PRODUCT QUALITY CHARACTERISTICS OF SOLAR DRIED CHILLIPRODUCTS

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This thesis is my original work and has not been submitted for award of a degree in any other university.

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DEDICATION

I would like to dedicate this thesis to my lovely family who supported me through life, whose moral support has remained unrelenting, and for their continued support and for never giving up on me.

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LIST OF ABBREVIATIONS AND ACRONYMS

FAOSTAT	-	Food and Agriculture Organization Corporate Statistical Database
PVDC	-	Polyvinyl Dichloride
SHU	-	Scoville Heat Scale
Hg/ha	-	Hectogram per Hectare
Ha	-	Hectares
Tons	-	Tonnes
$C_{18}H_{27}NO_3$	-	Capsaicin
$Na_2S_2O_5$	-	Sodium Meta Bisulphate
$CaCl_2$	-	Calcium Chloride
Gms	-	Grams
HPLC	-	High Pressure Liquid Chromatography
CRC	-	Colorectal Cancer
UV	-	Ultra-Violet
RH	-	Relative Humidity
IPM	-	Integrated Pest Control
Db	-	Dry Basis
Kw	-	Kilowatts
RDA	-	Rural Development Administration
MR	-	Moisture Ratio
CIE	-	Commission Internationale l'e'clairage
Cfu/g	-	Coliforms Forming Units per Gram
LSD	-	Least Significance Difference
RMSE	-	Root Mean Square Error
SEE	-	Standard Error of the Estimation

R^2	-	Coefficient of Determination
BET	-	Brunauer-Emmett-Teller
GAB	-	Guggenheim- Anderson-de Boer
EMC	-	Equilibrium Moisture Content
VPM	-	Vapour Pressure Monometric
ERH	-	Equilibrium Relative Humidity

OPERATIONAL DEFINITIONS

Temperature	-	Can be measured using a thermometer and is the amount of heat present in a food substance.
Moisture	-	The amount of water present in a food substance
Relative humidity	-	The amount of moisture content surrounding a food substance
Sensory analysis	-	The perception of consumers upon analysis of a food substance
Shelf life	-	The duration a food substance can stay without going bad

GENERAL ABSTRACT

Chilli is an important commercial crop grown worldwide and used as a condiment, culinary supplement, or vegetable. It's mainly consumed as a dried chilli powder and in other forms such as whole green and red chillies, chilli flakes, sauce, and pickles. Chillies are quite nutritious and are a good source of carbohydrates, proteins, lipids, fibre, mineral salts, and vitamins; however, they are perishable, and a large quantity of them is lost due to inadequate post-harvest handling technologies. Traditionally, chilli has been preserved through direct sun drying, but this method has the disadvantage of contamination by foreign matter and attack by animals and insects. This method also depends on the sunshine hours of a particular area, thus taking a long time.

Solar drying is a drying technology that involves the usage of solar drying panels that are economically and environmentally friendly. The moisture content of chillies can be reduced over a shorter period. The products are protected from contamination from foreign matter, insects, and fungal contamination, thus the high-quality dried chilli. The farmer can easily use this method. Moisture sorption isotherm curves showed the inverse relationship decreasing as the temperature increases at constant relative humidity. The analysis was evaluated using the static gravimetric technique with a salt solution to create different relative humidities. The accelerated shelf life method was used where the chillies were stored in the oven at 56 °C. The analysis was done every two days up to the twelfth day, packed into aluminium packages, glass jars, and plastic containers.

Fresh chillies were dried to reduce losses associated with quality and microbial loss due to the high moisture content of fresh chilies. Drying was done both for oven and solar drying at 60 °C. Different pre-treatment methods involved blanching with hot water at 85-90 °C and acetic blanching at 90-100°C and soaking in pre-treatment of Na2S2O5 and CaCl2 solution for ten minutes. The physiochemical, nutritional, and microbial characteristics of chillies were then analyzed for oven and solar-dried chilli products. With sensory evaluation, consumer testing

affective/ preference test was used with the scores noted over the standard seven-point hedonic scale where seven represented "like very much," and 1 represented "dislike very much ." A panel of 22 participants was used. Parameters to be evaluated were Colour, taste, texture, astringency, bitterness, flavour, and overall acceptability. A meat curry stew was used in tasting the chillies with plain white rice as a carrier. Consumer preference questionnaires were given to the participants to fill in as they conducted the analysis.

This study evaluated the quality and safety of solar-dried selected chilli varieties grown in Kenya by solar drying fresh chilli products using solar tunnel driers. Optimizing drying chillies using oven driers, the temperature of 60 °C was found to be the most appropriate as it had minimal effect on the quality characteristics of chillies that included vitamin A, vitamin C, and Colour. The newton model was also used in fitting the drying kinetics data and was found to be a good fit for the data as it had a residual value (Coefficient of determination or R^2) close to one of 0.9797 at 60 °C solar drying.

The isotherms also exhibited the phenomenon of hysteresis, where the equilibrium moisture content was higher at a particular equilibrium relative humidity for the desorption curve than for adsorption. The G.A.B. (Guggenheim- Anderson-de Boer) model applied in fitting the experimental data at the temperatures of 50 °C, 55 °C, 60 °C, 65 °C and 70 °C which was found to have good prediction accuracy indicated by the high values of R^2 (Coefficient of Determination) and the S.E.E. (Standard Error of the Estimation).

Of the three packagings used, the aluminium package was found to be the best in terms of nutrients retention [vitamin A of 8.9mg/100g, vitamin C of 13.66g/100g and Colour (Colour was however fairly constant in all the three packages at an average of 1.3 arc tan)] after the end of the shelf life analysis. The microbial analysis was, however, higher in the aluminium package at 2.301 CFU/G for the total viable count and 2.699 CFU/G for yeast and mold. This was attributed to inappropriate pre-processing of the chillies before and during drying that increased the microbial load in the final product after drying. The microbial load for glass and

plastic packages was 2.699CFU/G and 2.301CFU/G, respectively, for the total viable count with no growth for yeast and mold.

There was a significant difference in all the parameters analyzed, with more beta carotene retention for oven-dried chillies, with the range being 28.4 to 23.2mg/100 g. This was in agreement with reports done by (Kamal et al., 2019). The ascorbic acid quantity was also significantly different, with ranges from 52.44 to 24.32g/100g. The effect of the pre-treatment on Colour was also significant. The microbial analysis showed variations in the microbial also that were attributed to the areas of collection of the chillies or the type of treatment done to the chillies.

There was no significant difference between oven-dried chillies and solar-dried chillies on the parameters of Colour, taste, astringency, bitterness, texture, and overall acceptability. The flavour, however, had some significant differences between solar and oven-dried chillies. The findings will inform on the commercial viability of dried chilli products concerning meeting food safety standards in Kenya to promote the industry's commercialization and value addition of chilli adoption. This can be done by solar drying fresh chillies and effectively storing the finally dried chillie products under aluminium packaging, showing the best nutritional composition preservation. Care should also be taken when handling both before and after drying to prevent recontamination of the final dry product. This study, therefore, will guide the solar drying technique of fresh chillies from the study of the quality characteristics and storage of the finally dried chillies from the moisture sorption isotherm and the storability study. The sensory analysis guided the consumer's acceptability of the finally dried chillies.

CHAPTER 1: INTRODUCTION

1.1.BACKGROUND OF THE STUDY

Chilli, used as a vegetable, condiment, or culinary supplementation, is considered an important commercial crop worldwide (Pandit et al., 2020). It is mainly consumed as a dried powder known as chilli powder; it's an important spice worldwide and a potential cash crop (Hossian et al., 2005). Chillies are grown worldwide, with the highest production quantities in China, India, Korea, the United States of America, and Africa (Gupta et al., 2002). The total production of chillies in the world is 4,485,882 tonnes (FAOSTAT, 2020). The tropical climatic condition of Kenya makes farming of chill quite ideal in the country (Kwacha, 2018). The major production areas in Kenya are where the altitude is below 2000m, such as part of the Coastal region, Eastern regions such as Makueni, Machakos, Meru, Murang'a, Kiambu, and Western regions such as Kisumu. Commercial production may require irrigation (International Trade Centre, 2014). The total production of chillies in Kenya is 3,023 tonnes (FAOSTAT, 2020). Losses for chillies occur at different stages in the supply chain, from the farmer to the final consumer. The total loss is estimated at 29.32 %. These values are a 2.33 % loss at the farmer's level, a 5 % loss at the middleman level, 10.80 % at the seller's level, and 11.18 % at the customer's level (Darmawati et al., 2019).

Only Five species of the twenty-five to thirty known species of chilli are domesticated. These are *Capsicum annuum, Capsicum frutescens, Capsicum chinense, Capsicum pubescens* and *Capsicum baccatum* (Pandit et al., 2020). Chillies are a rich source of Carbohydrates, Proteins, Lipids, Mineral salts (Calcium, Phosphorus, and iron), Fibre, and Vitamins A, B2, B12, C, D, and E (Orobiyi et al., 2013). Green chillies are also a source of biologically active phytochemicals, including antioxidants known to provide health benefits exceeding basic nutrition (Bhattacharya et al., 2010). Capsaicinoids, naturally occurring alkaloids present in the capsicum species, are the substances responsible for the hotness of heat upon consumption of chilli by humans (Guzman and Bosland, 2017).

During the pick period of harvest, however, farmers get low returns due to low market prices at the time (Hossain et al., 2005), as freshly harvested chillies are quite perishable. Thus large amounts of product are wasted and lost due to inadequate post-harvest handling and processing facilities (Gupta et al., 2002).

Red chilli has been preserved by direct sun drying. This technique requires large open spaces and takes long periods before the required moisture is reached, as it's dependent on the sunshine hours in an area. Since the chilli to be dried is spread openly outside, there is also contamination by foreign matter (dust, stones), insects, animals, and fungal infestation, which causes low quality and losses in the final product (Fudholi et al., 2013). Spoilage and quality changes of green chilli have also been minimized through cold and humid storage conditions at a temperature of 15 °C. However, with cold storage, care must be taken to avoid chilling injury for chilli stored at temperatures below seven °C (Hameed et al., 2015). Vacuum drying is another method used to preserve herbs and spices, such as chilli, as it produces products with better organoleptic properties. This method is expensive as the equipment used to produce the vacuum is expensive (Guiné, 2018). Greenhouse drying uses thermal mass to collect and store heat energy and insulators to store the collected heat for cloudy days and at night. However, the installation of these is expensive due to the equipment requirements (Samreen et al., 2017).

Solar drying of chilli is an economical and environmentally friendly technology that can be applied in drying of chilli; which can be used in reducing the moisture content of freshly harvested chillies from around 80% to5% with a duration of 48 hours, thus an improvement of the traditionally used open sun drying method (Fudholi et al., 2013). Drying can be combined with pre-treatments such as blanching (done to improve the acceptability of the product) can be used to treat chilli (Gupta et al., 2002). Plastics are currently used as packaging materials because it's cheap, flexible transparent, and not fragile. Plastic is, however, not environmentally friendly as its non-biodegradable. Glass cups and polyvinyl dichloride (PVDC) plastic are other modes of packaging that can be used to package chilli with minimal influence on the quality characteristics of chilli such as Colour and vitamin C content (Renate, 2019). Vacuum packaging under cold storage is another method that offers better quality characteristics of chilli storing with a way for chilli products of moistures above 10% (Chetti et al., 2014). Therefore, the products need to be processed after harvest and prevent the losses incurred by the farmers by reducing the post-harvest losses with proper post-harvest processing technologies.

1.2.PROBLEM STATEMENT

Fresh chillies are naturally perishable; thus, large amounts are wasted and lost due to inadequate post-harvest handling technologies. Also, during the pick period of harvest, farmers get low returns for their produce due to a lack of processing units (Geetha and Selvarani, 2017: Hasan, 2012). Significant price fluctuations and decreases result in food waste from unsold chilli (Anoraga et al., 2018). Shriveling, wilting, and strong physiological activities are the most experiences post-harvest problems for fresh green chilli (Hameed et al., 2015). The total loss is estimated at 29.32 %. These values are a 2.33 % loss at the farmer's level, a 5 % loss at the middleman level, 10.80 % at the seller's level, and 11.18 % at the customer's level (Darmawati et al., 2019).

After harvest, farmers take the freshly harvested chillies to the market for sale but due to the perishability nature of the chillies, a large quantity is lost. For farmers that export their chillies, even the smallest delay that caused the chillies to over mature and change colour will make the chillies unsuitable for sale (The Star, 2020). To reduce these losses its important co come up with technology that reduce the post-harvest losses of fresh chillies.

Although cold storage allows products to be available for longer periods in the fresh state for both consumption and processing, chillies are susceptible to cold injury if stored below seven °C or below. Cold storage is also quite expensive and not affordable to many small-scale farmers. An increase in temperature, however, causes an increase in the rate of water loss (Hameed et al., 2015).

The burning sensation resulting from chilli consumption, especially due to capsaicin, is unpleasant to many people, especially those not used to eating chillies. The concentration of capsaicin in chilli pepper depends on the type of variety and its maturity, and this concentration is subject to change. The range of this capsaicin concentration is 0.1 to 1% in chilli peppers (Yang et al., 2019).

Improper post-harvest handling of chilli due to their perishability nature results in losses in quality and spoilage due to wilting, pathogenic disorders, shriveling, and water loss (Hameed et al., 2015). Price fluctuation is also a result of improper post-harvest handling technologies; thus, the crop harvested results in high yield losses (Yanti et al., 2018). The traditional direct sun drying of chilli requires a large, open space, depending on the sunshine hours of the area, thus, a long drying time. The chilli being dried is also likely to be affected by contamination from foreign matter, insects, and fungal infestation due to the moist conditions. This method thus results in poor quality of the final dried product regarding nutritional qualities, microbial load, and general physical appearance.

For this reason, the end product is of lower quality (Fudholi et al., 2013). Sun drying also causes the shrinking of the chillies resulting in an unattractive final product due to the hindrance of the outer layer of this fruit to transfer of water inner surface (Kamal et al., 2019). Solar drying can be either through: direct or open sun drying and indirect solar drying. Under direct sun drying, food products dried are directly heated with solar radiation when spread out into a thin layer outdoors. The end product is thus of higher quality in terms of nutritional quality and microbial load. Solar drying panels as also quite an affordable method of dying chillies compared to open sun drying (Belessiotis and Delyannis, 2011). The colour of red chilli is among the important quality characteristics; drying, however, causes a loss of color quality of the final dried product (Chaethong et al., 2012). Chillies contain three times as much vitamin

C as oranges and are loaded with vitamins A and E, folic acid, and potassium (Rohrig, 2014); their consumption is, however, low. This research therefore seeks to utilize the solar drying method to help in the post-harvest losses experienced in chillies through moisture reduction thus making the crop available all year round. Also shelf life study will help understand on proper packaging methods to ensure the final dried product is safe microbiologically and nutritionally.

1.3.JUSTIFICATION

With appropriate post-harvest technology innovation, losses of red chilli can be reduced from 20-30% to about 3-5%, and these technologies are simply applied at the farmer's level (Yanti et al., 2018). Drying is the main preservation method used today, whose main purpose is to reduce the enzymatic and microbial activity that causes spoilage, therefore, extending the storage life of the food product being dried. Drying also saves packaging, storage, and transportation costs (Montoya-Ballesteros et al., 2014). This will help farmers get more returns from the sale of chillies and make the crop available all year round for consumption.

There has been advancement in drying technologies such as pre-treatment use, techniques, and equipment to accelerate the drying process, enhance quality, and improve the safety of the foodstuff dried. Solar drying is one of the drying techniques used in drying foodstuffs, for example, chilli, whose energy source is the sun (Guiné, 2018). To counter these shortcomings of direct sun drying, the indirect solar drying method is used, which involves the use of thermal energy collecting equipment and driers with special techniques, thus higher drying rates shortening the drying period, zero or no losses from infestation and natural phenomena and also improved quality dried product (Wiriya et al., 2009). Under solar drying, the moisture content of freshly harvested chillies can be reduced from around 80% to 5% within 48 hours (Fudholi et al., 2013). Solar driers reduce drying time and can be applied to improve and provide uniform hygienic conditions at processing (Chaethong et al., 2012). Chillies were therefore dried using the solar drying method to reduce post-harvest losses and also analyze their quality and storage. Chillies also contain three times as much vitamin C as oranges. They are loaded with vitamins A and E, folic acid, and potassium (Rohrig, 2014), thus increasing the nutritional composition when consumed. The findings will inform on the commercial viability of dried chilli products concerning meeting food safety standards in Kenya to promote the commercialization and value addition of chilli adoption by the industry. The dried chillie products can be used packed by different food industries that specialize in spice processing and also combined with other spices to make mixes for sale. Fast food industries can also utilize the dried chillies in preparation of the different foods and with the higher nutritional composition the spice supplement the diet with vitamins and minerals found in chillies.

1.4.OBJECTIVES

1.4.1. MAIN OBJECTIVE

To evaluate the quality and storability of dried chilli by solar drying of fresh chilli products in Kenya

1.4.2. SPECIFIC OBJECTIVE

I. To determine and optimize the drying kinetics and process parameters for fresh chilli.

II. To determine the moisture sorption isotherms of chilli through desorption and adsorption experiments.

III. To determine the phytochemical, nutritional and microbial quality changes of driedchilli product.

IV. To establish the shelf stability and storability of dried chilli product

V. To evaluate the sensory quality and consumer acceptability of the solar dried chilli product.

1.4.3. HYPOTHESIS

H1: Drying process kinetics of chilli can be optimized for quality and safety for the final product

H2: Moisture sorption isotherms of chilli can be determined through desorption and adsorption experiments

H3: Solar dried chilli products will have a good phytochemical composition, high nutritional and microbial quality compared to fresh chilli

H4: Solar dried chilli product will exhibit high shelf life and longer storage stability

H5: The acceptability and preference of the solar dried chilli product will be favourable dueto high sensory quality.

CHAPTER 2: LITERATURE REVIEW

2.1. OVERVIEW OF CHILLIES PRODUCTION AND UTILIZATION

Chillies, known to originate from South America where its cultivation and trading has been ongoing over 6,000 years, come from dried fruits of the species of genus *capsicum* belonging to the nightshade family that includes other crops such as tomatoes, eggplants and potatoes (Robinson, 2007). *Capsicum* is from a Latin word *Capsa* that means chest or box because the chilli fruit encloses its seeds neatly similar to a box. Although commonly known as chilli used world-wide, some different spelling used include chile, chili, chilly excreta. Also known as red pepper, chillies used mainly in culinary supplementation, as a condiment or vegetable is considered an important commercial crop (Kaleemullah and Kailappan, 2003). Chilli, dried to make chilli powder is an important spice and considered potential cash crop in regions where it is grown in the world (Hossain et al., 2005). The popularity of chilli is as a result of the varieties of shapes and sizes, its sensory attributes including colour, pungency (and piquancy) generally making foods more appetizing. Of the different varieties of chilli, some tend to be very hot while others that have mild pungency are utilized in salads making, as pickles or food colorants. The use of chilli as food colourant is because of the presence of mixture of carotenes and xanthophylls present as free pigments, mono- or di-esters of fatty acids in the red chillies (Gupta et al., 2002).

2.2. ORIGIN OF CHILLIES

Chilli originated from tropical and subtropical America regions with remnant of wild chilli pepper in Mexico indicating harvesting of wild chilli back up to 8,000 years ago, with domestication and its cultivation occurring in Mesoamerica approximately around 6,000 years ago (García-Gaytán et al., 2017). Upon domestication, chillies spread very quickly all around Southern and Central America. Europeans had been using black pepper for medical aid and as a spice in cooking ever since the Greek and Roman times. The chilli ingredient, as was imported from Asia, the Spice Island, was so expensive and thus a luxury item. The discovery of this fiery pond (chillies) revolutionized cooking. By adding chilli to staple foods, it became one of the most important ingredient in the world as was used in making even the poorest foods in flavour rich in flavour. Chilli also become a luxury for the hundreds of millions poor that could afford it every day (Robinson, 2007). Chillies are mainly grown in India, the United States of America, China, Korea, Spain, Mexico and in Africa. The annual trade of chilli all round the world is 55 to 65 thousand tonnes, accounting for 16.7% of the total spice production (Gupta et al., 2002). Chillies are known as the first domesticated crop in America, cultivated by farmers primarily in protecting the primary crop from any damage from birds (Mehta, 2017).

2.3. CHILLI PRODUCTION IN THE WORLD/ IN KENYA

Being the most widely used universal spice, chillies are recognised as one among the commercial spices crops. Although chilli production is throughout the world, Asian countries hold the bulk share of production with India being the highest producing country followed by china and Pakistan (Subbiah and Jeyakumar, 2009).

Approximately 37.62 million tonnes of chilli is produced in the world cultivated on around 20.20 million hectares of land. The major countries producing chilli are India, Mexico, Thailand, Nigeria, Indonesia, China, Pakistan, Uganda, Japan, Turkey and Ethiopia. Other countries growing this crop include United State of America, Italy, Hungary and Spain. The chilli consuming countries with the highest demand for chilli include India, China, Mexico, United States of America, Germany, Thailand and Sweden (Geetha and Selvarani, 2017).

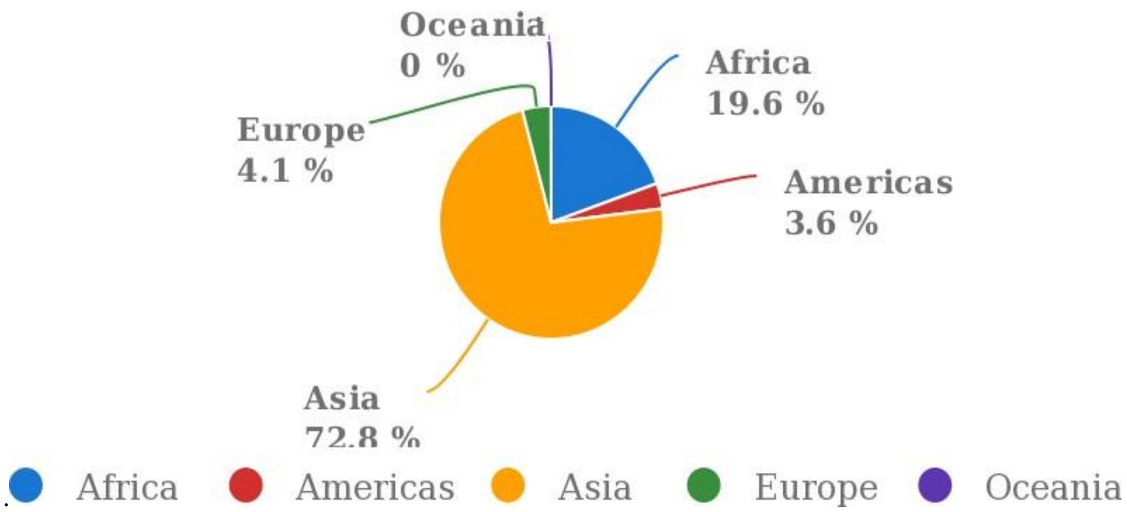

Figure 1: Production share of chili by region

Source: FAOSTAT (Sept 12, 2020). https://www.fao.org/faostat/en/#data/QCL/visualize

Table 1: Production, Area and Productivity of major chilli producing countries in 2018

	Country	Yield (hg/ha)	Area (ha)	Production(tons)
1	India	23,128	781,737	1,808,011
2	Myanmar	12,118	107,551	130,335
3	Bangladesh	13,968	101,072	141,177
4	Pakistan	22,691	65,275	148,114
5	Thailand	26,944	91,675	247,010
6	Vietnam	14,318	70,922	101,548
7	Romania	9,010	56,465	50,878
8	China	134,562	95,506	642,580
9	Nigeria	17619	40,225	70,871
10	Ethiopia	19,280	152,642	294,299
11	Mexico	19,233	31,590	60,755
12	Côte d'Ivoire	59,159	19,804	117,159
13	Nepal	50,000	10,500	52,500
14	Ghana	75,263	15,299	115,147
15	Egypt	26,059	24,010	62,569
16	Other countries	1,995,932	159,814	442,929
	World	2,519,284	1,824,087	4,485,882

Source: FAOSTAT, (Sept 12, 2020). https://www.fao.org/faostat/en/#data/QCL

Chillies do well in hot weather as the warmer the weather gets, the hotter the chillies will be. They can however grow in any area as long as the temperature does not fall below 15 degree

Celsius. With the tropical climatic condition of Kenya, chilli farming becomes quite ideal. With adequate sunlight, chillies flowering and propagation takes thus takes place at the right time (Kwach, 2018). The optimal ecological requirements for growing chilli are: an altitude of 0-1200 metres above sea level, 600-1200 mm of rainfall annually with a temperature of 20-30 °C. Well drained soil with a pH ranging from 6.0 to 6.5 is good (SHEP, 2016). The tropical climatic condition of Kenya makes the farming of chill quite ideal in the country (Kwach 2018). The major areas of production in Kenya are in areas where the altitude is below 2000m such as part of Coastal region, Eastern region such as Makueni, Machakos, Meru, Murang'a, Kiambu and Western regions such as Kisumu. Commercial production may require use of irrigation (International Trade Centre, 2014).

2.4. VARIETIES OF CHILLIES (JALAPENO AND BIRD'S EYE CHILLIES)

Just like any other plant-based food, chilli originated from naturally growing, undomesticated plant. Over the years however, all species in the genus are still not known as botanist have not yet explored this area rich in species diversity. Chilli belonging to genus capsicum contains about 25-30 species (Sape et al., 2016; Pandit et al., 2020). Five of the species are domesticated and cultivated. These are *Capsicum annuum*, *Capsicum frutescens*, *Capsicum chinense, Capsicum pubescens* and *Capsicum baccatum* (Orobiyi et al., 2013; Pandit et al., 2020; Magied et al., 2014). *C. annuum* pod type contains the varieties Serrano, Bell Asian, Cayenne, Chile de Arbol, Chiltepin, Hungarian Paprika, Jalape~ no, New Mexican, and Poblano and annuum. *C. Frutescens* pod type contains the Tabasco variety. *C. chinense* pod type contains the varieties Bhut Jolokia, Scorpion, Habanero and Scotch Bonnet *C. baccatum* contains the Aji variety while *C. pubescens* pod type contains the Rocoto and Manzano varieties (Magied et al., 2014; Guzman and Bosland, 2017).

C. annuum being the most commercially common species worldwide is characterised by pungent and non-pungent accessions, growing as herb and sub-shrub with fruits of differing shape, size and colour ones they mature. *C. frutescens* and *C. chinense* cultivation occurs in Asian, American and African countries. While *C.frutescens* is characterized with pungent accession and the fruits appearing as predominantly small to be less than 2cm long, *C. chinense* has highly pungent accessions and irregularly shaped fruits. *C. baccatum* and *C.pubescens* are cultivation is in the regions of Central and South America. These two are differentiated by their phenotypic characteristics with *C. baccatum* having yellow to green spots located in its corolla while *C. pubescens* has darker coloured seeds (Tripodi and Kumar, 2019).

Chillies come in a variety of sizes, shapes, colour, are available either fresh, dried, as flakes, powder, on their own or mixed with other spices. The colour of chilli range from red, orange, green and sometimes appear similar to brown, (the colour of chocolate). The shapes vary as either pointy, round, small, sometimes club like, long, thin, globular tapered or as though bell shaped. The skin of the chilli can be smooth, shiny or wrinkled with the walls either thin or thick (Ganga, 2013).

2.4.1. JALAPENO

Jalapeno pepper is a medium sized chilli of 2-3 inches in length when mature. Typically, these chillies are commonly eaten while still as green but occasionally can be allowed while still in the farm to fully ripen and turn red in colour. Jalapenos are a rich source of vitamins A (carotene) and C, (both antioxidants). It's also shown to reduce cholesterol and triglycerides. The common jalapeno varieties include senorita, Fresno chile, Sierra Fuego and Mucho Nacho (Kathryn et al., 2018)

Figure 2: Jalapeno chilli pepper variety

Source: Food Source Information- Colorado State University. https://fsi.colostate.edu/jalapeno-peppers/

a. Senorita Jalapeno

This type chilli, appearing first as dark green, eventually turns to purple and finally the red colour when left to mature while on the vine branch. The pod grows to reach about three inches in length and one and a half inches in width. This chilli matures after a period is eight days from planting the seeds to harvesting. These chillies are very hot registering 5,000 SHU on the Scoville scale.

Figure 3: Senorita Jalapeno

Source: https://www.amazon.com/Senorita-Hybrid-Hot-Pepper-Seeds/dp/B079W9ST4R

b. Fresno Chile

Fresno Chile is nearly similar to senorita although takes a shorter period to mature producing smaller and less mild fruits. It measures 2 inches in length and registers 300-400 SHU on a Scoville scale.

c. Sierra Fuego

This is a hybrid type producing larger amounts of chillies per plant. It measure 3.5 inches in length and 1.5 inches width upon maturity. Growing from dark green to red when mature, these chillies are mildly hot.

d. Mucho Nacho

This is a fast maturing hybrid maturing fully in sixty-eighty days from seed planting to harvesting. The fruits are about 4 inches long, large in size and flavour without extensive heat (Kathryn et al., 2018)

Figure 4: Mucho Nacho Jalapeno

Source: the tomato lady blog.com. https://thetomatoladyblog.com/tag/mucho-nacho/

2.4.2. BIRD'S EYE CHILLI

The bird's eye chilli is small and one of the hottest known chillies in the market (pungent) measuring 100,000-225,000 on the Scoville Heat Scale. This chilli is from the Capsicum frutescens family. The Kenyan variety of this chilli goes up to 180,000 SHU value on the Scoville Heat Scale. The bird's eye chilli is 2-3 cm in length, conical in shape and its green, orange or red when mature (Makoka et al., 2010)

Figure 5: Bird's eye chilli

Source: FarmBiz Africa. https://farmbizafrica.com/market/3320-african-birds-eye-chilli-farming-for-the-export-market-remains-an-untapped-lucrative-venture

2.4.3. CAYENNE PEPPER

Cayenne pepper a cultivar of *Capsicum annuumm* is a small-fruited pepper known to have originated from Cayenne, French Guiana. Its produces a spice that is very pungent of the same name by drying and grinding the orange to deep-red fruit (Peruzzelli et al., 2015). Cayenne pepper grows to a height of two to four feet tall. When immature, the pods are green but build in spice level as it ripen and turns red when mature and ready for harvest. The pods can also grow to yellow or orange shades. The fruit grows to about four to six inches in length. On the scoville scale, cayenne measures up to 50,000 scoville heat units (Gibson, 2019). Cayenne pepper contains vitamin E, C and K, carotenoids and complete B-complex vitamins. It also contains organic calcium, manganese, potassium and dietary fibre (Waymarks, 2011).

Figure 6: Cayenne Pepper

Source: theepicenter.com. https://theepicentre.com/spice/cayenne-pepper/

2.5. MATURITY INDICES

Upon transplanting form the seed bed, the crop takes 8 weeks (two months to mature. The harvesting period can las up to 7 months after the 1st harvest. Colour of the chillies is used an index in determining the maturity of chillies, light green chillies are considered immature but can be marketed as green chillies. Slightly mature chillies are dark green in colour and shiny and are marketed as red chillies. Those nearing maturity are red greenish in colour and are marketed as red chillies also. Fully mature chillies are fully red in colour but start turning red blackish with shrinking ones they over ripen (Rione Drevale, 2014).

2.6. NUTRITIONAL COMPOSITION AND BENEFITS OF CHILLI

Chillies are a rich source of Carbohydrates, Lipids, Proteins, Mineral salts (Calcium, Phosphorus and iron) Fibre and vitamin A, D3, E, C, K, B2 and B12 (Orobiyi et al., 2013).

Table 2: Nutritional value of chillies [per 100 grams]

	Value per 100 gms	
Parameter	**Fresh chilli (green)**	**Dry chilli**
Moisture	85.700gm	10.000gm
Proteins	2.900gm	15.000gm
Fat	0.600gm	6.200gm
Minerals	1.000gm	6.100gm
Fibre	6.800gm	30.200gm
Carbohydrates	3.000gm	31.600gm
Energy	29.000 K gm	246.000K cal
Calcium	30.000mg	160.000mg
Phosphorus	80.000mg	370.000mg
Iron	2.300mg	4.400mg
Vitamins		
Carotene	175.000µg	345.000µg
Thiamine	0.190mg	0.930mg
Riboflavin	0.390mg	0.430mg
Niacin	0.9000mg	9.500mg
Vitamin C	111.000mg	50.000mg
Minerals and trace Elements		
Sodium	-	14.000mg
Potassium	-	530.000mg
Phytin Phosphorus	7.000mg	71.000mg
Magnesium	272.000mg	-
Copper	1.400mg	-
Manganese	1.380mg	-
Molybdenum	0.070mg	-
Zinc	1.780mg	-
Chromium	0.040mg	-
Oxalic Acid	67.000mg	-
Caloric value		
Chilli (dry)	297	
Chilli (green)	229	

Source: The National Institute of Nutrition, Hyderabad, 2018. http://niftem.ac.in/newsite/pmfme/wp-content/uploads/2022/08/mizochilliwriteup.pdf

Vitamin C is water-soluble and thus, is easily leached into water and then degraded by heat with losses of up to 64.71 % at 55 in thirty minutes (NBR, 2018). Capsaicinoids are natural occurring alkaloids present only in capsicum species that results in the sensation of hotness and heat upon consumption by humans (Guzman and Bosland, 2017). Important members of this group are capsaicin, dihydrocapsaicin, nordihydrocapsaicin ,homocapsaicin and homodihyrocapsaicin. Approximately 90% of the total capsaicinoids are capsaicin and dihydrocapsaicin, capsaicin being the most abundant (Orellana-Escobedo et al., 2013). Capsaicin, whose chemical formula is ($C_{18}H_{27}NO_3$), is colourless, odourless, and oily like compound present in the fruit. Capsaicin primarily is present in the membrane that is known to be holding the seeds. This chilli hotness is analysed and measured by a Scoville heatscale involving a series of "heat units" ranging from 0 heat units to 16 million heat units depending on the amount of capsicum in the chillies. Capsaicin is so potent with concentrationof 10ppm producing long lasting burning sensation on the tongue. In its concentrated form, large dosage of capsaicin could be toxic if ingested. The amounts however found in hot chilli are so small thus little risk of harm from the toxic effects of capsaicin itself (Rohrig, 2014). The heat level of chilli can also be determined either using chemical, instrumental or sensory method. Today however, the high-performance liquid chromatography (HPLC) method that ismore reliable, rapid and efficient is used in identifying and quantifying capsaicinoids (Guzmanand Bosland, 2017). The anti-oxidant and nutritional content of the different consumption forms, varieties and species are quite different and vary (Saleh et al., 2018).

2.6.1. NUTRITIONAL BENEFITS

Chillies contain three times as much vitamin C as oranges, are loaded with vitamin A and E, folic acid and potassium (Rohrig, 2014). Chillies are also rich in phytochemical compounds including antioxidants such as ascorbic acid, carotenoids, tocopherols, flavonoids and capsaicinoids beneficial in preventing chronic diseases. Consumption of the fresh fruit aids in facilitating digestion of starchy foods (Orobiyi et al., 2013). Chilli consumption especially with people whole do not consumer chilli regularly has been shown to aid in reducing their energy intake, increasing their energy expenditure and also enhancing oxidation of fats (Shi et al., 2017). Capsaicin, the component that causes heat on consumption of chillies has both carcinogenic and anticancer effect. Excess consumption of chilli pepper may result in damage of the colonic mucosa with the long term damage causing the occurrence of colorectal cancer (CRC). Capsaicin may result in carcinogenesis role to cause CRC. On the other hand, anticancer effects of chilli pepper include promoting secretion of digestive juices and accelerating bowel movement thus reducing the risk of CRC (Yang et al., 2019).

2.6.2. PROPERTIES OF BIOACTIVE AND PHYTOCHEMICAL COMPONENTS OF CHILLI

Fresh chillies are quite nutritious although few people consume these products due to the heat resulting from their consumption. Green chillies are a source of vitamin, minerals and biological active phytochemicals that include antioxidants providing health benefits exceeding basic nutrition (Bhattacharya et al., 2010). As one of the most popular fresh vegetable, chilli are not only economically important but also considered functional foods because of the biological activities due to several bioactive phytochemicals such are capsaicinoids, carotenoids, ascorbic acid, flavonoid and phenolic compounds (Olatunji and Afolayan, 2019; Montoya-Ballesteros et al., 2014). Phytochemicals are natural bioactive compounds also known as secondary metabolites in plants acting as defence system. This defence system is to protect the plant cells essentially from environmental present hazards that include stress, pathogenic attack, drought, pollution and UV exposure and (Rohanizah, 2015).

Capsaicinoids and carotenoids exhibit anticancer and antioxidant activities with flavonoids acting as antioxidants while exhibiting anti-inflammatory, ant-allergic and antibacterial activities (Shaimaa and Mahmoud, 2015).

Biological active compounds present in the fruits are as a result of secondary metabolism. Vitamin C known for the antioxidant capacity prevents neuro-degenerative diseases, heart diseases, is found in chilli peppers. Carotenoids are a group of biological active compounds in chilli pepper providing the colour. Carotenoids such as capsanthin are functional phytochemicals due to their antioxidant activity in prevention of colon cancer (Montoya-Ballesteros et al., 2014). The pungency of chillies which is among the commercially important characteristics is as a result of capsaicinoids with capsaicin and dihydrocapsaicin being the most abundant (Simonovska et al., 2016). Their health effects include stimulation of the cardiovascular system, anti-inflammatory capacity and anticancer effect (Montoya-Ballesteros et al., 2014).

2.7. POST-HARVEST HANDLING OF CHILLI

Harvesting as the final activity of planting needs to be done with care to so as to maintain the quality of chillies (Yanti et al., 2018). Fresh red chillies in nature are quite perishable thus large amounts of the product is wasted and lost due to inadequate post-harvest handling and processing facilities (Gupta et al., 2002). Chillies require more attention towards harvesting, during storage and transportation (Kumar et al., 2010). Fresh chillies are estimated to have a shelf life of about 2-3 days on the basis of the 12-15% cumulative loss. Moisture content reduction and aeration of chillies after harvest reduces microflora development and thus reduction of loss of quality and total spoilage. Drying should not impact on the colour and pungency of the final dried chilli (Samreen et al., 2017).

At the peak period of harvesting, farmers get lower market return due to low market prices. There is also increased Interest of quality dried chillies both the locally and foreign market space. Drying of food products can be done traditionally by direct solar drying or using environmental friendly and economic solar drier (Hossain et al., 2005) as drying is the preservation method most widely used in preservation of food. Pre-treatments such as blanching used in inactivation of naturally occurring enzymes thus improving the colour and texture of the final product; are carried thus improving the acceptability of the final product (Gupta et al., 2002). In addition to blanching as a pre-treatment, chemical treatment with sulphite can be used in improving the quality and colour of the final dried chilli (Kwanhathai et al., 2012). Like other agricultural products, spices such as chill are faced with microbial contamination at harvest and in post-harvest handling mainly xerophilic storage moulds and bacteria. Most of these contaminations are because of poor hygiene at post-harvest but can be controlled with good hygiene at post-harvest handling including storage (Salari et al., 2012).

2.7.1. DRYING TECHNOLOGY

Almost all of the day-to-day types of food we use require preservation to either; minimise or completely stopping any microbiological spoilage while maintaining the desired level of nutritional properties for as long as the product is fit for consumption (Jangam, 2011). Drying is the main method of preservation actively utilized today. This process involves heat application under controlled environment thus removing the water that normally causes spoilage in foodstuff. The purpose of drying is in reducing the enzymatic activity and microorganisms that causes spoilage thus prolonging the storage-life of the dried products. Other advantages resulting from drying include minimising the requirement for packaging, storage and transportation cost. Drying however results in loss of some important bioactive compounds (Montoya-Ballesteros et al., 2014) with major losses in colour and textural quality of the final dried product. Browning resulting from enzymatic and non-enzymatic oxidation reactions of phenolic compounds and Maillard reaction during drying can be prevented with pre-treatments methods like chemical treatment (such as sulphites) and blanching in hot water (Chaethong et al., 2012; Saemgrayap et al., 2016). Pre-treatment methods are also known to minimise decrease of nutritional components of dried food. Blanching with the right combination of time-temperature is done with either hot water or stream to adequately inactivate enzyme peroxidase (Anoraga et al., 2018).

Another form of drying is the complete removal of water from the food products leaving no/zero moisture at all. When the dried food product is ready to use, the food product is re-watered thus almost regaining the initial moisture conditions. Convective drying, among the widest drying method involves heating by convection between hot air and the product's surface. The basic moisture transfer mechanisms involved in drying are:

a. Migration of the moisture from the mass inside to the surface and,
b. Transfer of moisture from the surface to the surrounding air (in form of water vapour) (Belessiotis and Delyannis, 2011).

In latest years, there has been much advancement in drying technologies such as pre-treatment, techniques, equipment with the aim of accelerating the drying process, enhancing quality and improvement of safety of the foodstuffs (Guiné, 2018). The choice of the method of drying of chillies will depend on the climatic condition at the time of harvest and the intended end use of the chilli. For home use, chillies can be dried using the cheapest available method such as sun drying while artificial drying methods can be used for chillies for the market (Azam, 2008). The method of drying chosen to dry chillies should ensure the products do not get contaminated with aflatoxins or contamination levels falls is below the maximum levels of aflatoxin contamination accepted (Muusha et al., 2019). At constant temperature and moisture content, biological food substances exhibit a characteristic vapour pressure and usually approach equilibrium at vapour pressure and temperature of the surrounding atmospheric gas. For equilibrium to be attained, the food substance either gains or loses moisture from the environment whether the vapor pressure surrounding the food is higher or lower. These are the adsorption and desorption processes respectively. Moisture sorption is important in technologies such as handling, drying, packaging, storage that aid in the study of a food stability, texture and in prevention of deterioration (Aviara, 2020).

2.7.2. SOLAR DRYING

In solar drying method, the sun is the source of the energy (Guiné, 2018). Drying with the use of solar energy is an economic procedure for especially for agricultural products used in preservation of the excess of production. Solar drying can be done in two ways: direct/open sun drying and indirect solar drying (Belessiotis and Delyannis, 2011).

a. Direct/ open-air sun drying (direct exposure to the sun)

Here, solar radiation is used to directly heat the materials to be dried. Drying can be either though the direct incidence solar radiation on to the materials surface dried or through a transparent cover used in partly protecting food products from either rain or other natural phenomena. Chillies are thinly spread out on a large outdoor free surface. Turning of the products from time to time is done as drying continues thus accelerating drying until the desired moisture content is reached. The drying surface depends on the type of product but generally is made up of concrete pavement floors onto which poly-ethylene net is spread/lined. For sensitive/easily spoilt food materials, perforated trays are used (Belessiotis and Delyannis, 2011). Sun drying is the convectional method of drying chilli most widely used taking an average of 5 days for attaining the moisture content of 4-11% dry basis (Wiriya et al., 2009). Sun drying however has some disadvantages in that it is dependent on the weather and sunshine hours, takes a long times thus possible infestation from insects, birds and animals (Dhumne, 2015). Also the red colour fades with resulting in brown pigment coupled with loss of vitamin C and pro-vitamin A (Wiriya et al., 2009). Despite these disadvantages, direct solar drying is still economical as the initial capital is very small and low and requites unskilled personnel for operation.

b. Indirect solar drying (convective solar drying).

The method of indirect solar drying involves the use of thermal energy collecting devices and driers with special technique. Advantages of using indirect solar drying include high drying rates thus shorter drying periods, zero losses as food products are not subjected to any natural phenomena. Smaller surface are of drying as the trays used are placed in stacks inside the drier (Belessiotis and Delyannis, 2011) and improved dried chilli quality (Wiriya et al., 2009). Solar drying systems have been shown to lower the moisture content of freshly harvested chill from around 80% to 5% under 48 hours (Fudholi et al., 2013).

2.7.3. STORAGE

Proper drying and storage have direct influence on the quality of chillies. The storage moisture of chilli should be 4.5% with a RH of 10% as higher moisture content can result in fungal infection during storage. Also the colour of chilli deteriorates when the moisture content is high. Excessive drying is also not preferred. To prevent loss of colour due to light, chilli should be stored in dark rooms/Packages. Farmers store chillies loose in bags, earthen pots or basket not more than a month. Chillies stored this way require occasional turning for aeration and removal of excess heat (Marketing of chilli, 2000). Chilli can be stored either for short term or long term. Storage under nitrogen gas gives the best storage by extension of shelf-life, vitamin E addition has also been found to extend shelf-life. The overall decomposition of pigments depends on storage time, presence of life and oxygen (Khobragade and Borkar, 2018). Fresh chillies are best stored within cold storage to maintain quality and reduce losses. Temperature of 8-12^{o} C with a humidity of 90-95% will maintains a shelf life of up to 3-8 days of fresh chillies (Yanti et al., 2018). Chilli fruits meant for storage for some few days should not be stored with other fruits such as apples and tomatoes as these fruits produce ethylene gas, causing ripening thus reduction of the storage life. Also, chilli fruits harvested while still green have longer storage life (Burt, 2016).

2.7.4. TRANSPORT

Transportation is an important part in dry chilli supply chain management as chillies move across the supply chain and ultimately to the final consumer because, if no proper planning is done, the farmers produce will not be sold in time thus will not get the right price, also the quality of the chilli will deteriorate. The main factor considered in transport of chilli is the transportation mode and the design of a transportation network (Somashekhar, 2017). Physical, biological and mechanical damage are among factors that can cause quality deterioration of chilli during transportation of chilli (Yanti et al., 2018). The nature of chilli possesses problems in transportation as chillies are bulky thus occupy larger spaces compared to their weight therefore increasing the cost of production. The various modes of transport utilized for transporting chilli include head load, pack animals, bicycle, carts lorries/trucks. Mode of transport used depends on the distance from the production area to the market and the condition of the roads. Mostly trucks /carts are used in transportation of chillies (Marketing of chilli, 2000). When transporting chilli from the field, plastic field crates should be used instead of sacks to avoid mechanical damage and friction (Yanti et al., 2018).

2.7.5. PACKAGING

Packaging is an important part of products processing and packaging as it has direct influence on the products life in relation to physical changes, chemical changes and the storability of the food. The nature of the package will determine air composition inside the package thus the rate at which nutrients are lost and the microbial activity. Gunny bags, cloth pieces and baskets are used in containing both the green and dry chilli from the farm to the assembling point. Plastic material ae the most widely used packaging food materials as they are light weight, have good productivity, are found in different forms and shape and are recyclable. The packaging material used for chillies depends on how long the products are to be stored before use. For short term storage of food product, fairly good moisture retention and colour preparation, high-density polyethylene amber/black polyethylene and Saran/cello/Saran poly laminate pouches can be used while for long term storage, aluminium foil laminate will offer maximum protection from the various physio-chemical changes (Khobragade and Borkar, 2018). Fresh red chilli is best stored in banana leaves to maintain the quality by ensuring lowest weight loss and vitamin C, maintain water content and the organoleptic characteristics in terms of colour and flavour (Yanti et al., 2018).

2.8. UTILIZATION OF CHILLIES

All over the world, chilli is consumed as fresh fruits, dried or ground in to powder form (Orobiyi et al., 2013). Research has shown that daily consumption of capsaicinoids has an impact on weight management and can be considered a natural weight loss aid by reducing energy intake (Whiting et al., 2014). Capsaicin has been used as a pain reliever, used in treating pains of arthritis, shingles or sore muscles. (Rohrig, 2013). Chilli are used either fresh, in pickles, salsa, sauces, pizzas, pastes or flavouring (Burt, 2016). Some of the non-food uses of chilli is in integrated pest control (IPM) programmes and in control of pests and diseases (Gamuchirai etal., 2019). Also, reports have been shown to indicate chilli extract use as biochemical pest repellent and pesticides (Kamal et al., 2019).

2.9. CHILLI VALUE ADDED PRODUCTS

Most farmers growing chilli sell their produces when fresh in the market. Their net returns can however be increased through value addition. Although value addition can help farmers get higher returns for their produce factors such as inadequate knowledge processing, equipment, packaging, skills on handling different machines and the high cost of setting up processing units are reasons why most farmers have not ventured into value addition (Kumar et al., 2010). Activities such as picking, cleaning, drying, grading and packing are done by farmers as value addition of chilli (Kumar et al., 2010). Value addition of chilli results in production of products including: green chilli powder, red chilli powder, green chilli paste, red chilli paste, red and green chilli pickles and sauces (Jaisingh, 2019). Fresh chillies can also be dried to be sold as whole dried chilli or ground (with roasting a times) to chilli flakes and chilli powder (Kaplinski & Morris, 2004).

2.10. TECHNOLOGIES IN PROCESSING OF CHILLI

Chilli like other agricultural produce contain high moisture content, therefore post-harvest processing technologies should ensure their proper conservation from spoilage as well as the important valued qualities of chillies basically the aroma and flavour, pungency and the colour. Different unit operations including washing to remove dirt, curing, drying for preservation, clearing, grading in terms of quality and packaging are done in preparation of chilli to the market and consumers (De, 2003). The quality of chilli can deteriorate ‘physically, mechanically, microbiologically, enzymatically and physiologically. Losses of this crop that reach up to 30-50% can be reduced to less than 10% while extending the shelf life through proper post-harvest handling technologies. Processing of chilli to various products can also be used as a way of value addition and loss reduction (Yanti et al., 2018).

2.11. CHALLENGES IN VALUE ADDITION AND COMMERCIALIZATION OF CHILLI IN KENYA

Although growing of chilli has been shown to earn farmers a good income, there are some challenges facing the farming of this crop. This include: inadequate drying space, high cost of fertilizer which has an irregular supply, high cost of quality seeds, lack of technical knowledge, lack of financial funding and infestation by pests and insects. Other challenges incurred during marketing are heavy commission charges, lack of market intelligence, inadequate storage facilities, high cost of transport and irregular payment by intermediaries (Balraj and Arockiasamy, 2018). The cultivation of chilli is faced with both biotic stress from (pests and diseases) and abiotic stress from (drought, soil poverty, excreta) yielding losses (Orobiyi et al., 2013).

Since the pandemic that was caused by Covid-19 thus closure of both local and international flights, farmers in Mwingi who sell their chilli in Netherlands, Germany and United Kingdom while it’s still green have watched as the crop turn red and dry and forced to uproot the chilli and plant other crops (The Star, 2020). Most farmers get low returns during the pick time of harvest due to lack of any proper processing units (Geetha and Selvarani, 2017).

2.12. GAPS IN KNOWLEDGE

- Increased utilization of chillies other than the common ground chilli and chilli sauce

- Incorporation in food consumed by people with weight management problems.

- Post-harvest management technologies to decrease losses of the crop

CHAPTER 3: PROCESS OPTIMIZATION AND DRYING KINETICS OF FRESHCHILLIES

3.1.ABSTRACT

Fresh chillies are quite perishable, with a shelf life of about 2-3 days. This results in losses and spoilage and farmers loss both the crops and money. To counter these losses, it is important to come up with a way to extend the shelf life of fresh chillies. Therefore, this study explored the use of solar drying to increase the shelf life of selected chilli varieties without compromising the quality. Drying involves reducing the moisture content of fresh produce, thus preventing spoilage and microbial growth with minimal effect on the quality of the dried chillies.

Optimization was done at temperatures of 50 °C, 60 °C, and 65 °C under the oven drier to determine the best drying temperature for chillies. Analysis of Vitamin A (beta carotene), Vitamin C, and colour was done for each drying temperature to determine temperature with the minimal effect of quality characteristics. The temperature of 60°C was chosen as the best temperature for drying chillies. Pre-treatments that involved acetic acid blanching and chemical soaking were used in combination with drying to help preserve the quality of dried chillies.2% acetic acid blanching with 0.3% sodium meta bisulphate and 1% calcium chloride soaking for 10 minutes was recommended as the best combination. These two combined treatments of temperature and chemicals mentioned above had minimal effects on the quality characteristics of chillies that included Vitamin C with a range of 41.48 g/100 g, Vitamin A (beta carotene) with a range of 23.20 mg/100 g with minimal effects on the colour after the drying was complete. The 60 °C temperature was then used for solar drying chillies using the solar tunnel drier. The drying kinetics was also studied for both oven and solar-dried chillies, and the newton model was used to fit the drying data as it had a residual value (R2) close to one.

Keywords: Drying, Quality Characteristics, Pre-treatment, Vitamin C, Vitamin A (beta carotene), Colour, Optimization, Drying Kinetics, Newton Model

3.2.INTRODUCTION

Chillies are an important commercial crop grown worldwide in countries such as India, Turkey, Mexico, Japan, Africa, and the United States of America (Gupta et al., 2002). It is mainly consumed as a dried powder known as chilli powder, is an important spice, and is considered a potential cash crop in regions where it is grown in the world (Hossain et al., 2005). The major production areas in Kenya are where the altitude is below 2000m such as part of the Coastal region, sand Eastern regions, such as Makueni, Machakos, Meru, Murang'a, Kiambu, and Western regions, such as Kisumu. Commercial production may require irrigation (International Trade Centre, 2014).

Dried chillies constitute a major share of the spices consumed. Fresh chillies are quite perishable with a moisture content of 300-400% db. and therefore need to be processed to avoid the losses that result (Shaik & Kailappan, 2005). The shelf life of fresh chillies is about 2-3 days. Thus it is essential to reduce the moisture content after harvest to prevent microbial spoilage and loss of quality through shriveling, water loss, wilting and pathogenic disorders (Hameed et al., 2015; Shaik & Kailappan, 2005). Chillies contain three times as much vitamin C as oranges and are loaded with vitamins A and E, folic acid, and potassium (Rohrig, 2014). Chillies are also rich in phytochemical compounds, including antioxidants such as ascorbic acid, carotenoids, tocopherols, flavonoids, and capsaicinoids beneficial in preventing chronic diseases. Colour and pungency are the most important attributes of chillies; therefore, the dying method used should not impair the colour or pungency of the chillies (Shaik & Kailappan, 2005).

Drying is the removal of water from food products through the application of heat, mainly for preservation. It also improves the stability of the food and reduces microbiological activities (Fadhel et al., 2012). The process is complex, dynamic, nonlinear, and unsteady, bringing about changes that depend on various factors, including properties of the fresh-wet material, chemical composition, dimension, shape, and process condition. Therefore, drying needs proper monitoring (Guiné, 2017).

Traditionally, the open sun drying method was used in dying chillies which is inadequate and results in microbial infection with over-drying causing undesirable quality losses. The solar drying method improves open sun drying and has been used to dry chillies with improved quality and reduced time (Shaik & Kailappan, 2005). It is important to conduct modelling and optimize this thermal process to increase process efficiency (Ajuebor et al., 2020). Several thin layer equations in a unified way have been used to describe the drying phenomena regardless of control mechanisms. The equations have been used for several agricultural products, estimating drying times, and thus generalizing drying curves (Fadhel et al., 2012). The selection of the optimal drying process ensures the final dried product's nutritional, chemical, physical, and sensory qualities are preserved.

This study, therefore, optimized the drying temperature that would maximize the dried product quality in regards to minimum moisture content and maximize the vitamin C, vitamin A(beta carotene), and the colour quality of dried chillies and model the kinetics of drying using empirical drying model through the drying characteristics of chillies in an oven and solar drier.

3.3.MATERIALS AND METHODS

Chillies for this study were obtained from Voi, three varieties; Nemo, Fanaka and Matilda were used. The chillies were obtained when they were red at the red stage of maturity.

3.3.1. Study design

Optimization was done by drying of chillies at three temperatures of 50 °C, 60 °C and 65 °C and at 60 °C for solar drier. For each drying temperature, the chillies were spread on the perforated tray on a single layer. During the drying period for both solar and oven, smaller samples of about 3 grams were placed on moisture dished and these were withdrawn and weighted using an electric balance every 30 minutes to monitor the change in moisture with time. The weighing was done within 1.5 minutes. Drying was done until there was no change in weight with time. The drying experiment was started at 9.00 a.m. and lasted up to 4.00 p.m.

3.3.2. Sample collection

Freshly harvested chillies were obtained from Voi and kept under refrigeration at 4 °C prior to the experiment.the varieties used in this study include Nemo variety, Fanaka Variety and Matilda variety

3.3.3. Sample preparation

Sample preparation involved sorting the chillies to remove dirt, the stalks, green coloured chillies and any other unwanted materials. The chillies were then washed with tap water, drained and divided into sections enough for each treatment. One lot of the sample was blanched in water at 85-90 °C at 3 minutes and drained in perforated basins before drying (control) while the other lot was blanched in 2% acetic acid at 90-100 °C for 2 minutes, drained and soaked in pre-treatment solution:

a. 0.1 % sodium meta bisulphate and 1 % calcium chloride for 10 minutes
b. 0.3 % sodium meta bisulphate and 1 % calcium chloride for 10 minutes

The initial moisture content was also determined using the drying oven fixed temperature of105 °C (AOAC, 2005; method 967.08) done in duplicates and average values were reportedas water/kg dry matter (d.b.).

3.3.4. Methodology for drying kinetics experiment

Drying of chilli was done through an oven drier and solar drier. For oven drying, a benchtop cabinet dried that contained six perforated trays (420 x 440 mm each) was used in drying. The dried fan that circulates air and an exhaust flap that opens and closes to release exhaust air and attain maximum heat, respectively. Heating power was provided by a 1.5-3 kW heaterconnected to a thermostat for automatic switching on and off. The dryer operates using the overcurrent principle in which inlet current splits and moves between the trays and over all the layers of the chillies. This, in combination with the registered profiled layout of the trays, ensures the desired uniform air distribution inside the drying chamber. The drier was switched on and the drying temperatures set before the dying was started. For solar dried, the tunnel drierwas used.

Different pre-treatment methods were used to reduce the drying effect on the nutritional, physical and microbial characteristics of the chillies. Blanching with hot water was done using water at 85-90 °C for 3 minutes and in 2% acetic acid solutions at 90-100 °C for 2 minutes. Acetic acid solution blanching has been shown to counter effects caused due to hot air drying preserving the colour and relatively enhances bio accessibility of the bioactive components (Kamal et al., 2019). Draining was done on perforated basins before soaking into the pre-treatment solutions. Sodium Meta bisulphate and calcium chloride solutions were used as the chemical pre-treatments at different ratios shown below. The ratio of 1:2 weights for weight for chillies and the pre-treatment solution respectively

c) 0.1 % sodium meta bisulphate and 1 % calcium chloride for 10 minutes

d) 0.3 % sodium meta bisulphate and 1 % calcium chloride for 10 minutes

Dried products were placed inside the solar drier on perforated trays fitted with aluminium foil. The drier had a fun that ensured air circulation inside, and to measure the temperature,an external thermometer was improvised for monitoring the temperature. The chillies were placed inside through opening of the windows and closing to allow for drying to take place.

3.3.5. Mathematical Model

The newton model was the mathematical model applied to the drying curves for fitting the experimental data at 50, 60, and 65 °C for oven drier and 60 °C for solar drier.

$$MR = \exp(-\mathrm{kt}) \quad (1)$$

where MR is the moisture ratio, t is the drying time and k in an empirical constant. The model was compared with the empirical model with the following temperature term, the moisture ratio:

$$MR = \frac{M-Me}{Mo-Me} \quad (2)$$

where M is the material moisture content at 0 time (%dry basis), Me is the equilibriummoisture content and Mo is the moisture at time 0 in dry basis

After completion of drying, chillies were analyzed for vitamin A (beta carotene), Vitamin C and the colour.The initial moisture content was also determined using the drying oven fixed temperature of105 °C (AOAC, 2005; method 967.08) done in duplicates.

3.3.6. Measurement of colour parameters

The surface colour of the dried chillies was done using the colour meter based on the C.I.E. L*a*b* colour space. Values of L* represent brightness, a* correspond to the red-green colour gradient while b* denotes to the yellow-blue colour gradient. Three measurements were conducted in each sample and the hue calculated as shown on the formula (Wiriya et al.,2009) below:

$$\boldsymbol{h} = \mathbf{tan}\frac{b*}{a*} \qquad (3)$$

3.3.7. Vitamin A (Beta Carotene) Analysis

The color from 2 grams of dried chilli was extracted using a mortar and pestle with small portions of acetone until the residual is colorless. All the extract was combined into a 100ml volumetric flask. 25ml of the extract was put into a 50ml round bottomed flask and evaporated to dryness in a rotary evaporator at about 60 ^{0}Cinto the evaporated sample, 1ml ofpetroleum spirit was added to dissolve beta carotene which was eluted through a packed column and received into a 25ml volumetric flask and the absorbance read at 450nm (Serrano et. al., 2010) and that content of beta carotene calculated as below:

$$\text{Beta Carotene} = \frac{0.4}{0.12}\ x\ \frac{50}{25}\ x\ 25\ xAbsorbance\ x\ \frac{100}{Sample\ Weight} \qquad (4)$$

3.3.8. Vitamin C Analysis

The method of determination of vitamin C used was the standard given by AOAC 2006. 5 grams of the dried chilli was mixed with 15ml of TCA (Trichloroacetic acid). This wasfiltered to obtain the extract/filtrate .5ml of this extract was mixed with 5ml of 4% (KI) Potassium iodide and some drops of starch solution. This was titrated with N- bromsuccinimide solution

$$Vitamin\ C = \mathrm{V.C} * \frac{176}{178}\ (mg) \quad (5)$$

V= Volume of N-brosuccinimide (ml)

C= Concentration of N-brosuccinimide (mg/ml)

3.3.9. Statistical Analysis

All measurements were conducted using two replications and results recorded as mean value ± standard deviation. The data was subjected to analysis of variance (ANOVA) using Genstat15th Edition statistical software package. Significance difference at 5% level of significance (p<0.05) was applied between the different temperatures and pre-treatments.

3.4.RESULTS AND DISCUSSION

3.4.1. Quality changes during drying of chillies at different drying temperatures

Quality parameters including changes in Vitamin C, Vitamin A (beta carotene) and colour were monitored at 50 °C,60 °C and 65 °C for the pre-treated chilli samples (table 3). Results showed that there was a significant difference on the quantity of vitamin C with the different pre-treatments at (P<0.05).

With vitamin C, the maximum value of vitamin C was at chillies dried at 65 °C treated with treated with 2% acetic acid blanching and soaking at 0.3 % sodium meta bisulphate and 1 % calcium chloride for 10 minutes (83.0mg/100g) for the Matilda chilli variety. The minimum content of vitamin C was for the Matilda variety dried at 50 °C and treated with treated with 2% acetic acid blanching and soaking at 0.1 % sodium meta bisulphate and 1 % calcium chloride for 10 minutes at (33.5mg/100g). The average content of vitamin C for chillies dried at 60 °C was 41.48 g/100g.

For vitamin A (beta carotene), the maximum content was on the chilli variety, Nemo Variety treated with treated with 2% acetic acid blanching and soaking at 0.3 % sodium meta bisulphate and 1 % calcium chloride for 10 minutes (23.20 mg/100 g) at 60 °C. Similar values of 23.20mg/100g were also seen for the blanched samples at 60 °C. The minimum content (6.8mg/100g) was seen on Matilda variety dried at 65 °C and treated with treated with 2% acetic acid blanching and soaking at 0.1 % sodium meta bisulphate and 1 % calcium chloride for 10 minutes. The average values for vitamin A (beta carotene) for chillies dried at 60 °C ranged at 23.20 mg/100 g.

In the case of the colour, the samples dried at 50 °C were mostly affected and showed areduction in the final colour after drying compared to samples dried at 60 and 65 °C.

Values recorded for the other pre-treatments are shown on the table below.

Table 3: Tables Showing Quality Characteristics Of Chillies Dried At Different Drying Temperatures.

65°C	**Vitamin A (beta carotene)**	**Vitamin C**	**Colour**
Pre-treatment A	6.8^{a} ±4.19	83.0^{a} ±4.77	0.9800^{a} ±0.014
Pre-treatment B	11.8^{ab} ±1.05	73.5^{ab} ±6.07	1.2700^{ab} ±0.014
Blanched samples	8.7^{ac} ±0.226	69.1^{bc} ±0.41	0.6400^{ac} ±0.014
P-Value	0.277	0.109	<0.001
L.S.D %	7.95	14.21	0.045
50 °C	**Vitamin A (beta carotene)**	**Vitamin C**	**Colour**
Pre-treatment A	10.0^{a} ±2.46	33.5^{a} ±0.07	0.44^{a} ±0.014
Pre-treatment B	10.1^{a} ±1.23	71.9^{ab} ±2.52	0.59^{ab} ±0.007
Blanched samples	9.7^{a} ±5.97	34.4^{a} ±11.43	0.48^{a} ±0.014
P-Value	0.994	0.017	0.003
L.S.D %	12.07	21.50	0.039
60°C	**Vitamin A (beta carotene)**	**Vitamin C**	**Colour**
Pre-treatment A	23.18^{a} ±0.51	36.73^{a} ±0.714	0.785^{a} ±0.007
Pre-treatment B	23.19^{a} ±1.65	46.52^{ab} ±2.02	1.525^{ab} ±0.007
Blanched samples	23.20^{a} ±1.29	43.16^{ab} ±2.87	1.375^{ab} ±0.007
P-Value	1.000	0.039	<0.001
L.S.D %	3.197	6.584	0.023

Note: Pre-treatment A- 2% acetic acid blanched and soaking into 0.1% sodium meta bisulphate and 1% calcium chloride for 10 minutes. Pre-treatment B- 2% acetic acid blanchedand soaking into 0.3% sodium meta bisulphate and 1% calcium chloride for 10 minutes. Blanched sample-Water blanched with no chemical soaking.
*All values are means ± standard deviation of two replicates
Superscripts with different letter along the same column show significance difference at ($p<0.05$)

Vitamin C content as reported by the Rural Development Administration (RDA) is about 26 mg/100g (RDA, 2001); there is a significant contribution as indicated in this report, with vitamin C content being recorded as 83.0 mg/100g compared to the RDA report. Loss of vitamin C from the chillies could be attributed to the prolonged exposure during drying to thedrying temperature, oxygen, metal and the pH. These factors cause destruction of the cell structure leading to oxidation of ascorbic acid to dehydroascorbic acid (Wang, 2018), for this reason, the ascorbic content of chillies can be used in evaluating nutrient loss during processing. The 60 °C temperature showed the best result for colour and also for the other variables of vitamin A (beta carotene) and Vitamin C. This, therefore, was the recommended temperature for drying chillies to produce the best quality of dried chillies (Kamal et al., 2019)

3.4.2. Changes of chillies Moisture Content at Different Drying Temperatures

Time required to oven dry the chillies from the initial moisture content of 237.302 dry basisto a final moisture of around 10.5 dry basis was 13.5, 12.5 and 10 hours at temperatures of drying of 50 °C, 60 °C and 65 °C respectively (Figure 7). With the solar drier oven, it took 6.5 hours to dry chillies from 252.485 to 10.5 dry basis at 60 °C. The figure below showscurves of moisture content against time of drying.

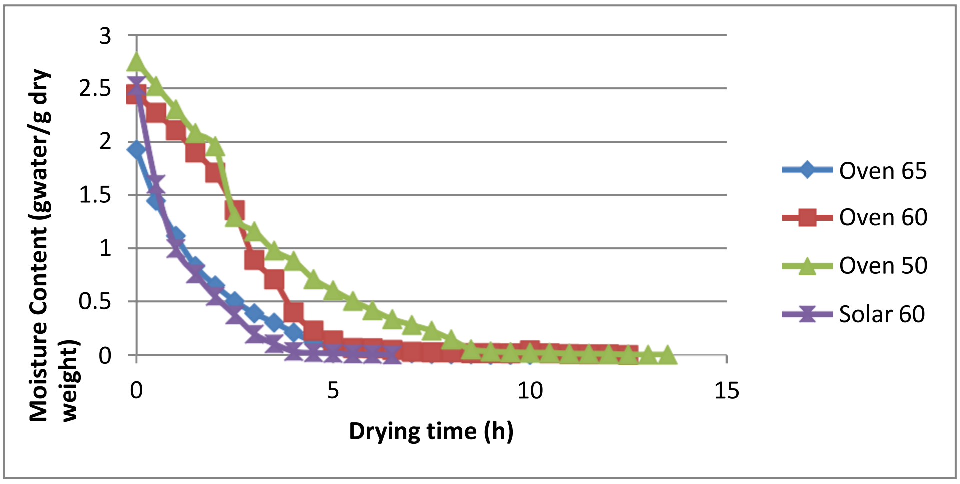

Figure 7: Moisture Content versus Drying Time of Chillies at Different Temperatures for Oven and Solar Drier.

Moisture content significantly decreased with drying time decreasing at a higher rate at higher temperatures. This was observed for both oven and solar drying. The figure above show curvesof moisture ratio (MR) against drying time that also reduces exponentially with drying time. This is in agreement with the reports quoted by (Kaleamullah and Kailappan, 2005). Moisturecontent decreased rapidly at the beginning of drying and later on slowed down up until reachingthe equilibrium moisture level. This phenomenon could be due to low moisture diffusion withinthe chilli other than the evaporation of moisture from the surface and thus diffusion-controlledmass transfer. As drying begins, due to the high moisture content of the chillies, the moisture of the chillies was readily evaporated off the surface of the chillies. As drying continues, the moisture is reduced, and thus evaporation zone shifts from the surface of the chillies to the inside of the chillies. The amount of water being evaporated is decreased and, thus the drying rate decreases with drying time (Kamal et al., 2019).

The newton model used is considered the simplest model because it has only one model constant. The model is widely used in describing the behaviour of drying foods and agricultural products. It is suitable for describing the drying behaviour of some fruits and vegetables (Onwude et al., 2016). The graph below shows the curves of moisture ratio againstdrying time for the different drying temperatures for oven drier and solar drier.

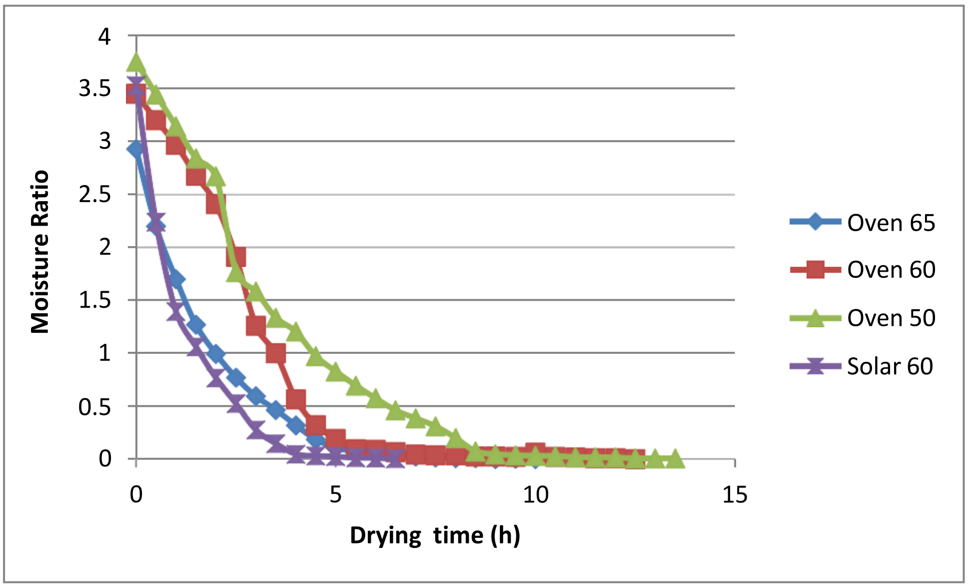

Figure 8: Moisture Ratio versus Drying Time of Chillies at Different Temperatures forOven and Solar Drier.

Moisture ration reduced exponentially with drying time. From the curves, it can be seen that an increase in drying rate given on the curve slope with temperature increase, this agrees with the report by (Kaleemullah and Kailappan, 2005). For chillies the rate period of drying is not constant thus the entire drying took place at falling rate periods. This is because of the quick removal of moisture from the skin (pericarp) of chillies. At the start of drying while the moisture content of the chillies was high, the rate of drying was also very high and as moisture of the chillies approached equilibrium, the drying rate was low.

The moisture ratio averages of the drying temperatures, 50 °C, 60 °C, 65 °C for oven dryer and60 °C for solar dryer were fitted using the Newton model with the estimated value of the model parameters shown in the table below. The residual values (R^2) for the Newton model were close to 1 i.e. the X axis to indicate the model was suitable for oven and solar drying of the chillies. Also the lower values for the relative mean standard error showed the goodness of fit for the newton model.

Table 4: Newton Model Results for Moisture Loss during Drying

Dry weight		**Statistical Parameters**		**Model Constant**	
	Temp (°C)	**R^2**	**SEE**	**K**	**RMSE**
Newton model	50 Oven	0.966	0.06361	0.527	0.047447
	60 Oven	0.8823	0.06361	0.611	0.168784
	65 Oven	0.8492	0.07052	0.992	0.10828
	60 Solar	0.9797	0.09047	1.107	0.024083

NOTE: R^2- Coefficient of Determination, SEE - Standard Error of the Estimation, RMSE -Root Mean Square Error, k- Drying Kinetics Model Constant

3.5.CONCLUSION

To dry the chillies from the initial moisture content of 237.30 % dry basis to 10.5 dry basis for50 °C, 60 °C and 65 °C for oven drying was 13.5, 12.5 and 10 hours respectively and 6.5 hoursfor solar drying. For all these drying temperatures, the processes took place at falling rate period. It is importance to thus choose a temperature of drying that has the minimal effects of important nutrient of the food substance being dried. Overall performance of chillies dried at 60 °C was best considering the quality attributes[Vitamin A (beta carotene), Vitamin C and colour analysis]. The drying temperature of 60 °C being the best in terms of nutrient preservation was recommended for use in drying fresh chilli.

The newton model used to fit the model was suitable for fitting the drying rate data.

CHAPTER 4: DRYING KINETICS AND MOISTURE SORPTION ISOTHERM OF SELECTEDCHILLI VARIETIES

4.1. ABSTRACT

Moisture sorption isotherm describes the relationship between moisture content and water activity in food. The project looked at the sorption thermodynamics of water and measured the sorption isotherm of chillies. The equilibrium moisture content of the chillies was determined at the temperature of 50 °C, 55 °C, 60 °C, 65 °C and 70 °C using the static gravimetric technique with the use of saturated salt solutions over the range of relative humidities from 0.115 to 0.865. Sorption isotherm curves showed the inverse relationship decreasing as the temperature increases at constant relative humidity. The isotherms also exhibited the phenomenon of hysteresis, where the equilibrium moisture content was higher at a particular equilibrium relative humidity for the desorption curve than for adsorption. The finding of this study helped in prediction of the product stability, shelf life and deterioration. Guggenheim- Anderson-de Boer's (G.A.B.) model is generalized by its theoretical bases, mathematical simplicity, and ease of interpretation when the water activity is up to 0.93. Nonlinear regression analysis was performed to estimate model parameters, and fitting quality was evaluated using the Coefficient of determination (R^2) and the standard error of estimate (S.E.E.). The G.A.B. model was applied in fitting the experimental data at the temperatures of 50 °C, 55 °C, 60 °C, 65 °C and 70 °C were found to have good prediction accuracy indicated by the high R^2 and S.E.E. values. The study will help predict the dried chilies' shelf life and ways of extending it by evaluating the critical water activity values to avoid clumping, changes in texture, and changes during different formulations.

Keywords: Sorption Isotherm, Equilibrium Moisture Content, G.A.B. Model.

4.2. INTRODUCTION

Chillies are the highest known sources of vitamin C (Pandit et al., 2020), contain three times as much vitamin C as oranges, and are loaded with vitamins A and E, folic acid, and potassium (Rohrig, 2014). Drying chillies is done to increase the shelf life of chillies and reduce the post-harvest losses resulting from the high perishability of chillies (Shaik & Kailappan, 2005). Fresh chillies are naturally perishable; thus, large amounts are wasted and lost due to inadequate post-harvest handling technologies. Also, during the pick period of harvest, farmers get low returns for their produce due to a lack of processing units (Geetha and Selvarani, 2017).). Chillies are also well known for their colour and pungency. During storage, the chillies undergo physiochemical and biological changes that strongly impact the colour and pungency; thus, it is important to investigate the Equilibrium Moisture Content (E.M.C.) of chillies at different temperatures and relative humidities to specify the storage conditions correctly.

Moisture sorption isotherm can predict changes in food stability and packaging material selection (Basu et al., 2006). Therefore, they are valuable tools for food science and technology researchers. Like other hygroscopic food substances, chillies exhibit the type two S-shaped sigmoid isotherm curves (Aviara, 2020). The total production of chillies in Kenya is 3,023 tonnes (FAOSTAT, 2020). Losses for chillies occur at different stages in the supply chain, from the farmer to the final consumer. The total loss is estimated at 29.32 %. These values are a 2.33 % loss at the farmer's level, a 5 % loss at the middleman level, 10.80 % at the seller's level, and 11.18 % at the customer's level (Darmawati et al., 2019).

The sorption isotherm describes the thermodynamic relationship between the water activity of the food and the equilibrium moisture content (E.M.C.) at constant temperature and pressure. These curves were developed to explain the state of the hygroscopic equilibrium of various food products (Andrade et al., 2011). The equilibrium moisture content relates food product properties with the environmental conditions. The E.M.C. is the moisture content of a hygroscopic material in equilibrium with a particular environment of temperature and relative humidity (Shaik & Kailappan, 2005).To understand the engineering operation related to dehydration (Maskan et al., 1998) and to ensure proper design and efficient optimization of drying equipment, good knowledge and understanding of sorption isotherm is key (Lemus et al., 2011).

Sorption isotherm can either be generated from desorption or an adsorption process. The sorption isotherm of food products can be measured using different techniques that include gravimetric, hygrometric and inverse gas chromatograph, vapour pressure monometric (V.P.M.), and the use of AquaLab equipment (Aviara, 2020). The gravimetric technique (either static or dynamic) involves measuring the weight of the sample with a balance. In contrast, the hygrometric and manometric methods measure the relative humidity of air and water vapour pressure when at equilibrium with a sample at a given moisture content (Iglesias and Chirife, 1978).

Several mathematical models have been developed to determine moisture sorption isotherms of various products, including linear and nonlinear regression models. Some of the models are product specific and only give appropriate predictive ability at certain water activity ranges (Lemus et al., 2011). The commonly used are the B.E.T., G.A.B., Oswin, Hailwood-Horrobin, modified Halsey, modified Henderson, and Peleg modified ChungPfost and Smith models (Aviara, 2020; Sahin and Gulum, 2006). Chillies are well known for their colour and pungency. The objective, therefore, was to determine the equilibrium moisture content of chillies at 50 °C, 55 °C, 60 °C, 65 °C, and 70 °C and to fit a suitable model to describe chillies sorption isotherm.the finding of this study will inform on estimating chillies drying time, texture and deterioration processes with regard to temperature and relative humidity.

4.3.MATERIALS AND METHODS

4.3.1. Sample preparation

Fresh and dried chillies (dried at 105°C for 24 hours) of the Matilda variety were used in determining the moisture sorption isotherm of chillies. Desorption and adsorption conditions at temperatures of 50 °C, 55 °C, 60 °C, 65 °C and 70 °C were used in determining the equilibrium moisture content (E.M.C.). This was done using six levels of relative humidities between 0.11-0.89 utilizing the static gravimetric technique. Supersaturated salt solutions of lithium chloride (0.111), potassium acetate (0.184-0.227), magnesium chloride (0.318-0.332),magnesium nitrate (0.440-0.540), sodium chloride (0.748-0.756) and potassium chloride(0.846-0.865) were used to come up with constant relative humidity at the temperatures of 50 °C, 55 °C, 60 °C, 65 °C and 70 °C.

4.3.2. Experimental design

A standard static gravimetric technique was used to determine the desorption and adsorption of fresh and dried chill with supersaturated salt solutions used in maintaining constant relative humidities in accordance with the COST 90 method (Wolf et al., 1985). The table below shows salt solutions and water activity values used in the adsorption and desorption experiment.

Table 5: Water Activities of Various Saturated Salt Solutions Used In Desorption and Adsorption Experiment for Chilli Products

WATER ACTIVITY					
Salt	**50 °C**	**55°C**	**60 °C**	**65 °C**	**70 °C**
Lithium chloride	0.11	0.11	0.11	0.11	0.11
Potassium acetate	0.189	0.189	0.1600	0.1725	0.1725
Magnesium chloride	0.31	0.3	0.31	0.305	0.30

Magnesium nitrate	0.45	0.45	0.45	0.6325	0.44
Sodium chloride	0.74	0.74	0.74	0.7395	0.75
Potassium chloride	0.81	0.81	0.8	0.7735	0.8

Six glass desiccators with insulated lids were used to contain the saturated salt solution to create the relative humidity of the range 0.11-0.89. These desiccators were first placed in a hot air oven at a desired fixed temperature to equilibrate the salt solution environment inside the containers. Duplicate samples of chillies (approximately 2 grams for desorption and adsorption) were measured in moisture dishes and place on the perforated base that is place about 5 cm above the salt solution, thus avoiding direct contact between chilli samples and salt solution. After every two days, the weights of the chilli samples were taken until the weights were constant. The equilibrium moisture content (X_{eq}) was determined for all the samples using the AOAC (2005) method 967.08.

$$X_{eq} = \frac{Mw - Md}{Md} \qquad (6)$$

where X_{eq} is equilibrium moisture content (g water/g dry matter); Mw and Md being weight before and after drying respectively.

Experiments were conducted twice with mean values of equilibrium moisture contentrecorded.

4.3.3. Analysis of sorption data

To fit the experimental data, the model G.A.B. shown below was utilized.

$$M_w = \frac{M_o \, C \, K \, a_w}{(1 - K \, a_w)(1 - K \, a_w + C \, K \, a_w)} \qquad (7)$$

where aw is the water activity, C and K are constants Mw is the equilibrium moisture content and Mo is the monolayer moisture (g water/g dry matter).

4.4.RESULTS

4.4.1. Moisture Content and Water Activity of Desorption at Different Temperaturesfor Oven and Solar Dried Chillies

The static gravimetric technique for the sorption determination was done using the temperatures of 50 °C, 55 °C, 60 °C, 65 °C and 70 °C. This was done with for fresh chillies and dried chillies dried overnight in the oven at 105 °C. Afterwards, the adsorption and desorption moistures were calculated which was plotted against the water activity. The G.A.B. model was used after plotting the water activity over moisture against water activity. This wasdone for both adsorption and desorption moisture content, the E.R.H decreased with increase in temperature for both isotherms.

Moisture sorption isotherm is used to describe the relationship between water activity and moisture content of a product at constant temperature and relative humidity (Andrade et al., 2011). This relationship depends on interaction between water and other ingredients. The amount of water a product can absorb depends on the product's chemical composition, physical structure and physical- chemical state. As a result, isotherm shapes are unique to each type of product because of capillary, surface and colligative effects.

The desorption isotherm obtained for the chillies were type 11, S shaped or sigmoid isotherms as of many hygroscopic products. There was a reduction in equilibrium moisture content at fixed relative humidity as the temperature increased. The moisture content decreases as the temperature is increased for a fixed vapour pressure. Byincreasing the temperature, the relative humidity was reduced.

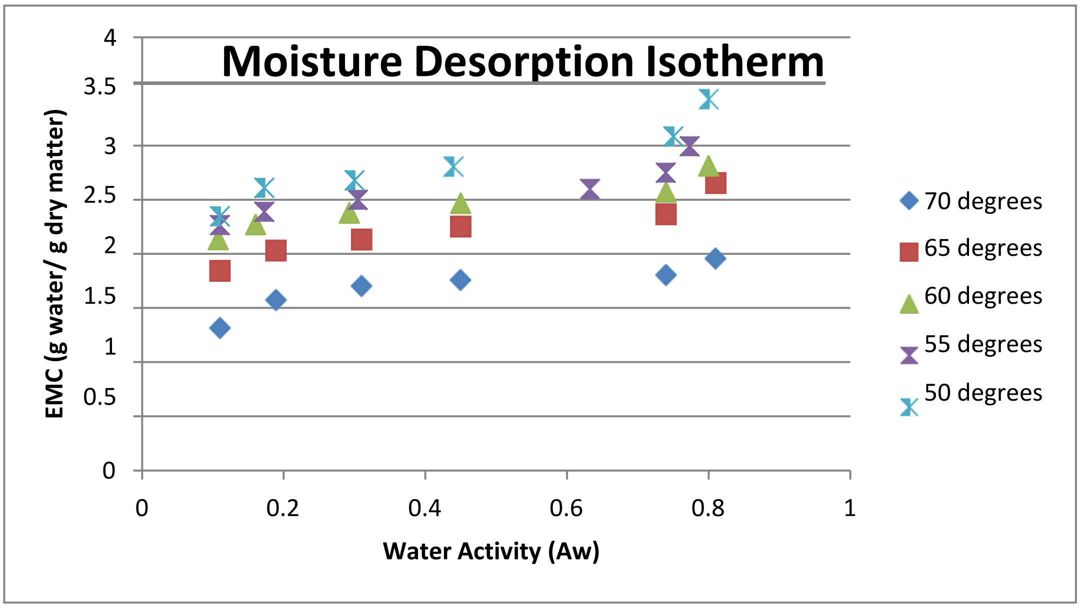

Figure 9: Equilibrium Moisture Content versus Water Activity of Desorption Isothermat Different Temperatures for Oven and Solar Drier.

4.4.2. Moisture Content versus Water Activity of Adsorption Isotherm at Different Temperature for Oven and Solar Dried Chillies

The adsorption isotherm obtained for the chillies were also type 11, S shaped or sigmoid isotherms as of many hygroscopic products. There was a reduction in equilibrium moisture content as the temperature increased at a constant relative humidity.

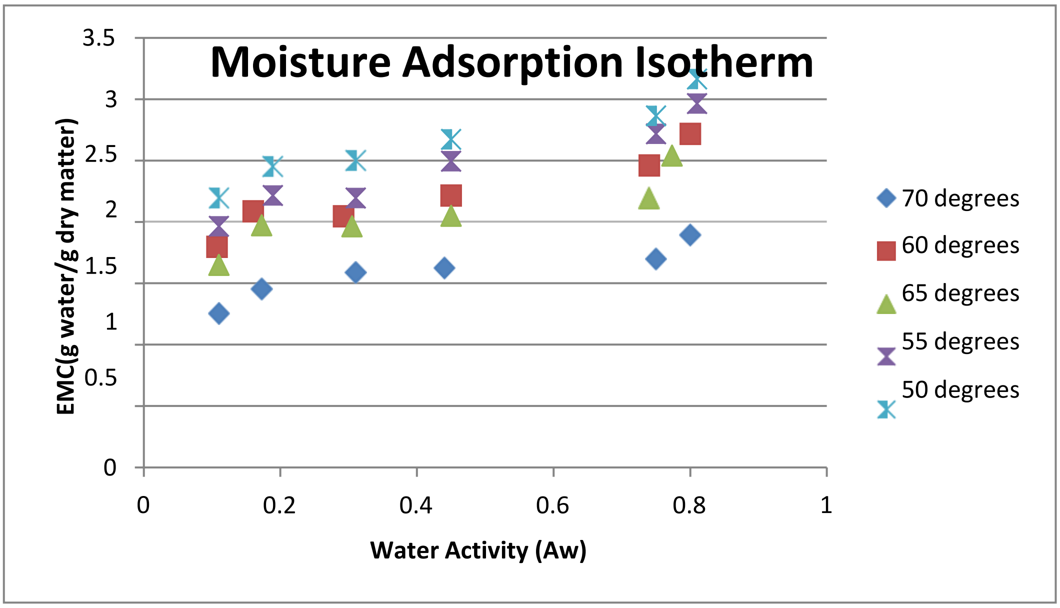

Figure 10: Equilibrium Moisture Content versus Water Activity of Adsorption Isotherm at Different Temperatures for Oven and Solar Drier.

The hysteresis phenomenon was shown with the adsorption and desorption isotherms whereby the E.M.C. was higher at a particular E.R.H. for desorption than a adsorption curved. The magnitude of the hysteresis for the isotherms at 50 exceeds that at 70. There was a gradual increase of the hysteresis value and then a sharp increase. There hysteresis then started declining and the magnitude of the hysteresis decrease with an increase in temperature.

Model: The G.A.B. model was fitted for both the adsorption and desorption isotherm of the chillies and is discussed below. Average data for the chillies at different temperatures is fitted for the model with estimates of the values of the parameter of the model listed in the table below. The standard error of estimation E_s, coefficient of determination R^2 are also presented in the table 6 and table 7.

Table 6: GAB (Guggenheim- Anderson-de Boer's) Equation Model Results for Desorption Data

Dry weight		**Statistical Parameters**		**Model Constant**			
Desorption	**Temp (ºC)**	**R^2**	**SEE**	**Xm**	**C**	**K**	**RMSE**
GAB	50	0.9948	0.381	2.30809	-87.9722	0.372641	0.1451
	55	0.9965	0.262	2.24855	-415.079	0.28124	0.06845
	60	0.9961	0.2381	2.16E+00	-1516.82	0.262148	0.05670
	65	0.9999	0.281	2.25552	6.068777	0.104257	0.07923
	70	0.9958	0.2195	1.79607	5.193209	0.109792	0.04819

NOTE: R^2- Coefficient of Determination, SEE - Standard Error of the Estimation,
Xm, C and K- Moisture Sorption Isotherm Model Constants, RMSE -Root Mean Square Error

Table 7: GAB (Guggenheim- Anderson-de Boer's) Equation Model Results for Adsorption Data

Dry weight		Statistical Parameters		Model Constant			
Adsorption	**Temp (ºC)**	**R^2**	**SEE**	**Xm**	**C**	**K**	**RMSE**
GAB	50	0.9951	0.340	1.48972	183.5175	0.327797	0.1157
	55	0.9958	0.372	1.78041	55.50356	0.364421	0.1381
	60	0.9957	0.326	1.69012	-70.2915	0.408066	0.1065
	65	0.9851	0.295	1.67158	-103.33	0.373574	0.08692
	70	0.9921	0.2177	2.09537	13.01946	0.221914	0.04741

NOTE: R^2- Coefficient of Determination, SEE - Standard Error of the Estimation,
Xm, C and K- Moisture Sorption Isotherm Model Constants, RMSE -Root Mean Square Error

4.5.DISCUSSION

All the isotherms both for desorption and adsorption showed similar sigmoid shapes. The E.M.C. of the chillies showed a decrease with increase in air temperature of the surrounding for both isotherms (adsorption and desorption) at the constant E.R.H. With increase in chamber temperature, the vapour pressure of the moisture within the chillies increased and hastened the transfer of moisture from chillies to the surrounding air. As the temperature increased, the vapour pressure of the moisture within the chillies increased and thus faster transfer of moisture. This trend was also observed in other crops such as mushrooms (Kaleemullah and Kailappan, 2004).

In regards to the E.R.H., the E.M.C. increased for both isotherms (adsorption and desorption) at a constant temperature. This was also observed for other reports for chillies (Wesley et al., 2000), red chillies (Shaik and Kailappan, 2004). An increase in temperature from 50-70 led to shifts in the isotherms to lowervalues of the E.M.C. This shows therefore, that at any constant moisture content, the E.R.H. decreased with increase in temperature for both isotherms. From the moisture sorption isothermcurves, basic information of the product and packaging to be used help determine the amount of moisture barrier in the package to be used by the packaged used in chillies. The choice of the product package is not always easy due to changes in the product during storage (Singh andAnderson, 2004). The data for the moisture sorption isotherm for both adsorption and desorption were fitted using the G.A.B model. The data for the parameters are shown in table 6 and 7 for desorption and adsorption respectively. The residual values obtained by the model showed patterns that the model was suitable in fitting desorption and adsorption data (Kaleemullah and Kailappan, 2004).

4.6.CONCLUSION

Both the adsorption and desorption isotherms for fresh and dried chillies respectively showed sigmoid curves, the type two isotherm. The equilibrium moisture content (E.M.C.) of both the fresh and dried chillies increased with increase in water activity and showed an increase as the temperature increased at the different levels of water activity. The G.A.B. model used to fit the sorption isotherm showed a good fit for the sorption data of desorption and adsorption. The G.A.B model for sorption isotherm was recommended as the best in fitting moisture sorption isotherm data

CHAPTER 5: PHYSIOCHEMICAL, NUTRITIONAL AND MICROBIAL QUALITY CHANGES OF SOLAR DRIED CHILLI PRODUCT

5.1. ABSTRACT

Fresh chillies are quite perishable due to the high moisture content of about 80-85% resulting in high post-harvest losses. The shelf life of these fresh chillies is about 2-3 days; therefore, farmers get losses for their harvest due to wilting and shriveling, and also, they sell their produce at losses due to the high supply at times of harvest. The traditional open sun drying also resulted in both nutritional and quality losses and microbial contamination of the final dried chillies, thus reducing quality. Fresh chillies were dried to reduce losses associated with quality and microbial loss due to the high moisture content of fresh chilies. Drying was done both for oven and solar drying at 60 °C. Different pretreatment methods involved blanching with hot water at 85-90 °C and acetic blanching at 90-100°C and soaking in the pretreatment of Na2S2O5 and CaCl2 solution for ten minutes. The physiochemical, nutritional, and microbial characteristics of chillies were then analyzed for oven and solar-dried chilli products. Parameters analyzed include the colour, vitamin A (beta carotene) and C, total ash and acid insoluble ash, Fat, and capsaicin content. There was a significant difference in beta carotene of chillies, both dried in the oven and solar drier dried at 60 °C with more beta carotene retention for solar-dried chillies compared to oven-dried chillies the range for the oven-dried chillies was from 28.4 to 23.2mg/100 g while for solar dried chillies was 33.3 to 24.5mg/100g.

The ascorbic acid quantity was also significantly different, with the ranges of 5.244 to 24.32mg/100g for oven-dried chillies and 46.97 to 30.07mg/100g for solar-dried chillies. Although the value for oven-dried chillies was high, the average for the solar-dried chillies was higher. Pretreatments had a significant effect on the quality of dried chillies.

Fat, Ash, acid-insoluble Ash, and Capsaicin also showed the same trend of being significantly different with the different pretreatments and between the oven and solar drying. The value ranges for oven-dried chillies were 17.03 to 45.00 % for Fat, 3.660 to 4.625 % for Ash, 0.06 to 0.535 % for Acid Insoluble Ash, and 2.14 to 3.35 % for Capsaicin. Those for solar-dried chillies were 7.90 to 23.95 % for Fat, 3.610 to 4.225 % for Ash, 0.125 to 0.495 % for Acid Insoluble Ash, and 1.60 to 2.01% for Capsaicin. Overall, the values for the color of solar-dried chillies were higher than those of oven-dried chillies. The effect of the pretreatment on colour was also significant. The microbial analysis showed variations in the microbial also that were attributed to the areas of collection of the chillies or the type of treatment done to the chillies. This study showed the most appropriate pretreatment method for drying chillies and indicates that solar drying can be used as an alternative to drying fresh chillies.

Keywords: Pretreatments, Solar drying, Quality characteristics.

5.2. INTRODUCTION

Fresh chillies are quite perishable; thus, large amounts of the product are wasted and lost due to inadequate post-harvest handling and processing facilities (Gupta et al., 2002). The shelf life of the fresh chillies is estimated to be about 2-3 days based on the 12-15% cumulative loss. Moisture content reduction and aeration of chillies after harvest reduce microflora development and thus reduce loss of quality and total spoilage (Samreen et al., 2017). Dying is mostly used for chillies in reducing the moisture content to about 5-11%; however, drying results in losing these important qualities (Saengrayap et al., 2016). Chillies are the highest known sources of vitamin C (Pandit et al., 2020) and contain three times as much vitamin C as oranges, are loaded with vitamin A and E, folic acid and potassium (Rohrig, 2014). The purpose of drying is to reduce the enzymatic activity and microorganisms that cause spoilage, thus prolonging the storage life of the dried products. Other advantages resulting from drying include minimizing the requirement for packaging, storage, and transportation cost. Drying can result in losing some important bioactive compounds (Montoya-Ballesteros et al., 2014).

Drying should not impact the final dried chili's nutritional quality, colour, and pungency (Samreen et al., 2017). The colour, for instance, is affected, leading to undesirable changes that lower the quality of the chilli and thus decrease income. Pretreatment methods applications are used to counter these changes to improve the final dried product (Gupta et al., 2002). Blanching (in hot water and acetic acid solution) and soaking in chemical solutions improve the quality of dried food products (Saengrayap et al., 2016). Chillies are excellent sources of antioxidants, vitamin A (carotenoids), and vitamin C (ascorbic acid), which aid in preventing carcinogens and delaying aging. Chillies are also the richest plant sources of vitamin C that need to be retained during the drying process (Wall, 2010). The moisture content and water activity of dried chillies were reduced, thus largely preventing /postponing the growth of microorganisms. Like other agricultural products, spices such as chill are faced with microbial contamination at harvest and post-harvest handling, mainly xerophilic storage moulds and bacteria. Most of these contaminations are because by poor hygiene at post-harvest but can be controlled with good hygiene at post-harvest handling, including storage (Salari et al., 2012). In dried foods, yeast and molds continue to grow in transportation and storage, and if enough viable counts are present, the food can cause health problems. To ensure food safety, it is important to maintain hygienic conditions throughout the processing process.

Chillies have been preserved by the traditional direct sun drying, where the technique required large open spaces and took long periods before the required moisture was reached, as it is dependent on the sunshine hours in an area. Since the chilli to be dried was spread openly outside, there was also contamination by foreign matter (dust, stones), insects, animals, and fungal infestation, which caused low quality and losses in the final product (Fudholi et al., 2013). Solar drying of chilli, an improvement of the traditional open sun drying, is an economical and environmentally friendly technology that can be applied in drying of chilli; which can be used in reducing the moisture content of freshly harvested chillies from around 80% to5% with a duration of 48 hours (Fudholi et al., 2013). Drying can be combined with pretreatments such as blanching (done to improve the acceptability of the product) can be used to treat chilli (Gupta et al., 2002). Solar drying coupled with the pretreatment methods results in a better quality of the dried chillies products.

5.3. MATERIALS AND METHODS

5.3.1. Sample collection and preparation

Fresh red chillies were obtained from Voi. Two varieties were dried; Fanaka variety and Nemo variety. Upon receipt, the chillies were graded, washed and stored under refrigeration at 5 °C. The initial moisture content of the chillies was determined using the AOAC (2005) method 967.08 and the moisture content was determined to be 60.40 % wet weight basis.

Different pre-treatment methods were used to reduce the drying effect on the nutritional, physical and microbial characteristics of the chillies. Blanching with hot water was done using water at 85-90 °C for 3 minutes and in 2% acetic acid solutions at 90-100 °C for 2 minutes. Acetic acid solution blanching has been shown to counter effects caused due to hot air drying preserving the colour and relatively enhances bio accessibility of the bioactive components (Kamal et al., 2019). Draining was done on perforated basins before soaking into the pre-treatment solutions. Sodium Meta bisulphate and calcium chloride solutions were used as the chemical pre-treatments at different ratios shown below. The ratio of 1:2 weights for weight for chillies and the pre-treatment solution respectively

a) 0.1 % sodium meta bisulphate and 1 % calcium chloride for 10 minutes
b) 0.3 % sodium meta bisulphate and 1 % calcium chloride for 10 minutes

5.3.2. Drying parameters

Drying took place at 50 °C, 60 °C and 65°C for oven drying and at 60°C for solar drying. The drying process was continued up until where there was no change in weight with time. After drying, the dried chilli products were wrapped in aluminium foil and placed in a desiccator for cooling. Some quality characteristics including Fat, ash and acid insoluble ash, Vitamin A (beta carotene), Vitamin C, capsaicin content and the colour where analysed to evaluate how drying and pre-treatment affect quality of chilli and select the best combination of drying and pre-treatment.

5.3.3. Methods of Analysis

5.3.3.1. Measurement of colour parameters

The surface colour of the dried chillies was done using the colour meter based on the C.I.E. L*a*b* colour space. Values of L* represent brightness, a* correspond to the red-green colour gradient while b* denotes to the yellow-blue colour gradient. Three measurements were conducted in each sample and the hue calculated as shown on the formula (Wiriya et al.,2009) below:

$$\boldsymbol{h} = \mathbf{tan}\frac{b*}{a*} \qquad (8)$$

For data analysis and interpretation, the hue was calculated from the Hunter L, a. b colourspace using the standard calculation [Arc tan (b/a)] used only when [+a, +b]

5.3.3.2. Capsaicin content analysis

The capsaicin content was analyzed to evaluate the taste. 0.5gram of dried chilli powder was weighted and extracted with 25ml of ethyl acetate. The mixture was shaken and allowed to stand overnight. 2 ml of this extract was passed through a basic alumina column (10cm x 1cm)to obtain pure capsaicin which was eluded with methanol: acetone: water solvent system (75:25:1) collecting 50 ml. The column was made by putting a glass wool at the bottom, layer of basic alumina (about 1.5 gm) in the middle and 1 cm later of sodium sulphate on top of the column which measured about 1cm diameter and 20 cm in height. After passing the extract, the column was washed with 5 ml acetone thrice. 10 ml of the collected solution was taken in a beaker and kept for 24 hours for complete evaporation to take place. 0.5 ml of folin's reagent and 6.5ml of distilled water was added to the beaker and allowed to stand for 3 minutes.1 ml of saturated sodium carbonate was added and the volume made to 10 ml with distilled water. The optical density of this solution was then read in the spectrophotometer at 760nm wavelength.

Capsaicin content was calculated from a calibrated curve prepared with the pure capsaicin. (Rosebrook et al., 1968)

5.3.3.3. Vitamin A (beta carotene) Analysis

The color from 2 grams of dried chilli was extracted using a mortar and pestle with small portions of acetone until the residual is colorless. All the extract was combined into a 100ml volumetric flask. 25ml of the extract was put into a 50ml round bottomed flask and evaporatedto dryness in a rotary evaporator at about 60 ^{0}Cinto the evaporated sample, 1ml of petroleum spirit was added to dissolve beta carotene which was eluted through a packed column and received into a 25ml volumetric flask and the absorbance read at 450nm (Serrano et. al., 2010) and that content of beta carotene calculated.

$$\text{Beta Carotene} = \frac{0.4}{0.12}\ x\ \frac{50}{25}\ x\ 25\ xAbsorbance\ x\ \frac{100}{Sample\ Weight} \qquad (9)$$

5.3.3.4. Vitamin C Analysis

The method of determination of vitamin C used was the standard given by AOAC 1975. 5 grams of the dried chilli was mixed with 15ml of TCA (Trichloroacetic acid). This wasfiltered to obtain the extract/filtrate .5ml of this extract was mixed with 5ml of 4% (KI) Potassium iodide and some drops of starch solution. This was titrated with N- bromsuccinimide solution

$$Vitamin\ C = \text{V.C} * \frac{176}{178}\ (mg) \qquad (10)$$

V= Volume of N brosuccinimide (ml)

C= Concentration of N-brosuccinimide (mg/ml)

5.3.3.5. Ash Content

2 grams of dried chilli powder sample was weight accurately in a porcelain crucible and ashing done in a muffle oven at 500 ^{0}C until a white ash of constant weight was obtained thenthe ash content of the sample calculated (AOAC, 2006).

5.3.3.6. Acid-Insoluble Ash

The ash above was covered with concentrated HCL and evaporated to dryness on a boiling water bath twice. 25 ml of 10% HCL was added, covered with a watch glass and allowed to boil gently on a low flame for 10 minutes. The liquid portion was filtered through an ash-less filter paper. This was repeated twice and after final boiling, the liquid portion was filtered through the same ash-less filter paper. The residue was washed with hot distilled water into a filter. The residue on the filter paper was then washed with hot distilled water. Both the residue and filter paper was returned into the crucible then re-ashed in the muffle oven to constant weight and the acid insoluble ash content calculated (AOAC, 2006).

5.3.3.7. Volatile Oil Content

5 grams of chilli powder was weight accurately in an extraction thimble, covered with a glass wool and the thimble placed in the sohxlex extractor. The tared flat bottomed flask was placed with 200 ml of petroleum on a heating mantle and connected to the sohxlet extractor. The extraction continued for about 8 hours. The solvent was evaporated in a rotary evaporator and the residue dried in an air-oven at 105 ^{0}C for 1 hour and the oil content calculated (AOAC, 2006)

5.3.4. Statistical Analysis

All measurements were conducted using two replications with results recorded as mean value ± standard deviation. The data was subjected to analysis of variance (ANOVA) using Genstat15th Edition statistical software package. Significance difference at 5% level of significance ($p<0.05$) was applied between the different drying methods and pre-treatments.

5.4. RESULTS AND DISCUSSIONS

5.4.1. Phytochemical, nutritional and microbial quality changes of dried chillies

5.4.1.1. Quality Characteristics of Two Chilli Varieties (Nemo and Fanaka) Dried under Oven Drier at 60 ^{0}C at Different Pre-Treatments

There was a significance difference in Vitamin A (beta carotene) of chillies, dried under oven drier dried at 60 °C. Table 8 below show more Vitamin A (beta carotene) retention for oven dried chillies with the range being 28.4 to 23.2mg/100 g This was in agreement with reports done by (Kamal et al.,2019; Anoraga et al., 2018).

The ascorbic acid quantity was also significantly different as shown in table 8. The ranges were 52.44 to 24.32mg/100g. Pre-treatments had a significance effect on the quality of dried chillies.

Fat, ash and the acid-insoluble ash also showed the same trend of being significantly different with the different pre-treatments for oven drying as shown on the table below. The ranges of the values were 17.03 to 45.00 % for Fat, 3.660 to 4.625 % for Ash, 0.06 to 0.535 % for Acid Insoluble Ash and 2.14 to 3.35 % for Capsaicin. The significance difference was seen in fat content, ash content, acid insoluble ash and capsaicin content

Table 8: Quality Characteristics of Two Chilli Varieties Dried Under Oven Drier at 60⁰C at Different Pre-Treatments.

OVEN	Fat (%)	Ash (%)	Ash-In (%)	Vitamin A (beta carotene)	Vitamin C	Capsaicin (%)
100	17.03^{a} ±0.69	4.050^{a} ±0.06	0.535^{ac}±0.06	23.2^{a} ±0.51	36.73^{ab} ±0.71	3.05^{a} ±0.43
101	17.19^{a} ±0.69	4.230^{a} ±0.06	0.17^{a} ±0.03	23.2^{a} ±1.65	46.52^{bc} ±2.02	2.79^{a} ±0.00
102	17.70^{a} ±1.42	3.495^{ab} ±0.08	0.18^{a} ±0.01	26.3^{a} ±0.23	52.44^{a} ±0.83	3.34^{a} ±1.09
103	38.56^{ab} ±0.68	3.660^{ab} ±0.06	0.06^{ab} ±0.01	25.6^{a} ±1.19	45.70^{bc} ±3.50	2.98^{a} ±0.01
104	45.00^{ab} ±1.27	4.000^{a} ±0.03	0.085^{ab}±0.01	23.2^{a} ±1.29	43.16^{bc} ±2.87	3.35^{a} ±0.62
105	31.62^{a} ±1.76	4.625^{a} ±0.50	0.19^{a} ±0.01	28.4^{a} ±9.84	24.32^{a} ±2.35	2.14^{ab} ±0.38
P Value	<0.001	0.016	<0.001	0.743	<0.001	1.26
L.S.D	2.859	0.5176	0.07408	10.14	5.588	1.379
C.V %	4.2	5.3	14.9	16.6	5.5	19.2
S.E	1.17	0.21	0.03	4.14	2.28	0.56

Note: 100- Fanaka variety Pre-treatment A; 101- Fanaka variety Pre-treatment B; 102- Nemovariety Pre-treatment A; 103- Nemo variety Pre-treatment B; 104- Fanaka variety Blanched sample; 105- Nemo variety Blanched sample.
All values are means ± standard deviation

*Superscripts with different letter along the same column show significance difference at *($p<0.05$)*

5.4.1.2. Quality Characteristics of Two Chilli Varieties (Nemo and Fanaka) Dried under Solar Drier at 60 ⁰C at Different Pre-Treatments

There was a significance difference in beta carotene of chillies dried at solar drier dried at 60 °C. Table 9 below show more beta carotene retention for solar dried chillies compared to oven dried chillies the range for the oven dried chillies was from 28.4 to 23.2mg/100g as shown on table 8 above while for solar dried chillies was 33.3 to 24.5mg/100g as shown on table 9 below. This was in agreement with reports done by (Kamal et al., 2019; Anoraga et al., 2018).

The ascorbic acid quantity was also significantly different as shown in table 9 below. The ranges were 46.97 to 30.07mg/100g for solar dried chillies. Although the value for oven dried chillies was high, the average for the solar dried chillies was higher. Pre-treatments had a significance effect on the quality of dried chillies.

Fat, ash and the acid-insoluble ash also showed the same trend of being significantly different with the different pre-treatments for and solar drying as with oven drying as shown on table 9.

Table 9: Quality Characteristics of Two Chilli Varieties Dried Under Solar Drier At 60^{0}C At Different Pre-Treatments.

SOLAR	Fat	Ash	Ash-In	Vitamin A (beta carotene)	Vitamin C	Capsaicin (%)
100	23.95^{a} ±1.43	3.855^{a} ±0.19	0.275^{a} ±0.08	27.2^{a} ±2.24	33.40^{a} ±2.97	1.60^{a} ±0.04
101	21.21^{a} ±0.69	3.805^{a} ±0.25	0.195^{ab} ±0.02	27.8^{a} ±3.74	34.30^{a} ±1.43	1.80^{a} ±0.14
102	12.64^{ab} ±1.42	3.610^{a} ±0.26	0.125^{ab} ±0.05	28.4^{a} ±0.53	30.07^{a} ±0.70	1.73^{a} ±0.23
103	7.90^{bc} ±0.16	3.910^{a} ±0.14	0.295^{a}±0.02	24.5^{a} ±1.82	41.98^{ab} ±2.11	2.01^{ab} ±0.11
104	10.75^{ab} ±1.08	3.635^{a} ±0.28	0.290^{a}±0.01	33.3^{ab} ±8.69	30.30^{a} ±0.21	1.71^{a} ±0.31
105	17.43^{ab} ±1.39	4.225^{ab} ±0.32	0.495^{ac} ±0.02	28.3^{a} ±0.98	46.97^{ab} ±1.41	1.76^{a} ±0.05
P-Value	<0.001	0.275	0.001	0.497	<0.001	1.19
L.S.D	2.761	0.5992	0.1001	9.94	4.216	0.4239
C.V %	7.2	6.4	14.7	14.4	4.8	9.8
S.E	1.13	0.24	0.04	4.06	1.72	0.17

Note: 100- Fanaka variety Pre-treatment A; 101- Fanaka variety Pre-treatment B; 102- Nemovariety Pre-treatment A; 103- Nemo variety Pre-treatment B; 104- Fanaka variety Blanched sample; 105- Nemo variety Blanched sample.
All values are means ± standard deviation of two replicates
*Superscripts with different letter along the same column show significance difference at *($p<0.05$)*

5.4.1.3. Effect on colour characteristics on Oven Dried Chillies at 60 ^{0}C

Quality chillies are characterized mainly through their colour and pungency. These two qualities reflect the chilies' consumer acceptability, natural compounds present and ultimately the market value. From table 10 below, the values of L*, a*, b* and the hue for oven dried chillies showed a significance difference *($p<0.05$)*. The effect of the pre-treatmenton colour can also be seen from the tables below. In terms of colour preservation of the dried chillies, pretreatment that involved 2% acetic blanching and soaking in solution of 0.3 % sodium meta bisulphate and 1 % calcium chloride for 10 minutes was found to have the best results. The results showed in this analysis were in agreement this analysis done by (Kamal et al., 2019; Anoraga et al., 2018).

Table 10: Colour Parameters of Chillies Dried Under Oven Dried at 60 ^{0}C for Different Pre-Treatments

Oven	L*	a*	b*	Arc tan
100	41.52^{a}±0.01	28.225^{a} ±0.01	22.105^{a} ±0.01	0.785^{a} ±0.01
101	45.275^{a}±0.01	29.4^{a} ±0.01	44.67^{a} ±0.01	1.525^{ab}±0.01
102	47.78^{a} ±0.01	27.03^{a} ±0.01	35.515^{a} ±0.01	1.315^{ab} ±0.01
103	69.08^{bc} ±0.01	23.285^{a} ±0.11	43.73^{a} ±0.00	1.878^{ab} ±0.02
104	44.10^{a} ±0.01	27.215^{a} ±0.01	37.285^{a} ±0.01	1.375^{ab} ±0.01
105	50.31^{ab} ±0.01	23.14^{a} ±0	22.95^{a} ±0.01	0.992^{a} ±0.02
P-Value	<0.001	<0.001	<0.001	<0.001
L.S.D	0.02997	0.1083	0.02347	0.03313
C.V%	0.0	0.2	0.0	0.3
S.E	0.01	0.04	0.01	0.01

Note: 100- Fanaka variety Pre-treatment A; 101- Fanaka variety Pre-treatment B; 102- Nemo variety Pre-treatment A; 103- Nemo variety Pre-treatment B; 104- Fanaka variety Blanched sample; 105- Nemo variety Blanched sample.
All values are means ± standard deviation of two replicates
*Superscripts with different letter along the same column show significance difference at *($p<0.05$)*

5.4.1.4. Effect on Colour Characteristics for Solar Dried Chillies at 60 ^{0}C

From the table of the values of L*, a*, b* and the hue for solar dried chillies showed a significance difference *($p<0.05$)*. Overall, the values for solar dried chillies shown below in table 11 were higher than those of oven dried chillies in table 10 above. The effect ofthe pre-treatment on colour can also be seen from the tables below.

Table 11: Colour Parameters of Chillies Dried under Oven Dried at 60 ^{0}C for Different Pre-Treatments

Solar	**L***	**a***	**b***	**Arc tan**
100	49.24^{a} ±0.01	33.765^{a} ±0.02	45.70^{a} ±0.01	1.355^{a} ±0.01
101	35.885^{ab}±0.01	32.745^{a} ±0.01	36.16^{ab} ±0.01	1.15^{ac} ±0.07
102	46.765^{a} ±0.01	31.83^{a} ±0.04	48.195^{a} ±0.02	1.53^{ab} ±0.01
103	50.06^{a} ±0.01	30.945^{a} ±0.01	41.675^{a} ±0.01	1.345^{a} ±0.01
104	49.355^{a} ±0.02	30.985^{a} ±0.01	45.835^{a} ±0.01	1.485^{ab} ±0.01
105	38.945^{ab}±0.01	31.63^{a} ±0.01	41.15^{a} ±0.07	1.31^{a} ±0.01
P-Value	<0.001	<0.001	<0.001	<0.001
L.S.D	0.03159	0.05094	0.07705	0.07442
C.V%	0.0	0.1	0.1	2.2
S.E	0.01	0.02	0.03	0.03

Note: 100- Fanaka variety Pre-treatment A; 101- Fanaka variety Pre-treatment B; 102- Nemovariety Pre-treatment A; 103- Nemo variety Pre-treatment B; 104-

Fanaka variety Blanched sample; 105- Nemo variety Blanched sample.
All values are means ± standard deviation of two replicates
*Superscripts with different letter along the same column show significance difference at *($p<0.05$)*

Pre-treated chillies showed a lower rate of moisture removal. This could have been attributed to soaking and blanching that increases the moisture content of the chilies. Previous researches have shown that pre-treatments that involved blanching chillies in acetic acid solution prevents enzymatic reactions (browning reactions) that results in discolouration of food products. These reactions result from the oxidase reaction of polyphenol; groups (Hossain and Bala, 2007; Wiriya et al., 2009). In addition to acetic blanching, soaking chillies in chemical solutions ($Na_2S_2O_5$ and $CaCl_2$) preserved the colour of chillies. $Na_2S_2O_5$ plays the roles of inhibiting browning reactions by binding with carbonyl groups of reducing sugars and other compounds. $CaCl_2$ on the other hands improved stability of colour by reacting with water molecules, thus increased water mobility and reduced drying time (Kamal et al., 2019). In terms of variety, the colour was not affected as the varieties had fairly a uniform arc tan value with an average value of 1.35 arc tan. For the two varieties of the chillies used, the Nemo variety performed better in all the quality characteristics analyzed.

5.4.1.5. Microbiological Composition of Solar and Oven Dried chillies at 60 ^{0}C

The microbial analysis conducted for chillies included; total plate count, coliforms, *Salmonella*, *Staphylococcus*, yeast and molds and the results from the analysis showed some variation. This variation could be due to a number of reasons: the area of collection, the type of treatment or the type of microbial present for example *E.coli, Staphylococcus or Salmonella.*

The final dried chilli is not microbiologically safe and clean as perceived by consumers; during the drying process, the water activity of dried foods is reduced to levels where microorganisms cannot survive. Initial microbial load and processing conditions also determine the safely and the wholesomeness of the final dried product. Inappropriate packaging, transportation and storage can cause recontamination of the safely dried chilli products and thus cause major health risks. Coliforms, salmonella and yeast and mold did not show any growth when the analysis was carried out

Table 12: Microbiological Composition of Dried Chillies at 60 ^{0}C

Solar Drying 60 ^{0}C			Oven Drying 60 ^{0}C	
Pre-treatments	**TVC (CFU/G)**	***Staphylococcus* (CFU/G)**	**TVC (CFU/G)**	***Staphylococcus* (CFU/G)**
Pre-treatment A (Fanaka Variety)	4.031 log	Absent	3.991 log	Absent
Pre-treatment B (Fanaka Variety)	2.332 log	Absent	2.114 log	3.021 log
Blanch samples (Fanaka Variety)	4.030 log	1 log	3.041 log	2.477log
Pre-treatment A (Nemo Variety)	2.836 log	3.18 log	2.740 log	Absent
Pre-treatment B (Nemo Variety)	2.279 log	3 log	2.130 log	2.740log
Blanch samples (Nemo Variety)	4.672 log	2.97 log	4.301 log	2.602 log

Note: TVC- Total Viable Count, CFU/G- Colony Forming Units per Gram

5.4. CONCLUSION AND RECOMMENDATION

There was a significance difference of drying the chillies under the different drying methodsthat is oven drying and tunnel solar drying. The difference was also attributed to using the different pre-treatment methods.

Solar drying at 60 °C did not affect the nutritional composition of the finally dried chillies. The use of pre-treatments also helped in the preservation of important nutritional components especially vitamin C that is easily lost in the drying of many food products and thus this drying temperature was recommended for drying chillies in combination with the pretreatment methods. It is also important to maintain hygieneic conditions throughout the supply chain to ensure the final dried chillies are safe microbiologically. This can be done from the farm level, during transportation, at processing and handling. Use of clean water is also recommended during the processing and ensuring drying is done under hygienic conditions

CHAPTER 6: SHELF-LIFE ANALYSIS AND SENSORYEVALUATION OF SOLAR DRIED CHILLI VARIETIES

6.1.ABSTRACT

Fresh food products have a very short shelf life; for instance, the shelf life of fresh chillies is about 2-3 days. Thus, the processing is important to ensure the chillies are available all through and reduce the losses associated with spoilage. However, after processing, chillies are not consumed immediately. Thus, it is necessary to determine how long the processed food product can stay before it is considered unfit for human consumption. Therefore, this study was designed to evaluate the shelf life stability of solar-dried chilli by monitoring changes in physical, chemical, and microbial characteristics of chillies stored under three different packages and sensory characteristics of solar-dried chillies.

For the dried chillies, the nutritional qualities tested included Vitamin A (beta carotene), Vitamin C, colour, and microbial quality, which were analyzed in the shelf life study. The accelerated method of shelf life study involved storing the chillies at a temperature of 56 °C and analysis done every second day up to the twelfth day. The three different packages, i.e., plastic, aluminium, and glass, were used. The consumer/preference sensory analysis method was used to evaluate the sensory attributes of the chillies with the seven scale hedonic scale with 22 panelists conducting the analysis. Attributes analyzed included colour, taste, texture, astringency, bitterness, flavour, and overall acceptability. A meat curry stew was used in tasting the chillies with plain white rice as a carrier. Consumer preference questionnaires were given to the participants to fill in as they conducted the analysis. Pre-treated solar-dried and oven-dried samples of chillies were used, with oven-dried blanched chillies used as the control.

The aluminium package was recommended from these three packages as it had a minimal effect on the nutritional composition of the dried chillies. It was, however, important also to consider aseptic conditions during the packaging process to ensure the microbial load is as low as possible. The aluminium package was the one that retained the most of the nutritional composition in terms of vitamin A (beta carotene) and Vitamin C at 13.66mg/100g and 8.9g/100g, respectively. The colour was fairly constant in all three packages, with an average of 1.3 arc tan. The plastic and glass package absorbed the package's odor and thus had a faint plastic odour as the storage days preceded. The microbial content was fairly high in all the packages. This could have been due to pre-processing handling of the chillies before and during the drying process and the drying conditions that introduced the microorganism.

New and improved products are constantly being produced. Solar-dried chillies are an improvement of the traditionally open sun-dried chillies that are of better quality both nutritionally and microbiologically. This change in the drying method would affect the sensory and palatability characteristics of chillies. Upon conducting a sensory analysis, there was no significant difference in the overall sensory attributes of the chill products other than the flavour that had a significant difference between the solar-dried and oven-dried samples.

This study aimed to assess the sensory characteristics of solar-dried chillies to determine consumer acceptability and palatability. There was no significant difference between solar and oven-dried chillies other than in the flavor; thus, solar, dried chillies were recommended. On storability, the aluminium package was found to be the best in terms of nutrient retention and also on the physical attributes of colour and odour,

Keywords: Accelerated Shelf Life Test, Sensory Attributes, Packages

6.2.INTRODUCTION

About 20-50 % of vegetables, chillies being one of the vegetables, are lost due to poor Post-Harvest handling in developing countries, with 5-25 % for developed countries. Drying chillies are among the ways in which chilli storage is increased (Alsebaeai et al., 2017). After drying, it's important to store the final dried product safely during the usage of the product. This period should consider the product's nutritional, physical, and sensory attributes during storage. The duration a product can remain stable, safe for consumption, or useful under the recommended storage conditions is known as shelf life (Valero et al., 2012). The period a food can be stored depends on many factors: the manufacturing process, type of packaging, type of ingredient, and how the food product is stored (Rodiles-López et al., 2020). Shelf life is an important feature for manufacturers and consumers, understood and interpreted differently by different parties. Of importance in shelf life analysis is the safety of the products then the chemical, physical and sensory properties to ensure high-quality products all through the storage period (Phimolsiripol & Suppakul, 2016). Still, it essentially means the period when a food product can be kept safe and fit for use from preparation, manufacturing, or packaging stored under defined conditions (Singh and Anderson, 2004). Alsebaeai et al., 2017 define shelf life as the period between a product's production and the time it loses its state of safety and satisfactory quality regarding nutritional value, appearance, flavour, texture, and microbial status.

The food product should maintain desirable physical, chemical, microbiological, and sensory characteristics during this shelf life period and meet any nutritional claims on the product label. The product's shelf life is mainly shown on the product label as a date mark of "use by date," "best if used by date," "better if used by date," or "best before ." Use by is indicated on highly perishable foods with safety risks if consumed after the date shown passes. These dated help consumers make informed decisions on the storage of bought products (Singh and Anderson, 2004). The packaging material used for a product is important in maintaining the food's quality and shelf life. Packaging is important in the preservation system, acting as an interface between the food and its external environment. The food package should not only contain the food but also protect and add value to the final consumer's purchasing decision (Alsebaeai et al., 2017).

The nature of the package determines its air composition inside the package, which ultimately affects its rate and extent of nutrient loss and microbial activity (Alsebaeai et al., 2017).

On the other hand, the best before is used for non-perishable foods, and it is legal and okay to sell/consume the food product after the best before the day passes. These conditions must be easily achieved in distribution, retailers, and at-home storage systems. Proper storage instructions should be available on labels where applicable to ensure the product will keep up to the specified period of the date marking. Instructions also need to be indicated for storage after opening the storage container. The packaging materials used for food should control the entry (ingress) or exit (egress) of moisture vapour from the product (Singh and Anderson, 2004). The accelerated shelf-life test (ASLT) is used to rapidly estimate a product's shelf life (Singh and Anderson, 2004). Shelf life can be assessed in two ways: real/actual time and acceleration. Under real/actual time storage conditions, quality deterioration/depletion occurs fairly slowly and, thus, application of accelerated shelf life testing. ASLT helps reduce the time needed to estimate the food product's shelf life by applying accelerating factors such as temperature (Calligaris et al., 2019). An accelerated shelf life study needs to include physico-chemical, microbiological, and sensory evaluation (Rodiles-López et al., 2020). The objective of accelerated shelf life is to get a rapid estimation of the expected shelf-life of the product (Taoukis & Giannakourou, 2004).

Chillies are among the most important vegetable and spices in the world. Capsaicinoids, present in chillies, are the components responsible for the heat (burning) sensation (Guzmán & Bosland, 2017). The sensory characteristics of a food product are one of the most important factors in determining consumer perception of that particular food product (Cherdchu et al., 2008). Different types of chillies have different heat sensations of heat in the mouth. Other than the burning sensation, other taste sensations involved with chilli are sweet, salty, sour, bitter, and umami (Guzmán & Bosland, 2017). Depending on cultural or personal preferences, the heat or burning profile of a chill may be considered an inferior or superior product (Guzmán & Bosland, 2017).

6.3.MATERIALS AND METHODS

6.3.1. Sample preparation

Three packaging methods, aluminium packages, plastic containers and glass jars were used in conducting the shelf life analysis. Solar dried red chillies dried at 60 °C were obtained from Voi were used for the study. Physical, chemical and microbiological analyses were then conducted for all the samples. All experiments were conducted in duplicate.

6.3.2. Packaging and Storage Conditions for shelf life analysis

The accelerated shelf life method was used where the chillies were stored in the oven maintained at 56 °C with analysis done after every two days up to the twelfth day. From the first day up to the twelfth day, parameters analysed included vitamin A (beta carotene), vitamin C, colour, and odour and for microbial analysis; total plate count, yeast and mould. Dried chillies (15 grms) were packed into aluminium packages, glass jars and plastic containers.

6.3.3. Chemical Analysis

6.3.3.1.Vitamin A (Carotenoids) Analysis

The color from 2 grams of dried chilli was extracted using a mortar and pestle with small portions of acetone until the residual is colorless. All the extract was combined into a 100ml volumetric flask. 25ml of the extract was put into a 50ml round bottomed flask and evaporated to dryness in a rotary evaporator at about 60 ^{0}Cinto the evaporated sample, 1ml of petroleum spirit was added to dissolve beta carotene which was eluted through a packed column and received into a 25ml volumetric flask and the absorbance read at 450nm and that content of beta carotene calculated.

$$\text{Beta Carotene} = \frac{0.4}{0.12}\ x\ \frac{50}{25}\ x\ 25\ x Absorbance\ x\ \frac{100}{Sample\ Weight} \quad (11)$$

6.3.3.2.Vitamin C Analysis

The method of determination of vitamin C used was the standard given by AOAC 1975.

5 grams of the dried chilli was mixed with 15ml of TCA(Trichloroacetic acid). This was filtered to obtain the extract/filtrate .5ml of this extract was mixed with 5ml of 4% (KI) Potassium iodide and some drops of starch solution. This was titrated with N-bromsuccinimide solution

$$Vitamin\ C = \mathrm{V.C} * \frac{176}{178}\ (mg) \qquad (12)$$

V= Volume of N-brosuccinimide (ml)

C= Concentration of N-brosuccinimide (mg/ml)

6.3.4. Microbiological analyses

For microbiological analysis, the Total plate count, Yeast and Mold were analyzed. The tests were done using Plate Count Agar for total plate count and Potato Dextrose Agar for yeast and mold, Petri-dish, Incubator, Peptone water and samples tested by Pour Plate Technique. Standard ISO 4831:2006 Methods were used for the analysis.

6.3.5. Physical Analysis

6.3.5.1.Colour Analysis

The surface colour of the dried chillies was done using the colour meter based on the C.I.E. L*a*b* colour space. Values of L* represent brightness, a* correspond to the red-green colour gradient while b* denotes to the yellow-blue colour gradient. Three measurements were conducted in each sample and the hue calculated as shown on the formula (Wiriya et al., 2009) below:

$$\boldsymbol{h} = \mathbf{tan}\frac{b*}{a*} \qquad (13)$$

6.3.5.2. Odour Analysis

The odour of the stored chilli samples was detected by simultaneously sniffing immediately after removing from the storage conditions (Brassica, 2017).

6.3.6. Sensory Evaluation Analysis

In conducting the sensory analysis, consumer testing affective/ preference test was used with the scores noted over the standard seven point hedonic scale where 7 represented “like very much” and 1 represented “dislike very much”. A panel of 22 participants was used. Parameters to be evaluated were colour, taste, texture, astringency, bitterness, flavour and overall acceptability. A meat curry stew was used in tasting the chillies with white plain riceas a carrier. Consumer preference questionnaires were given to the participants to fill in as they conducted the analysis. Pre-treated solar dried and oven dried samples of chillies were used with oven dried blanched chillies used as the control.

To check for differences of the dried chillies, a triangle test was conducted by using three chilli samples where two were similar and one was different but all coded and asked participants to check for any noticeable changes (Everitt, 2009)

6.3.7. Statistical Analysis

All measurements were conducted using two replications. The results were recorded as mean value ± standard deviation. The data was subjected to analysis of variance (ANOVA) using Genstat 15th Edition statistical software package. Significance difference at 5% level of significance ($p<0.05$) was applied between the different types of packages.

Data from sensory analysis was also analysed using the GenStat 15th Edition Statistical software where the analysis of variance (ANOVA) was done to check for any variation between the chilli samples from the responses received. Table 15 below represents the results obtained from the analysis.

6.4.RESULTS

The major concerns during the shelf life analysis were the microbial quality, nutritional quality and the physical quality. The variable analysed were the total plate count and yeast and mould. Table 13 below shows the data upon analyse of the microbial quality for the three packaging options and the entire shelf life study. One day of the accelerated study represented three months in real time.

6.4.1. Microbial Quality during Shelf Life Analysis

From table 13 below, it can be seen that the microbial load for all the packages; Glass package, Plastic package and Aluminium packages were within the minimum values from the three; however, the glass package maintained the least microbial growth throughout the shelf life analysis period. For the plastic and aluminium package, microbial grown was higher. Reasons for the difference in microbial load could be the packages were contaminated before package the dried chillies or contamination took place during the packaging process. Also, if the dried chillies were not handled properly during cleaning and drying, this could have been the source of the contamination and thus higher microbial load.

Table13: Microbial Quality of Chillies Stored under Three Different Packages.

Shelf life microbial analysis						
	Glass Package		Plastic Package		Aluminium Package	
Months	**TVC (CFU/G)**	**Mold (CFU/G)**	**TVC (CFU/G)**	**Mold (CFU/G)**	**TVC (CFU/G)**	**Mold (CFU/G)**
0	2.477	-	2.477	-	2.477	-
2	2.699	-	3.061	-	2.875	-
4	2.740	-	1.699	-	3.000	2.000
6	2.301	2.699	3.525	3.176	2.845	-
8	2.929	2.699	3.415	2.301	3.516	3.000
10	2.778	2.699	1.699	1.699	3.398	5.279
12	2.699	-	2.301	-	2.301	2.699

Note: TVC- Total Viable Count, CFU/G- Colony Forming Units per Gram

6.4.2. Vitamin C during Shelf Life Analysis

Vitamin C also showed the same results as the content of vitamin C deteriorated/ decreased with the storage time. The initial content of vitamin C was 30.67mg/100g at the start of the shelf life study. The deterioration for the three packaging types was fairly the same, but the plastic package had the lowest content of vitamin C at the end of the shelf life study. The loss of vitamin C was due to oxidation by residual air trapped inside the packages. On evaluation the effects of the packaging material on the dried chilli samples, finding were agreed as with (Alsebaeai et al., 2017) who reported that samples stored in aluminium foil retained more vitamin C compared with other packages as was the finding in this report shown in figure 11.

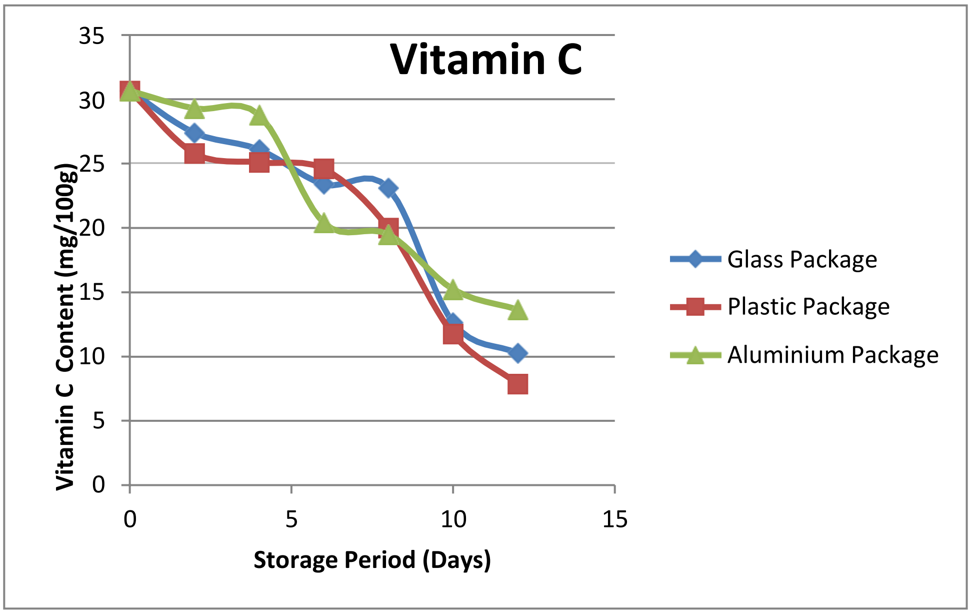

Figure 11: Vitamin C Content in g/100g against Days of Shelf Life Analysis

6.4.3. Vitamin A during Shelf Life Analysis

The content of vitamin A at the initial of drying was lower that the permitted specification (this is because of the effect of drying). The content of Vitamin A deteriorated for all the types of packaging with time during the shelf life period. From the three packages, vitamin A content deteriorated more in the glass package. However, at the end of the shelf life analysis, the content of Vitamin A was fairly the same. Aluminium Package retained the most of vitamin A from the three packages used.

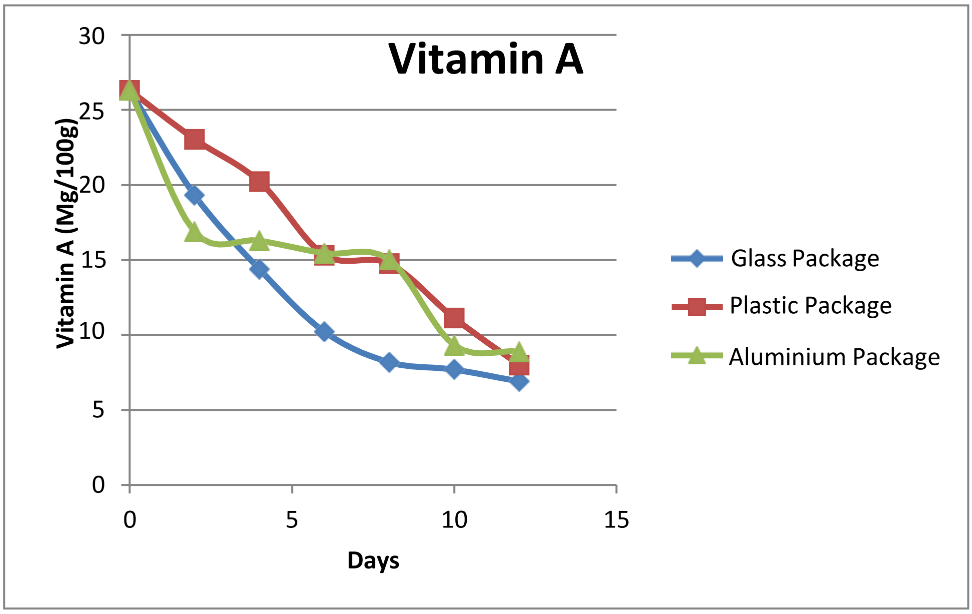

Figure 12: Vitamin A Content in mg/100g against Days of Shelf Life Analysis

6.4.4. Colour and Adour during Shelf Life Analysis

The colour and aroma (odour) of the chillies were also analysed during the storage time. There was no significant change in the colour of the chillies during the analysis time. For the aroma, as the storage days passed, chillies stored in the plastic and glass package absorbed the smell of the package with the intensity of the smell absorbed increasing with time.

Table 14: Colour Change of Dried Chillies for the Shelf Life Analysis

Package	**Glass**							**Plastic**							**Aluminium**						
Day	0	2	4	6	8	10	12	0	2	4	6	8	10	12	0	2	4	6	8	10	12
Colour	Normal							Normal							Normal						
Odour	Normal			Mild plastic odour				Normal			Slightly plastic odour				Normal						

6.4.5. Sensory Evaluation Analysis

Table 15: Sensory Evaluation of Dried Chillies

Treatments	**Taste**	**Colour**	**Astringency**	**Bitterness**	**Flavour**	**Texture**	**Overall acceptability**
AAB-100	4.82[a]	5.23 [a]	4.55 [a]	4.64 [a]	4.68 [a]	5.32 [a]	5.59 [a]
BAA-101	4.95 [a]	5.59 [a]	4.82 [a]	4.73 [a]	5.05 [ab]	5.32 [a]	5.27 [a]
BAB-102	4.95 [a]	5.77 [a]	4.32 [a]	4.59 [a]	4.82 [a]	5.41 [a]	5.32 [a]

P-value	0.906	0.170	0.447	0.929	0.679	0.955	0.570
L.C.D	0.713	0.583	0.789	0.730	0.839	0.698	0.651

Note: AAB = Solar Dried Chilli Sample; BBA = Oven Dried Sample; BAB = Oven Dried (Blanched).
*Means with the same superscript letter in the same column are not significantly different P (<0.05) for taste, colour, astringency, bitterness, flavour, texture and overall acceptability. Scores were not significantly different P (>0.05), had different L.S.Ds therefore, treatments were not different and any can be recommended.

The panelist who conducted the sensory analysis, the reason they gave for liking the Oven dried chilli were the deep colour, flavour and taste balance, was less astringent and blended well with the food (Rice). Reasons for not liking the other chilli sample were it was more astringent and bitter. Factors that the panellist gave for consideration during buying of chillies were the taste, flavour and the colour.

A triangle test was also conducted to check if there was a difference between the treatments (oven dried and solar dried samples) and the patricians were easily able to differentiate the samples when presented with two similar samples and odd sample. The participants were able to determine the odd sample on basis of colour, appearance and the flavour

6.5.DISCUSSION

Reasons for the difference in microbial load were attributed to the packages being contaminated beforepackage the dried chillies or that the contamination took place during the packaging process. Also, improperly handling of the chillies during cleaning and drying, could be the source of the contamination and thus higher microbial load.

The lossof vitamin C during the shelf life analysis was due to oxidation by residual air trapped inside the packages. On evaluation the effects of the packaging material on the dried chilli samples, finding were agreed as with (Alsebaeai et al., 2017) who reported that samples stored in aluminium foil retained more vitamin C compared with other packages and thus aluminium was recommended as the best packaging. The content of Vitamin A deteriorated for all the types of packaging with time during the shelf life period. From the three packages, vitamin A content deteriorated more in the glass package. This could have been brought about by the fact that all the three packages were transparent thus the decrease with storage time. However, at the end of the shelf life analysis, the content of Vitamin A was fairly the same. Aluminium Package retained the most of vitamin A from the three packages used. For the aroma, as the storage days passed, chillies stored in the plastic and glass package absorbed the smell of the package with the intensity of the smell absorbed increasing with time. The panelist who conducted the sensory analysis, the reason they gave for liking the Oven dried chilli were the deep colour, flavour and taste balance, was less astringent and blended well with the food (Rice). Reasons for not liking the other chilli sample were it was more astringent and bitter. Factors that the panellist gave for consideration during buying of chillies were the taste, flavour and the colour.

A triangle test was also conducted to check if there was a difference between the treatments (oven dried and solar dried samples) and the patricians were easily able to differentiate the samples when presented with two similar samples and odd sample. The participants were able to determine the odd sample on basis of colour, appearance and the flavour

6.6. CONCLUSION AND RECOMMENDATIONS

Accelerated shelf life analysis is a standard method that is used by industries in new product development for their new or improved products. The aluminium package retained the most nutrients, that is; vitamin C, Vitamin A (beta carotene) and was highest in the three packages. The aluminium package however had higher microbial load. The high microbial load was attributed of contamination of the aliminium package before the dried chillies were packed and tush recommended to ensure the packages were first cleaned and to perform aseptic packaging. The chillies should also be well clean using enough clean water and dried under hygienic conditions

It is essential to conduct shelf life analysis for all new products and any other that have been modified or improved. This is important as consumer acceptability of a new or improved product will determine how the product will perform ones in the market.

The drying method either solar drying or oven drying had no significant effect on the sensory attributes of dried chillies. The attributes analyses included taste, colour, astringency, bitterness, flavor, texture and overall acceptability. Flavour however was significantly different for the differently dried chillies, i.e. solar dried and oven dried. Therefore, the solar dried chillies are acceptableand recommended.

CHAPTER 7: GENERAL CONCLUSION AND RECOMMENDATIONS

7.1. CONCLUSION

Drying chillies improved the shelf life compared to that of the fresh products. Temperature being an important parameter to consider, the temperature of 60 °C was recommended to use in drying chillies. This temperature was found to be the best in terms of nutrients preservation after drying the chillies in combination with the pretreatment of acetic blanching and soaking in solution of 0.3 % sodium meta bisulphate and 1 % calcium chloride for 10 minutes. It is also important however to consider the hygiene and cleanliness of the drying process as this will ensure the final dried product microbial load is low.

There was a significance difference of drying the chillies under the different drying methods that is oven drying and tunnel solar drying. The difference was also attributed to using the different pre-treatment methods before the drying of the chillies. For this reason solar drying of fresh chillies can be utilized and implemented as a method of drying chillies.

Both the adsorption and desorption isotherms for fresh and dried chillies respectively showed sigmoid curves, the type two sigmoid isotherm curve. The equilibrium moisture content (E.M.C.) of both the fresh and dried chillies increased with increase in water activity and showed an increase as the temperature increased at the different levels of water activity. The G.A.B. model used to fit thesorption isotherm showed a good fit for the sorption data.

The aluminium package was the best to use in chilli packaging has it had better nutrient retention compared to glass and plastic packages. The nutrients of interest analyzed were vitamin C, vitamin A(beta carotene) and colour. However, the aluminium packages should be properly cleaned before aseptically packing the chillies. This is to avoid recontamination of the already dried chillies bythe packaging used. There being no significant difference between on the sensory evaluation of the solar and oven dried chillies, the solar dried chillies were recommended as a suitable replacement of the oven dried chillies.

7.2. RECOMMENDATIONS

Chilli drying at 60 ^{0}C is recommended as it had minimal effect on the quality characteristics of chillie in terms of nutrition, physical and sensory characteristics. To minimize the effects of the temperature of heating, it is important to use the action of pretreatment while drying the fresh chillies. During drying process, proper hygienic processes should be ensured and maintained to minimize the microbial load of the final dried chilli products and ensure safety of the products. For packaging, the package used should ensure safety of the stored chilli products. The aluminum package was recommended as it ensured safety of the chilli products with minimal effects on the quality characteristic of the chillies. To reduce microbial load in the final dried chille products it's important to ensure proper hygienic conditions throughout the supply chain from the farmer's level up to the final consumer's level.

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APPENDICES

SENSORY EVALUTION TEST - TRIANGLE TEST IN ASSESSING ATTRIBUTE DIFFERENCES AMONG DRIED CHILL PRODUCTS
PRODUCT ACCEPTABILITY SURVEY QUESTIONS

Sex of respondent [F] [M] Age ………………….

Name of group ……………………………………………………………………………….

Level of Education…………………………………………………………………………

Respondent number……………………………….

You are provided with three differently dried chilli samples. Of these samples, two of them are identical and one is odd. Identify the odd sample and indicate the degree of difference between the samples. Starting with any order, first rate the appearance of the dried product on colour, appearance and flavour. Rank each sample as either 1 or 2 where:

1. 1 is for same
2. 2 is for odd

Sample	Colour	Appearance	Flavour	Overall acceptability
ABA				
BBA				
ABB				

Then try each sample with meat and rice accompaniment provided and score accordingly using a spoon provided. Take a scoop of the prepared food sample that contains the dried chilli product, hold it in your mouth for 10 seconds and rate it on: taste, colour, astringency, bitterness, flavour, texture and overall acceptability. Proceed through the other samples in similar manner, rinsing your mouth using the water provided in between each sample.

Sample	Taste	Colour	Astringency	Bitterness	Flavour	Texture	Overall acceptability

AAB							
BAA							
BAB							

Score scale

1. Dislike very much
2. Dislike moderately
3. Dislike slightly
4. Neither like or dislike
5. Like slightly
6. Like moderately
7. Like very much

Comments____

____

Preference questions

I. What did you like about the chilli sample you picked as your most favourite?

____

II. What did you not like about the one you picked as our least favourite?

____

III. What is your most important factor when buying chilli products?

a) Nutrition
b) Colour
c) Taste
d) Flavour
e) Other, specify

____

THANK YOU FOR PARTICIPATING