemical and nutritional compositions of the flakes produced. These values were obtained by varying the independent test factors which were variety of mangoes, pressure of steam and ripening stages. Mangoes of three different varieties, Tommy, Apple, and Kent, were obtained at two different ripening stages. Pulp from each of the variety was incorporated with 30% cooked mungbean paste and 15% starch. Pressure of drum drying was varied at 0.4, 0.8, and 1.6 bar. Variations in the formulations was further made at 5%, 15%, 20%, and 25% starch concentration.

4.2.2 Raw materials acquisition

Mango varieties of Ngowe, Apple, and Tommy Atkins; and green grams were obtained from farmers in Embu and Makueni counties. The raw products were then transported to the University of Nairobi, College of Agriculture and Veterinary Sciences. At the Department of Food Science and Technology, mangoes were stored in a cold room ready for processing the following day (Refer to section 3.2)

4.2.3 Sample preparation

Firm ripe and fully ripe mangoes were randomly selected from the three varieties (*Ngowe*, Kent, and Tommy) after sorting had been done. The selected mangoes were washed and peeled using knives and sliced. The fleshy part of the mangoes was grounded using a blender (Multifunctional Mini Electric Blender Manufactory Kd308A). The blender was cleaned with clean running water after every grinding cycle. Mungbeans were separately washed and cooked using clean water for an average of 45 minutes. To turn them into a consistent paste, the fully cooked green grams were blended using a blender. Processing of mango flakes was done using the same method as described in Section 3.2. On the other hand, mango slices from the 3 mango varieties at their firm ripe stage were sundried at approximately 50℃ for 48 hours.

4.2.4 Analytical Methods

4.2.4.1 Determination of Ascorbic acid

The vitamin C content before and after processing was determined using the method previously described by (Duckworth, 1996). According to this method, 5 ml of the juice was mixed with 15ml of the prepared Trichloroacetic acid (TCA) solution. The mixture was filtered and 5 ml of the filtrate used for the next step. 5 ml of 4% Potassium Iodide (KI) solution was added with some drops of starch solution. The mixture was titrated against N-Bromo succinimide.

4.2.4.2 Determination of βeta carotene

Quantification of the βeta carotene content was done using the same method described by Pakistan *et al*.,(2007). Briefly, an extract of 200 petroleum ether was evaporated at 40^0C under vacuum to a final volume of 1 ml. A chromatography column was prepared with silica gel and suspended to a height of 8 cm of petroleum ether. The extract was introduced into the column. Eluting of the carotene was done using petroleum ether into a volumetric flask of 25 ml and volume made to the mark using petroleum ether. Reading of the eluted beta carotene was carried out at 450 nm in one cm cuvette and concentration determined from the initially prepared standard curve.

4.2.4.3 Determination of moisture content

Quantification of the total moisture content were done using AOAC (2016) 934.01. The analysis was conducted using an air oven. In this method, 5g of the weighed samples was put in an air oven which was set at 105^0C. The temperature was maintained for four hours after which it was removed, cooled and weighed in a desiccator. The dish was returned to the oven and dried for another 30 minutes after which it was cooled in a desiccator and its weight taken.

The operation was done repeatedly until the moisture content acquire a value within 0.05%. The moisture content of the sample was calculated in percentage.

4.2.4.4 Determination of minerals

Mineral elements concentrations were determined using a method described by (Mohamed, 2015). An atomic Absorption Spectrophotometer (AAS) was used to quantify the specific minerals (phosphorus, magnesium, and zinc) and calculation done in ppm (mg per 100gram dry weight).

4.2.4.5 Determination of protein

This analysis was conducted using the Kjeldahl method by Horwitz (2000). Approximately, 0.5grams of samples were weighed into a 50 ml Kjeldahl flask and eight ml of concentrated H_2SO_4 added together with a five-gram copper sulfate catalyst. The composition was digested until it became colorless. The solution was distilled and ammonia collected in a conical flask containing 25ml of Boric acid solution. The distilled sample was titrated against 0.1N Hydrochloric acid until a pink colour was observed.

4.2.4.6 Determination of crude ash

The method of determination was described by Horwitz (2000). Four grams of samples were places into clean crucibles and placed in a muffle furnace and heated to 550°C. Upon turning into a light grey colour the sample containing crucibles were removed and a change in weight was calculated to get the ash content.

4.2.4.7 Determination of crude fiber

Fiber was analyzed using a method reported by Horwitz (2000). Two-gram samples of flakes were digested over a hot water plate in one-litre beakers for one hour while subsequentially digested with H_2SO_4 (2.5N) with same volume of NaOH (2.5N). The samples were continuously filtered using glass wool while adding small amounts of ethanol. The precipitate was transferred into crucibles which were heated in an oven at 105°C until there was no more weight change. The sample-containing crucibles were then transferred to muffle furnace where they were incinerated at 550°C for three hours. The samples crucibles were removed, cooled and weight taken to compare change in weight which was used to obtain the amount of fiber.

4.3 RESULTS

4.3.1 Effects of processing factors on the physicochemical and nutritional content of mango flakes

Physicochemical changes and nutritional configurations were recorded for mung-bean enriched mango flakes and analyzed in Table 4.1. The drum drying process was carried out within a constant processing duration of five minutes per slate of processed flakes.

Table 4.1: Physico-chemical changes in mungbean enriched mango flakes in relation to mango variety, drum-drying pressure and ripening stage

	Parameter	Ash (g/100g)	Beta carotene (µg/100g)	Vitamin C (mg/100g)	Crude fiber (g/100g)	Protein (g/100g)
Mango variety	Ngowe (n=6)	0.12±0.02[b]	3.00±1.14[c]	13.70±3.56[c]	0.63±0.05[b]	15.52±0.31[a]
	Apple (n=6)	0.25±0.02[a]	3.25±1.54[b]	17.17±3.67[b]	0.45±0.05[c]	16.85±0.70[a]
	Tommy (n=6)	0.09±0.01[c]	17.00±6.24[a]	23.75±0.26[a]	0.66±0.06[a]	15.25±1.12[ab]
Pressure (BAR)	0.4 (n=6)	0.22±0.02[b]	21.50±1.50[a]	26.28±0.27[a]	0.45±0.02[b]	14.01±0.03[ab]
	0.8 (n=6)	0.15±0.01[c]	13.00±3.00[b]	23.46±0.02[b]	0.41±0.01[c]	13.83±0.07[a]
	1.6 (n=6)	0.23±0.01[a]	7.50±1.50[c]	22.93±0.06[c]	0.47±0.03[a]	14.06±0.17[a]
Ripening stage	Firm ripe (n=6)	0.16±0.09[a]	6.00±4.31[b]	16.07±6.09[b]	0.54±0.09[a]	16.47±0.78[a]
	Ripe (n=6)	0.14±0.08[a]	9.17±10.08[a]	20.33±2.87[a]	0.63±0.10[a]	15.27±0.90[a]

*Values with different letters across the columns are statistically different at $P<0.05$

4.3.1.1 Ash

The average ash content in mango flakes enriched with mungbeans was 0.21±1.50 g/100 g mango flakes. The assessment further showed significance differences in ash composition in mango flakes processed from different mango varieties as well as those drum-dried at different steaming pressure ($P<0.05$). However, no statistical difference ($P>0.05$) was seen to be resulted from processing mango flakes from different ripening stages.

4.3.1.2 βeta carotene

Mango variety, steam pressure, and ripening stages influenced the βeta carotene content in the produced mango flakes. The mean carotenoid content was 15.75±13.22 µg/100 g mango flakes with significant differences observed in means within the above-mentioned product and process factors ($P<0.05$).

4.3.1.3 Vitamin C

Ascorbic acid content was highest in mung-bean enriched mango flakes processed at 0.4 bar. Nevertheless, the constitution was influenced by the process factor (pressure of steam), as well as the product factors (mango variety, and ripening stages). On average, vitamin C content recorded was 22.17±5.81 mg/100 g mango flakes with a significant variation within the process parameters ($P<0.05$).

4.3.1.4 Crude fibre

Fiber composition showed significant differences within mango flakes samples processed from different mango varieties and at different steam pressure ($P<0.05$). Flakes from Tommy variety recorded the highest fiber content (0.63±0.05 g/100 g mango flakes) while those processed at 0.8 bar had the lowest (0.41±0.01 g/100 g mango flakes). The average crude fiber in mungbean-based mango flakes was 0.63±0.17 g/100 g mango flakes. Elsewhere, mangoes' ripening stages did not influence the fiber composition of the mungbean-enriched mango flakes ($P>0.05$).

4.3.1.5 Protein

Protein content ranged between 15.25 and 16.85 g/100 g mango flakes with an average of 15.57±1.50 g/100 g mango flakes. Comparatively, there was no significant difference in protein content resulted from variations in the three above-mentioned parameters ($P>0.05$).

4.3.1.6 Moisture content

Results on moisture composition of mungbean-based mango flakes are summarized in Table 4.2.

Table 4.2: Moisture content of mungbean enriched mango flakes subjected to process and mango source variations

Process variable	Variations	Mean scores±SD (%)	*P*-value
Starch concentration (%) (n=12)	5%	10.04±0.01	
	15%	8.21±0.00	
	20%	8.21±0.00	
	25%	8.21±0.00	0.000
Pressure (BAR) (n=9)	0.4	5.70±0.03	
	0.8	7.28±0.00	
	1.6	5.68±0.08	0.000
Ripening stage (n=6)	Firm ripe	6.59±0.01	
	Ripe	4.9±0.02	0.000
Variety (n=9)	Ngowe	6.89±0.02	
	Apple	5.42±0.08	
	Tommy	4.92±0.04	0.000

*Means are significantly different at P≤0.05

The average moisture content recorded was 6.39±1.65% with the lowest and highest values ranging between 4.91±0.02% and 10.04±0.01% respectively. There were significant differences in the moisture content within variations of starch concentration, mango variety, pressure of steam and ripening stages of mangoes (P<0.05).

4.3.2 Mineral composition of mango flakes after enrichment with cooked mungbeans

Table 4.3 summarizes effects of the incorporation of green-grams paste on the mineral composition of mango-based flakes.

Table 4.3: Comparison of mineral content in mungbean enriched mango flakes and in sundried mango chips

Mineral (n=6)	**Variations**	**Mean±SD**	***P*-value**
Phosphorus (mg/100g)	Mungbean enriched flakes	15.04±2.03	
	Sun-dried mango slices	11.13±1.50	0.027
Magnesium (mg/100g)	Mungbean enriched flakes	44.16±2.52	
	Sun-dried mango slices	19.05±2.21	0.000
Zinc (mg/100g)	Mungbean enriched flakes	3.7±0.63	
	Sun-dried mango slices	0.15±0.00	0.000

* Means are significantly different at P≤0.05

Magnesium was the predominant mineral with a maximum value of 44.16±2.52g. Zinc was the least prominent after phosphorus with values of 3.7±0.63, and 15.04±2.03 respectively. Addition of green-grams significantly enhanced the mineral quantity in mango flakes ($P<0.05$). Figure 4.1 further shows the comparison between mineral composition in sun-dried mango slices versus in green-grams-enriched mango flakes.

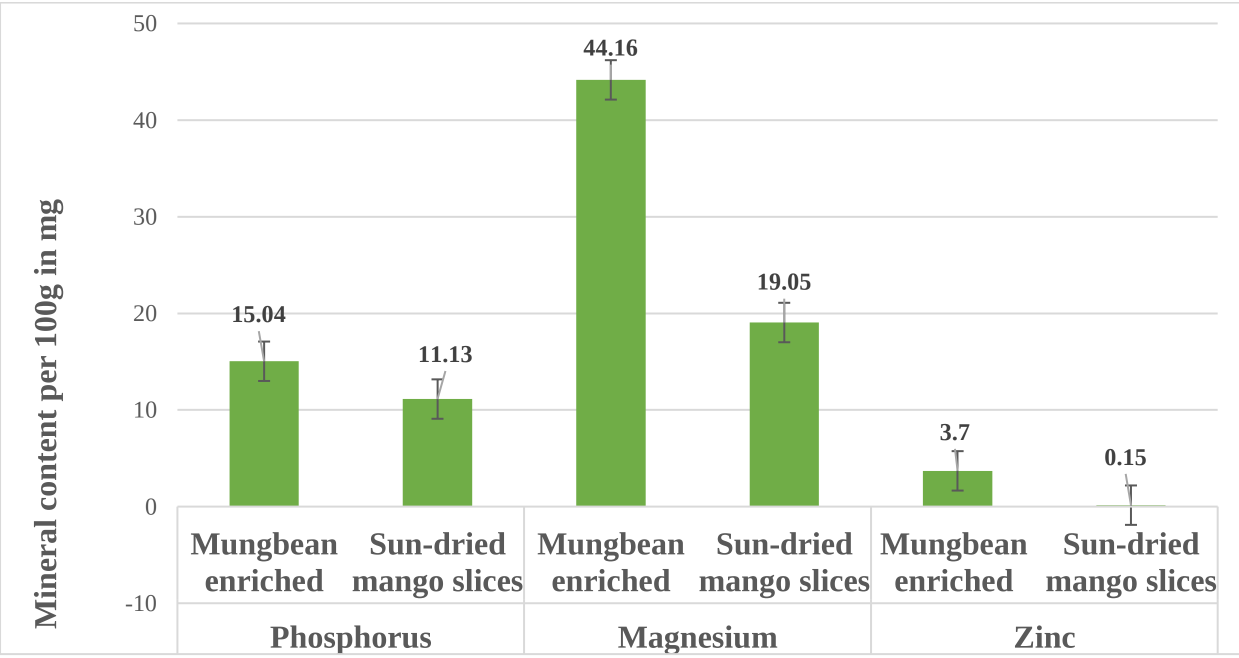


Figure 4.1: Mineral composition in sundried mango slices against those in mungbean-enriched flakes. The bars show mineral content in mg/100g.

4.3.3 Proximate and nutritional composition of green grams-enriched mango flakes

Contents recorded were crude protein, crude fiber, and ash with means of 15.57g, 0.63g, and 0.21g respectively. A very low water content was established with moisture composition of 6.39% established. Magnesium was the prominent mineral while zinc was the lowest with mean values of 44.16mg, and 3.7mg respectively. Table 4.4 shows a breakdown the proximate constituents of optimally processed mango flakes.

Table 4.4: Proximal content analysis of mango flakes enriched with mungbeans

Physicochemical component (per 100g) (n=6)	Sundried mango chips	Mungbean enriched flakes
Moisture (%)	10.11 ± 0.34^{a}	6.39 ± 1.65^{b}
Ash (g)	0.52 ± 0.02^{a}	0.21 ± 1.50^{b}
Beta carotene (μg)	12.03 ± 0.41^{a}	15.75 ± 13.22^{a}
Vitamin C (mg)	65.61 ± 1.90^{a}	22.17 ± 5.81^{b}
Crude protein (g)	0.40 ± 0.11^{b}	15.57 ± 1.50^{a}
Crude fiber (g)	1.06 ± 0.33^{a}	0.63 ± 0.17^{a}
Phosphorus (mg)	$11.13 + 1.50^{b}$	15.04 ± 2.04^{a}
Magnesium (mg)	19.05 ± 2.21^{b}	44.16 ± 2.52^{a}
Zinc (mg)	0.15 ± 0.00^{b}	3.70 ± 0.64^{a}

* Values with different letters across the columns are statistically different at $P<0.05$

4.4 DISCUSSION

4.4.1 Physicochemical and nutritional changes during processing of mungbean-enriched flakes

Mango fruits contain macronutrients and micronutrients that may be subject to change as a result of processing treatments. Drum drying with starch in particular exposes fruit-based products to factors that may alter their nutritional and physicochemical characteristics. Starch is useful in gelatinization in mango flake production. During the drum drying of Dragon Fruit Peel, Chia & Chong, (2015) reported a substantial reduction in the water content, crude ash, crude fiber, and crude protein. These results were in congruent with the current findings which established a large disparity between the nutritional and physicochemical features of fresh mangoes reported by Maldonado-Celis *et al.*, (2019), and those recorded in the current research. Water content in particular which is a shelf-life determinant, was reduced from over 82% to below 11%. High-pressure treatment is associated with subjection to high temperatures

(Kaushik *et al*., 2014). Increasing the pressure of steam during the production of mango flakes significantly affected the ash, fiber, vitamin C, beta carotene, and crude fiber composition. Combined with variations in ripening stages, highly volatile components such as vitamin C were susceptible to be negatively impacted as values were as low as 22.17±5.81mg/100g compared to 182.55mg/100g in mango pulp and 8g/100g in mungbean's (Muchomba *et al.*, 2023; Rocha Ribeiro *et al.*, 2007). Nonetheless, the protein content was not affected by the high pressure-high temperature variations. This may be associated with the protein's solubility enhanced by the incorporation of protein-rich green grams. As. Changes in the ripening stage are characterized by an increase in simple sugars, and starch, as well as vitamin C degradation (Ellong *et al*., 2015). While crude fiber and protein were not significantly affected by the two ripening stages, the mungbean-enriched mango flakes had varied compositions of vitamin C, beta carotene, and ash as a result of different stages of mango ripening. The findings are further buttressed by other research such as Rocha Ribeiro *et al*., (2007), which established an increase in carotenoids in mangoes over time.

Varietal differences have an impact on the chemical and nutritional content of drum-dried mango flakes. This can be extrapolated to the primary characteristics of the raw fruits from which the flakes are made. Suriati *et al*., (2020) reported different changes in vitamin C, texture, and moisture content in freshly cut fruits over five days. With different biochemical changes in different mango varieties, notable contrasting contents were recorded in terms of crude fiber, vitamin C, crude ash, and beta carotene in the current study. As was the case in high-pressure treatment, protein composition was not affected by this parameter. The coherent protein structure in all mango varieties, at all ripening stages, makes them unique and resilient to change over time (Asimah VK *et al*., 2016).

4.4.2 Effects of enrichment of mango-based flakes with mungbeans on their physicochemical and nutritional attributes

Generally, the protein content of mangoes, like any other fruit, is extremely low with Maldonado-Celis *et al*., (2019) reporting values ranging between 0.36g/100 to 0.40g/100g. The incorporation of mungbean paste into mango pulp during the processing of flakes boosted the product’s protein value. Research has shown that green grams have a protein composition of up to 22.9% (Mmbando *et al*., 2021; Muchomba *et al*., 2023). With the protein enhancement, mung-bean-based flakes were able to attain as high values as (15.57±1.50 g/100g). The efficiency of this incorporation is further supported by Dahiya *et al.*, (2014) who attributed the low amount of antinutrients in green grams to their efficiency in the production of mungbean-based products.

The processing effectiveness of drum-drying was seen in the extent to which water content was reduced. Whereas the recommended water composition needed for enhanced shelf stability is less than 10% (KEBS, 2018), mango chips had values slightly higher than that (10.11%). On the other hand, green grams-based mango flakes had an average of 6.39% which is lower than the ideal ranges that support fungal growth. βeta carotene content, although in small quantities, increased due to the addition of mungbean paste. This justifies the differences in carotenoid contents in the two raw products as established by (Hou *et al.*, 2019; Rocha Ribeiro *et al.*, 2007). Due to the superiority of mungbeans in mineral composition as earlier reported, phosphorus, magnesium, and zinc content significantly improved with magnesium increasing by more than two-fold. However, the high-temperature exposure may have detrimentally affected vitamin C and crude ash content. This was observed in other drum drying experiments (Akemi *et al.*, 2020; Chia & Chong, 2015).

4.5 CONCLUSION

Product and process factors have both positive and negative effects on the nutritional and physicochemical composition of mung-bean-based mango flakes. Drum drying pressure is responsible for the destruction of volatile components such as vitamin C, and vitamin A. Additionally, mango variety and ripening stages are responsible for different chemical and nutritional content. The incorporation of mung beans efficiently enhances the nutritional profile of mango flakes especially proteins and essential minerals.

4.6 RECOMMENDATIONS

It is advisable to reduce high-pressure exposure to mango-based products during drum-drying to prevent loss of nutrients. This can be achieved by employing the maximized time-low pressure approach. Finally, it is important to encourage more studies to be done to assess the extent of losses caused by the process factors.

CHAPTER FIVE: SHELF-STABILITY OF MANGO FLAKES SUBJECTED TO DIFFERENT PACKAGING AND TEMPERATURE

ABSTRACT

Dried mango products have been gaining popularity among consumers as healthy snacks in the recent past. This may be attributed to their good nutritional attributes in the form of vitamins, minerals, fibers, and antioxidants; with their unique flavor, taste, and scent. The extremely low water content of flakes enhances their shelf stability by reducing microbial water activity. The current study sought to determine whether the storage temperature, packaging materials, and the variety of mangoes impact the shelf-life of mango flakes. Drum-dried mango flakes were subjected to microbiological assessment to determine the growth of yeasts and mold within an 8-month duration. The bacteriological status analysis for yeasts and molds was determined using dextrose potato agar. A randomized block design was used to compare means between variables and test for significance. A total of 16 samples were taken through microbial analyses. Data was analyzed using Excel and SPSS where associations between variables were determined using independent t-tests and one-way ANOVA.

Results showed that the average yeast and mold counts were 2.8 log_{10}cfu/g within the eight-month storage duration, with 98.4% of the samples ranging below, and compliant to Kenya Bureau Standards (KEBS), and East African Standards for dried mango products. However, yeast and mold growth exceeded the regulatory threshold of 10 log_{10}cfu in the eighth month while stored at room temperature without a seal (11.28 log_{10}cfu/g). It was further observed that there was no statistical association between microbial growth due to differences in mango variety (P>0.05). Furthermore, the packaging material, and storage temperatures did not play a role in influencing the rate of microbial growth with one-way ANOVA analysis indicating P-values of 0.064 and 0.851 respectively for statistical differences. Comparatively, mango flakes stored at controlled refrigeration temperature recorded lower microbial count compared to flakes stored at room temperature, and at 50℃. Although not significantly, coupled with product exposure, storage temperature, storage material, and mango variety may affect the microbial quality of mango flakes to some extent over time. Therefore, there is a need for appropriate storage attention to prevent the growth of yeasts and molds and possibly other hygiene-related micro-organisms.

5.1 INTRODUCTION

Recently, there has been a big demand for items made from dried mangoes. This can be attributed to their good nutritional attributes in the form of vitamins, minerals, fibers, and antioxidants; with their unique flavor, taste, and scent (Dereje & Abera, 2020; Yamato *et al.*, 2020). Dried products offer convenience during storage, transportation, and standardization. The extremely low water content of flakes enhances their shelf stability by reducing water activity. Generally, the shelf stability of dried food products is a result of the lowering of water activity (a_w) to levels that cannot support the growth of spoilage. Water activity is a measure of the amount of water available to support biological reactions, and is determined by calculating the ratio of the equilibrium vapor pressure of food and the equilibrium vapor pressure of pure water at the same temperature (Valková *et al*., 2021). The association between these two factors may be useful in informing decision-making when selecting packaging materials as well as suitable storage conditions. Ideally, microbiologically stable food products are represented with an $a_w<0.60$ (Valková *et al*., 2021). Similarly, it is documented that this is the minimum growth requirement for fungi with some species of yeasts and molds able to survive at a_w 0.62-0.70 (Beuchat, 1983). The bottleneck in ensuring the stability of mango-based flakes is the ability of the products to gain moisture from the environment which consequently affects their consumer acceptability. In the case of breakfast flakes, for example, the product can stay up to one year without undergoing physical deterioration when properly seal-packaged and stored in cool-dry places (Azanha & Faria, 2005).

The use of additives such as starch and pectin is important in achieving stability during the drum drying process. Drying products using a drum dryer has many advantages including energy efficiency, high profitability, and high production flexibility (Tonin *et al*., 2018). These additives have high molecular weights that increase the glass transition temperature (T_g) of the mango pureed formulations during processing (L. Deng *et al.*, 2018). The shelf-life of flakes, however, varies depending on several factors. The type of packaging material is one of these factors (Galić *et al*., 2009). Texture and flavor vary with time when the product is not properly stored.

The growth of microorganisms determines the shelf-life of dried mango products as it is responsible for their spoilage. Their presence in food may be a result of unhygienic food handling practices during processing, inappropriate time and temperature during storage as well as the use of contaminated ingredients. Consumption of microbiologically spoilt flakes can seriously affect the health of consumers. Thus, this study was designed to determine the effects of storage temperature and packaging materials on the microbiological quality of drum-dried mango flakes from different mango varieties.

5.2 MATERIALS AND METHODS

5.2.1 Preparation of mango flakes

Pureed formulations constituting of mango pulp from Apple, and *Tommy Atkins* mango varieties; and 20% starch were passed through a steam heated drum dryer (model number BK.2406.C) at a speed of 7.57 rpm for 5 minutes with a constant gauge pressure of 8 BAR. (Drum-drying was done as per section 3.2)

5.2.2 Enumeration of yeasts and molds

The drum-dried mango flake treatments were microbiologically analyzed with respect to storage temperatures, packaging materials, and mango varieties used. 16 samples, which were representative of mango varieties (Tommy and Apple), packaging materials (airtight, normal seal, and no seal), and storage temperatures (5℃, 28℃, and 50℃) were taken through the analysis.

The microbiological assessment for yeast and mold was done in accordance with ISO 21527-2:2008. Enumeration was done on Potato Dextrose Agar (PDA) media. Sample mango flakes were grounded using a dry hand-held juicer blender, and 20g of the powder was transferred into 180 ml of sodium chloride (0.85%), and mixed for one minute. The samples were then serially diluted up to 10^{-6}. Under aseptic conditions, a Pasteur pipette was used to transfer 1 ml of each serial dilution into a sterile petri plate. For each dilution, pour plating of the dilutions was carried out in triplicate. For five days, the medium was incubated at 25℃ after which areas of fungal growth in Petri dishes were selected and observed under a microscope using the colony count technique and results expressed in log_{10}CFU/g.

5.2.3 Statistical analysis

The records of colonies count were analyzed using Statistical Package for Social Sciences (SPSS) version 25 and Microsoft Excel of windows 16. One way ANOVA test was used to analyze the significance of variables differences of storage materials and storage temperatures. Means were separated and compared using the dependent variables at $P<0.05$. Independent t-tests were used to determine the relationships between microbial growth and mango varieties.

5.3 RESULTS

Results in Table 5.1, Table 5.2, and Table 5.3 show findings from assessment of yeasts and molds count with respect to different mango varieties, packaging materials, and under different storage temperature. Yeast and mold growth started from the third month except for samples which were stored in packages without seal where microbial colonies were detected in the second month.

5.3.1 Shelf life of mango flakes samples made from different mango varieties

Quantitatively, the highest yeast and mold counts were recorded in the eighth month, for both Tommy and Apple (5.44±0.25 $\log_{10}$cfu g^{-1}, and 5.93±0.07 $\log_{10}$cfu g^{-1}) respectively. For the first two months, the two samples did not show fungi growth as the microbial colonies were visible from the third month. The growth, however, did not exhibit differences in relation to the variety of the mangoes from which the flakes were made from, with the number of yeasts and molds averaging 3.03±0.19 $\log_{10}$cfu g^{-1}, and 3.27±0.25 $\log_{10}$cfu g^{-1} for Tommy and Apple respectively ($P>0.05$). Regardless, Apple's colonies count was slightly higher than Tommy's. Figure 5.1 shows growth of yeast and mold in flakes from different varieties. Table 5.1 and Figure 5.1 show growth of yeasts and molds in drum-dried mango flakes from different mango varieties while stored at room temperature.

Table 5.1: Yeast and mold counts ((log_{10} CFU/g) of mango flakes made from different mango varieties at room temperature

	Time in months										
Mango varieties	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**N**	**Mean**	***P*-value**
Tommy	ND	ND	2.13±0.80	3.02±0.05	4.22±0.14	4.30±0.13	5.15±0.13	5.44±0.25	6	3.03±0.19	
Apple	ND	ND	2.61±0.16	3.02±0.90	4.33±0.23	4.91±0.38	5.39±0.28	5.93±0.07	6	3.27±0.25	0.832

ND-not detected *All values are means, differences significant if P≤0.05 level, N=12

Table 5.2: Yeast and mold counts ((log_{10} CFU/g) of mango flakes stored in different types of packages at room temperature

	Time in months										
Type of packaging	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**N**	**Mean**	***P*-value**
Airtight seal	ND	ND	0.85±0.04	1.94±0.90	2.13±0.08	2.62±0.10	3.19±0.30	4.54±0.16	6	1.91±0.20	
Normal seal	ND	ND	1.13±0.03	2.68±0.07	2.96±0.29	3.22±0.16	4.17±0.13	4.81±0.06	6	2.37±0.09	0.064
No seal	ND	0.24±0.03	2.23±0.10	3.77±0.05	6.63±0.46	7.53±0.18	9.95±0.14	11.28±0.22	6	5.20±0.15	

ND-not detected *All values are means, differences significant if P≤0.05, N=18

Table 5.3: Yeast and mold counts ((log_{10} CFU/g) of mango flakes stored at different temperatures in closed punnets

	Time in months										
Storage temperature	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**N**	**Mean**	***P*-value**
5℃	ND	ND	0.32±0.02	1.61±0.04	2.71±0.05	3.04±0.10	3.55±0.17	3.93±0.07	6	1.90±0.06	
28℃	ND	ND	1.04±0.05	1.86±0.06	2.56±0.14	3.16±0.10	4.71±0.07	5.98±0.13	6	2.41±0.07	0.851
50℃	ND	ND	0.97±0.12	1.96±0.07	2.34±0.03	3.94±0.14	4.15±0.05	5.08±0.14	6	2.31±0.07	

ND-not detected *All values are means, differences significant if P≤0.05, N=18

Table 5.4: Moisture content (%) of drum-dried mango flakes under different storage conditions

		Time in months								
		1	**2**		**3**	**4**	**5**	**6**	**7**	**8**
Type of packaging	Airtight	5.2	5.3	5.3	5.3	5.7	5.8	6	6.1	6.2
	Normal	5.7	5.7	5.9	6.1	6.1	6.4	6.5	6.8	7.0
	No seal	6.3	6.5	6.6	6.7	6.6	7.1	7.3	7.3	7.4
Storage temperature	5℃	6.5	6.5	6.7	6.5	6.9	6.8	7.2	7.5	7.5
	28℃	6.6	6.7	6.6	6.8	6.9	6.9	7.1	7.1	7.2
	50℃	6.9	6.9	7	7.1	7.3	7.4	7.5	7.7	7.8

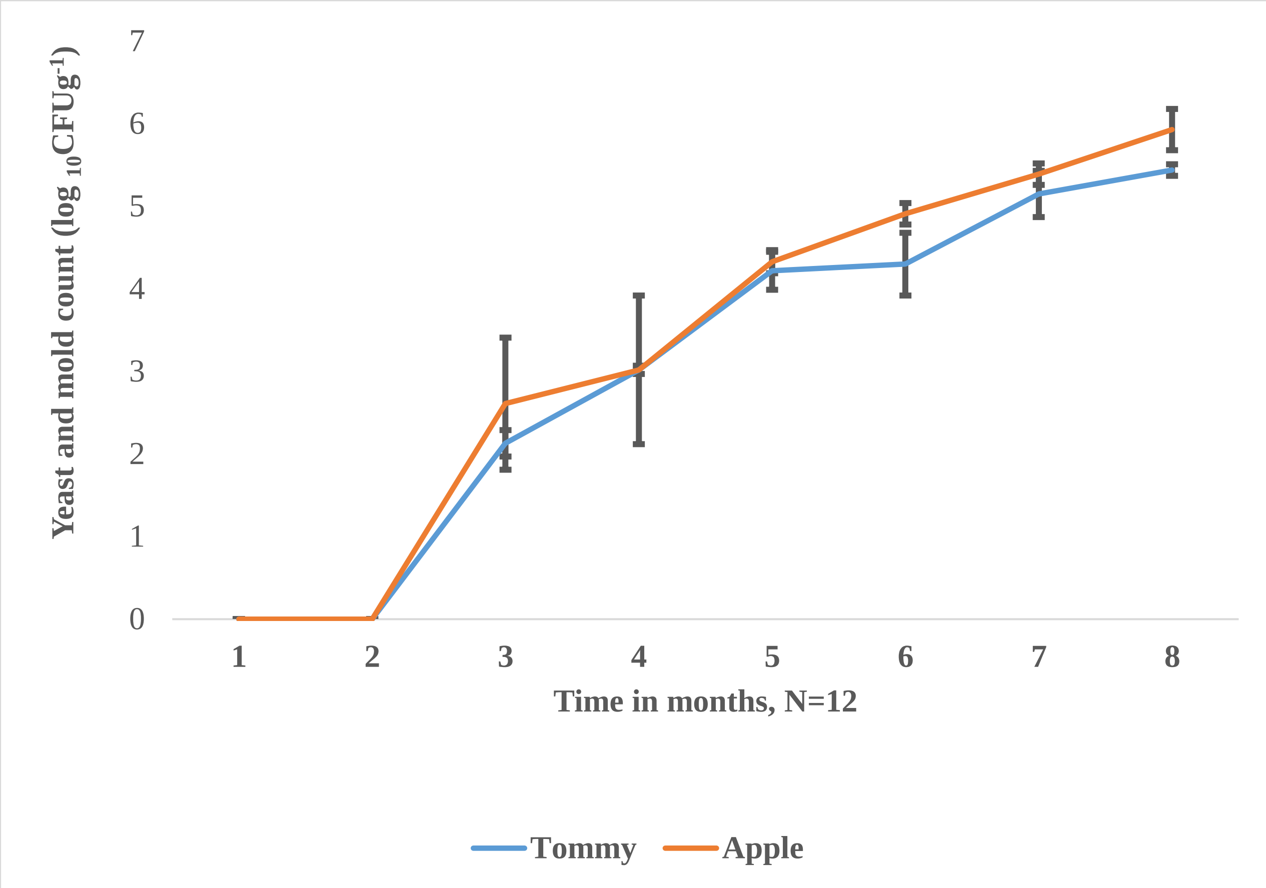


Figure 5.1: Yeast and Mold growth on mango flakes made from two mango varieties at room temperature. The bars indicate standard error of means.

5.3.2 Shelf life of mango flakes stored in different packaging materials

Notably, when an airtight packaging material was used to store mango flakes, the microbial growth was lower compared to normal seal packages, and packages without seal. However, statistically, the average growth difference was inconsequential indicating a lack of significant association between packaging materials and microbial growth ($P>0.05$). Yeast growth averaged 1.91±0.20 log_{10}cfu g^{-1}, 2.37±0.09 log_{10}cfu g^{-1}, and 5.20±0.15 log_{10}cfu g^{-1} for airtight seal, normal seal, and no seal packaging respectively. Nevertheless, this fungal growth was only visible from the third month, except in the case of no seal packaging where colonies were enumerated from the second month. Of concern is the microbiological growth in samples from the no seal packages in the eighth month of storage which exceeded 10 log_{10}cfu g^{-1} (11.28±0.22 log_{10}cfu g^{-1}). This represented a 1.6% deviation from standard microbial compliance out of total analyzed samples. Figure 5.2 shows fungal growth in mango flakes under different packages.

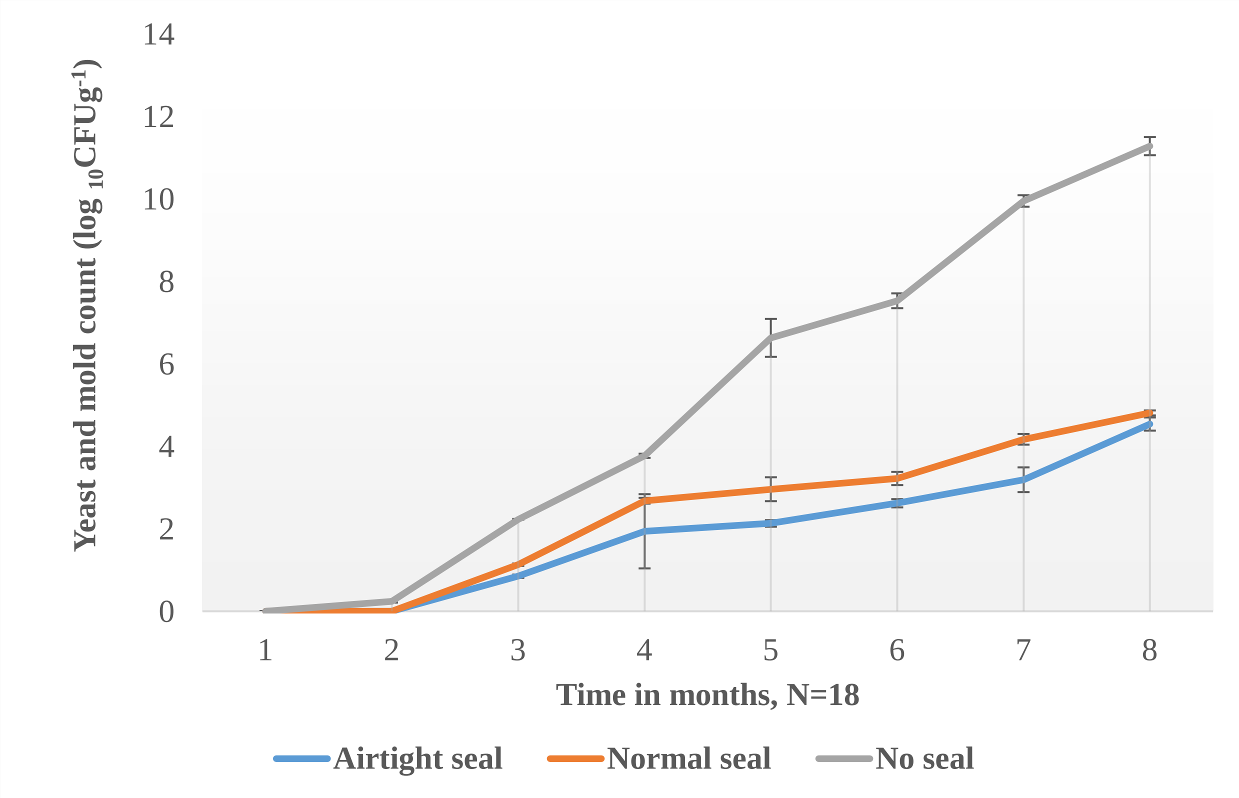


Figure 5.2: Fungal growth on mango flakes stored in different packaging materials at room temperature. The bars indicate standard error of means.

5.3.3 Shelf Life of mango flakes stored under different temperatures

The growth of yeast and mold was observed from the third month of storage. During the storage time, yeasts and molds grew progressively in all the three samples. On average, the population of microbial colonies were 1.90±0.06 log_{10}cfu g^{-1} for refrigerated samples, 2.41±0.07 log_{10}cfu g^{-1} for room temperature storage, and 2.31±0.07 log_{10}cfu g^{-1} for flakes stored at 50°C. The highest fungal growth was recorded in the eighth month of storage (mean 5.0±0.11 log_{10}cfu g^{-1}) with no indication of a relationship between the growth of colonies, and storage temperature ($P>0.05$). Results in Figure 5.3 show the yeast and molds load of mango flakes determined under different temperatures; (5°C ±1°C), (28°C ±2°C), and (50°C ±2°C).

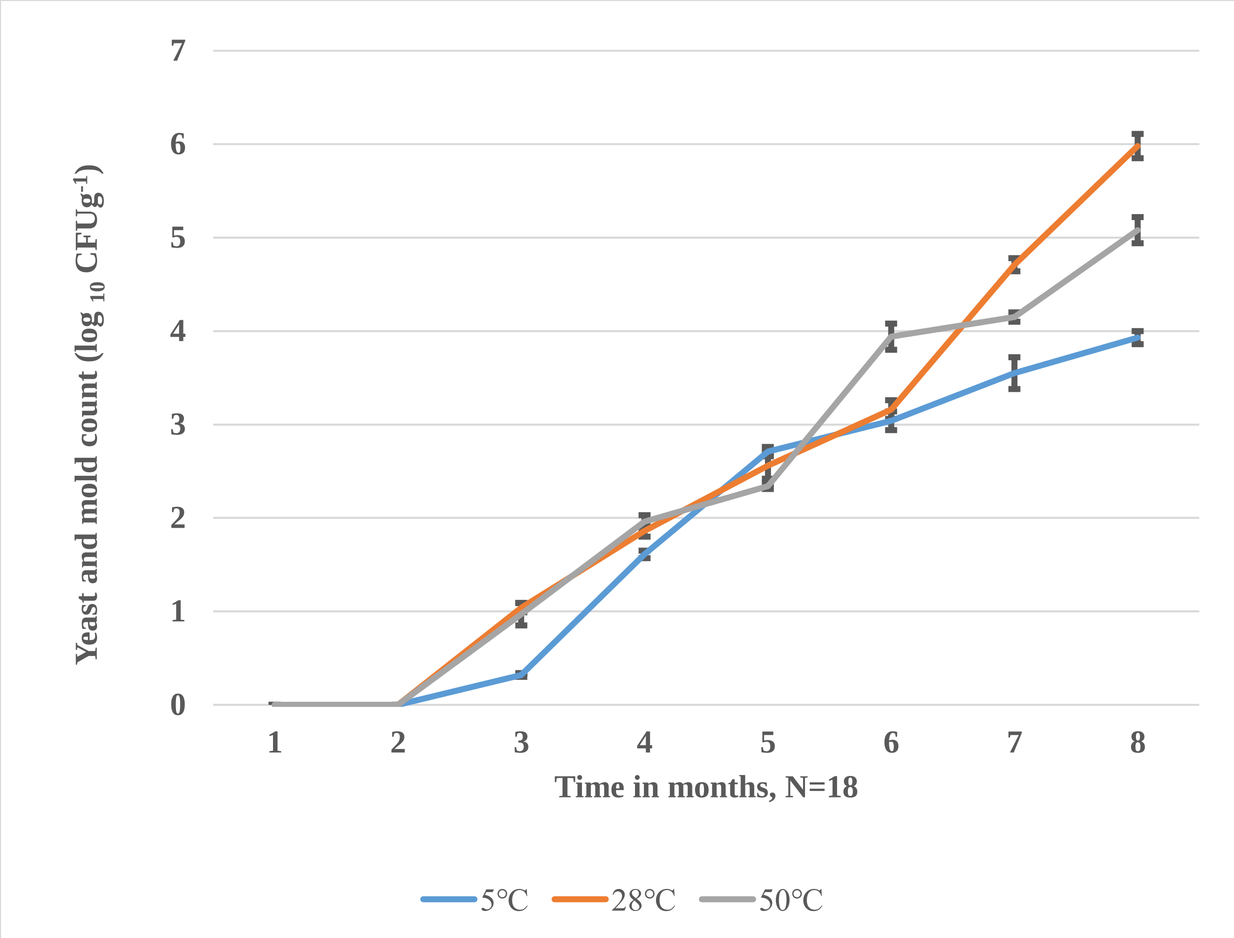


Figure 5.3: Yeast and mold growth on mango flakes stored at different temperatures in closed punnets. The bars indicate standard error of means.

5.4 DISCUSSION

5.4.1 Effect of packaging materials on shelf stability of mango flakes

Package serves the three purposes of protecting, containing, and marketing. Active packaging, as opposed to conventional packaging, which must be completely inert, is intended to interact with the contents or the environment (Roopa *et al.*, 2022). Some of these components include oxygen scavengers, odor absorbers, and antibacterials. It is from the above-mentioned factors that packaging materials can influence the microbial safety of food (Carraher, 2001). The drying process of the mango flakes reduced the water activity up to 0.874, which was still suitable for the growth of mold and yeasts that grow at a minimum water activity of 0.62 (Fontana Jr, 2020). However, with an EAC and KEBS recommended yeast count of less than 1.0×10^3 CFU/g (KEBS, 2018) , the shelf-life test showed a congruence with the set standards as 98.4% of the samples showed fungal populations that were within the set limit. Besides, the growth of yeasts and molds was observed to take place from the third month after storage. It is reported that moisture content as a factor influencing the growth of micro-organisms spontaneously increases over time (Saddozai *et al.,* 2017). This rise may be explained by the products' ability to absorb water from the atmosphere during storage due to the storage package's minimal permeability. In the same connection, the current outcomes are in line with those of Zorić *et al.,* (2016) who argued that the nature of the packaging material used to package food products influences the shelf-stability of the food products. In the same study, it was reported that airtight containers stabilize the shelf-life of dried food products in multi-layer packages, as it has barrier properties against light, gases, and water vapor.

The growth of yeasts and molds may occur regardless of the type of package material. While there might be a variation in the rate of growth as observed in the current study, degradation in microbial quality of dried mango products and human consumable flakes might also be a result of the product's intrinsic, processing, and implicit factors (Hamad, 2012).

5.4.2 Effect of storage temperature on shelf stability of mango flakes

The type of packaging and storage temperature has a major impact on the development and survival of microorganisms (Chauhan & Patil, 2013). While heat treatment plays a key role in reducing microbial load in stored food products by inhibiting the growth of yeasts and molds, spores indicate great resistance (O'Grady *et al.,* 2020). This may explain why mango flakes that were stored at 50^0C showed higher microbial load in the first month of enumeration compared to those stored at a refrigeration temperature. The results from the present study on diversified temperature storage are further buttressed by those of Pistouri *et al*., (2010) which indicated that low-temperature storage is one of the most effective methods of storing dry food products for more than 180 days. Conversely, higher microbial values were recorded in mango flakes stored at 28^0C, than at higher temperatures (50^0C**).** High temperatures generate higher moisture content, coupled with high chemical reactions leading to rapid growth in fungal populations (Beuchat, 1983; L. Z. Deng *et al*., 2019)**.** These findings conform with the findings of Cabello-Olmo *et al.,* (2020), who in their study indicated that temperatures significantly impact the shelf-life of food products. Under the same study, it was established that the use of. Despite the results from this study showing the propriety of low-temperature storage in preserving the shelf-life of mango flakes, *Food and Nutrition Service* (2010), recommends storage of dried food products in dry environments through their phrase "Store in a Cool Dry Place," which represented an optimum temperature of 50°C and a relative humidity of 50–70%. Finally, Rawat, (2015), reported that spoilage of dried food products by molds may pose a great challenge due to its existence in different species which can survive a wide range of temperatures. However, low-temperature storage is recommended compared to higher-temperature storage due to the detrimental effect of heat on the nutritional quality of mango flakes (Ferrari *et al*., 2021).

5.4.3 Effect of mango variety on shelf stability of mango flakes

Mango varieties were established to not have an impact on the shelf-stability of drum-dried mango flakes from the current study. However, there was a high probability that mangoes with higher Brix levels might have a slightly shorter shelf life. The hygroscopic sugar nature of mango flakes made from mangoes with higher brix content expedite yeast growth (Khachatourians, 2003) Physiologically, yeasts, and molds multiply significantly in environments with the appropriate PH (2-9) and food (Setya Utama *et al*., 2020). Yeasts break down simple sugars as their source of nourishment for growth (Ruzauskas *et al.,* 2014). While many studies have focused on exploring the physiological changes and shelf life of mango products influenced by post-harvest treatments (Din *et al*., 2011; Jahurul *et al*., 2015; Kementerian Kesehatan Republik Indonesia, 2016; Membré & Boué, 2018), limited researches have been conducted so far to determine whether the variety of mangoes influences the shelf-life of dried mango products.

5.5 CONCLUSIONS

Under the right temperature and storage, mango flakes can be fit for human consumption for a minimum of seven months. While longer storage duration exacerbates microbial growth, storing mango flakes under different temperatures has minimal impact on the growth of fungi. However, using airtight containers prolongs the microbial safety of flakes. Nonetheless, low-temperature storage such as refrigeration is the most effective method of ensuring microbial and nutritional safety of drum-dried mango flakes due to the inability of fungi to survive low temperatures. Active packaging can only be effective if extrinsic and implicit factors such as proper drying mechanisms and an extremely low water activity below 6 is achieved.

5.6 RECOMMENDATIONS

Product factors that may affect the shelf life of dried mango products needs to be evaluated. Suitability of other packaging materials especially biodegradable materials should be evaluated.

CHAPTER SIX: GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

6.1 GENERAL DISCUSSION

Sugar content and starch composition influence the consumer acceptability of drum-dried mango flakes. This finding is consistent with the outcome of a research by Mwaurah *et al*., (2020), which associated the physicochemical characteristics of starch with its effect in dissolution with mango pulp. Similarly, the current study established that an increase in sugar concentration inversely affected the quality of mango flakes due to the constitution of reducing sugars, 16-18 w/v (fructose, glucose, and sucrose) in ripe mangoes (Lebaka *et al*., 2021).

Increasing the speed of the drum dryer reduces the contact time between the pureed formulation and the drum-drying plate. As a result, heat treatment is constrained leading to low-quality flakes. Despite the negative effects of heat exposure on the volatile components of mangoes, heat treatment enhances dried products' quality by increasing their crunchiness (Gates, 2007; Mwaurah *et al*., 2020). Generally, the contoured model used in optimization revealed that the four production parameters (sugar, starch, drum drying speed, and pressure of steam) had a significance influence on the sensory quality of drum-dried mango flakes. The variation recorded by the model for the overall acceptability of the drum-dried mango flakes was 50.23%. This high variation is a result of the close relationship between the predicted and actual values as earlier described by (Banga et al., 2003). Physicochemical results showed congruence with other studies (Yamato et al., 2020) that reported a decrease in vitamin C, proteins while other values of some components such as minerals were retained (Maldonado-Celis *et al*., 2019).

The drying process of the mango flakes reduced the water activity up to 0.874, which was still suitable for the growth of mold and yeasts that grow at a minimum water activity of 0.62 (Fontana Jr, 2020). However, with an EAC and KEBS recommended yeast count of less than 1.0 × 103 cfu/g (KEBS, 2018; STANDARD, 2018), the shelf-life test showed a congruence with the set standards as 98.4% of the samples showed fungal populations that were within the set limit. Besides, the growth of yeasts and molds was observed to take place from the third month after storage. It is reported that moisture content as a factor influencing the growth of micro-organisms spontaneously increases over time (Saddozai *et al.,* 2017). This rise may be explained by the products' ability to absorb water from the atmosphere during storage due to the storage package's minimal permeability. In the same connection, the current outcomes are in line with those of Zorić *et al*., (2016) who argued that the nature of the packaging material used to package food products influences the shelf-stability of the food products.

The type of packaging and storage temperature has a major impact on the development and survival of microorganisms (Chauhan & Patil, 2013). While heat treatment plays a key role in reducing microbial load in stored food products by inhibiting the growth of yeasts and molds, spores indicate great resistance (O'Grady *et al.,* 2020). This may explain why mango flakes that were stored at 500C showed higher microbial load in the first month of enumeration compared to those stored at a refrigeration temperature. The results from the present study on diversified temperature storage are further buttressed by those of Pistouri *et al.,* (2010) which indicated that low-temperature storage is one of the most effective methods of storing dry food products for more than 180 days. Mango varieties were established to not have an impact on the shelf-stability of drum-dried mango flakes from the current study. However, there was a high probability that mangoes with higher Brix might have a slightly shorter shelf life. The hygroscopic sugar nature of mango flakes made from mangoes with higher brix content expeditate yeast growth (Khachatourians, 2003) Physiologically, yeasts and molds multiply significantly in environments with the appropriate PH (2-9) and food (Setya Utama *et al*., 2020).

The drum drying process in particular exposes fruit-based products to factors that may alter their nutritional and physicochemical characteristics. During the drum drying of Dragon Fruit Peel, Chia & Chong, (2015) reported a substantial reduction in the water content, crude ash, crude fiber, and crude protein. These results were in agreement with the current findings which established a large disparity between the nutritional and physicochemical features of fresh mangoes reported by Maldonado-Celis *et al.,* (2019), and those recorded in the current research. Varietal differences have an impact on the chemical and nutritional content of drum-dried mango flakes. This can be extrapolated to the primary characteristics of the raw fruits from which the flakes are made. Suriati *et al*., (2020) reported different changes in vitamin C, texture, and moisture content in freshly cut fruits. The incorporation of mungbean paste into mango pulp during the processing of flakes boosted the product's protein value. Research has shown that green grams have a protein composition of up to 22.9% (Mmbando *et al.,* 2021; Muchomba *et al.,* 2023). With the protein enhancement, mung-bean-based flakes were able to attain as high values as (15.57±1.50 g/100g).

6.2 CONCLUSIONS

1. The acceptability of the mango flakes is dependent on the concentration of corn starch, speed of drum drying, gauge pressure, and the sugar content of the formulations. Mango flakes produced from formulations of 20% starch, 0% sugar, and drum dried at a speed

of 7.57 rpm for 5 minutes 2 seconds at a constant pressure of 0.8 bar has the highest sensory acceptability.

2. Under the right temperature and storage, mango flakes can be fit for human consumption for a minimum of seven months. The type of storage material, storage temperature, and mango variety have some impact on the shelf stability of mango flakes processed through drum-drying.
3. Product and process factors have both positive and negative effects on the nutritional and physicochemical composition of mung-bean-based mango flakes. Higher drum drying steam pressure leads to increased loss of vitamin C and vitamin A.

6.3 RECOMMENDATIONS

i. Analysis of microbial product factors outside process factors that may affect the shelf life of dried food products and consumer preference need to be investigated.

ii. Further research should be done by food processors to evaluate the optimum processing conditions that affect nutritional composition of locally produced food products in an effort to promote intake of foods with good nutritional value.

iii. Engagement between stakeholders at the county level to make sure there are policies that advocate for value addition and fortification using locally produced crops to enhance nutritional value of foods consumed. This should be initiated by the respective county administrations.

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APPENDICES

Appendix 1: Sensory Evaluation Questionnaire

INTRODUCTION

You are presented with mango flakes pieces. Please give scores for each attribute listed below on a scale of 1-7 as indicated at the bottom. Kindly rinse mouth before and after tasting a sample before proceeding with the evaluation.

Date......................... Gender........................... Respondent Age……..…..

Parameters		Color	Odor	Hardness/ tenderness	Flavor /Taste	Crunchiness	Texture	After taste	**Overall Acceptability**
	YFX								
Samples	BZN								
	NXN								
	FZB								
	ZBY								
	NFX								
	FYB								
	BYA								

Scoring scale

1 = Dislike Strongly

2 = Dislike Moderately

3 = Slightly Dislike

4 = Neither like nor dislike

5 = Like Slightly

6 = Like Moderately

7 = Like Strongly

Please share any feedback ---

-THANK YOU FOR PARTICIPATING

APPENDIX 2: Product formulation and treatment by acronym

Acronym	Composition and treatment
YFX (control)	500g mango pulp, 0% starch, 0% sugar
BZN	500g mango pulp (Ngowe), 20% starch, 0% sugar
NXN	500g mango pulp (Apple), 20% starch, 0% sugar
FZB	500g mango pulp, 2% sugar, 20% starch,
ZBY	500g mango pulp, 20% starch, 0% sugar, 7.57 rpm speed
NFX	500g mango pulp, 20% starch, 0% sugar, 4.2 rpm speed
FYB	500g mango pulp, 4% sugar, 20% starch
BYA	500g mango pulp, 6% sugar, 20% starch
KZM	500g mango pulp, 8% sugar, 20% starch
NDB	500g mango pulp, 0% sugar, 5% starch
FAN	500g mango pulp, 0% sugar, 10% starch
MFX	500g mango pulp, 0% sugar, 15% starch
DYY	500g mango pulp, 0% sugar, 25% starch
KNM	500g mango pulp, 20% starch, 0% sugar, 0.8 BAR pressure
GBK	500g mango pulp, 20% starch, 0% sugar, 1.6 BAR pressure