# EFFECT OF PRETREATMENTS AND SOLAR TUNNEL DRYER ZONES ON DRYING CHARACTERISTICS AND QUALITY OF PUMPKIN (*Cucurbita maxima*) PULP SLICE AND POWDER

**M.Sc. THESIS** 

BY

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JANUARY 2020

JIMMA, ETHIOPIA

# EFFECT OF PRETREATMENTS AND SOLAR TUNNEL DRYER ZONES ON DRYING CHARACTERISTICS AND QUALITY OF PUMPKIN (*Cucurbita maxima*) PULP POWDER

By

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A Thesis Submitted to the School of Graduate Studies, Jimma University, College of Agriculture and Veterinary Medicine, in Partial Fulfillment of the Requirements for the Degree of Master of Science (M.Sc) in Food Science and Technology

> January 2020 Jimma, Ethiopia

### **DEDICATION**

All my family members, especially to my beloved father, you are my greatest role models in my life though you are not here to witness my achievement, but you will always be in my heart. And my beloved sister, for being by my side to give your encouragement and support with endless patience.

### STATEMENT OF THE AUTHOR

By my signature below, I declare and confirm that this Thesis is my own work. I have followed all ethical and technical principles of scholarship in the preparation, data collection, data analysis and completion of this Thesis. Any scholarly matter that is included in the thesis has been given recognition through citation.

This Thesis is submitted in partial fulfillment of the requirements for M.Sc. degree in Food Science and Technology at Jimma University. The Thesis will be deposited in the Jimma University College of Agriculture and Veterinary Medicine library and will available to borrowers under the rules and regulations of the library. I declare that this Thesis has not been submitted previously to any other institution for the award of any academic degree, diploma, or certificate.

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#### **BIOGRAPHIC SKETCH**

The author, Hayat Hassen Mohammed, was born on May 23, 1991 G.C from her father Hassen Mohammed and mother Bire Beshir, in Kelala wereda, Borena zone, South Wollo. She completed her elementary education at Salayish primary school, secondary education at Kokebe Stibah secondary school and preparatory school at Dej.Wondirad preparatory school, Addis Ababa. Then she joined Jimma University in 2013/2014 and completed with a B.Sc. degree of Food Science and Postharvest Technology in June 2016/2017 with great distinction. After graduation, she was employed by Jimma University as senior technical assistant starting from September 2017.Meanwhile she was also given the chance to start postgraduate study in Food Science and Technology in the same year.

### ACKNOWLEDGMENT

This work was made possible with the help of the almighty Allah. No doubt I will not forget my supporters in this work.

Words are not enough to describe my great honor and thanks towards my advisors, Dr. Yetnayet Bekele and Dr Addisalem Hailu for their encouragement, supervision, patient guidance, and constructive criticism by spent long tireless hours on this work.

My great gratitude is to Mrs. Lelise Tilahun (my Instructor), for her help and encouragement. I want to extend my appreciation and thank to Mr. Ebisa Olika, Mr. Abebe Yimer, Miss Zeneba Kedir and Mrs. Abaya Hordofa for being by my side and give their support whenever I want.

I gratefully acknowledge, Jimma University College of Agriculture and Veterinary Medicine (JUCAVM) for allowing and sponsoring me to do my M.Sc. Thesis as early as I finished the undergraduate studies.

Finally, I would like to thank my families, friends and colleagues who supports me in different direction so that I can finish this work successfully.

# LIST OF ABBREVIATION AND ACRONYMS

ANOVA	Analysis of variance	
AOAC	Association of Official Analytical Chemists	
BD	Bulk Density	
CRBD	Completely Randomized Block Design	
DPPH	1,1-diphenyl-2picrylhydrazyl assay	
FAO	Food and agriculture organization	
KMS	Potassium Metabisulphite	
Р	Mean percent relative error	
PPO	Polyphenol Oxidase	
PPO	Polyphenol Oxidase	
R <sup>2</sup>	Coefficient of determination	
RMSE	Root mean square error	
RR	Rehydration ratio	
SO <sub>2</sub>	Sulphur dioxide	
SR	Shrinkage ratio	
ТА	Titrable acidity	
TPC	Total Phenolic Content	
TSS	Total Soluble Solid	
UN	United Nation	
UV	Ultraviolet	
$X^2$	Reduced chi-square	

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#### ABSTRACT

The objective of this study was to investigate the effects of pre-drying treatments and solar tunnel dryer zones on drying characteristics and quality parameters of pumpkin pulp powder. Pumpkin pulp slices (2 mm, thickness) were pretreated with 1% citric acid solution, 2% salt solution, blanched at  $65^{\circ}C$  water containing 1% salt solution for and untreated, then dried at three zones of solar tunnel dryer with average temperature ,45.64, 54.62 and 64.97°C for zone I, zone II and zone III respectively. As quality parameters, physical, functional, chemical and nutritional parameters of dried pumpkin were studied. Pumpkin slice dried at zone III achieved high drying rate and short time. In addition, salt blanched and citric acid treated also increase moisture removal. Effective moisture diffusivity at zone I, control  $(7.63*10^{-9} \text{ m}^2/\text{s})$  was found to be lower than that of zone III, citric acid treated  $(2.34*10^{-8} m^2/s)$ . Among the seven thin layer drying models tested, the diffusion approximation, was found best fitting whereas the logarithmic, two term exponential and Henderson and Babis were found to be suitable models to describe the drying behavior of pumpkin slice. The highest bulk density value was recorded at zone III for salt blanched sample and lowest is at zone II for control, 0.78±0.02 (g/ml) and 0.52±0.006(g/ml), respectively. Pumpkin which dried at zone III with salt blanched treatment exhibited high values of water hydration capacity, shrinkage ratio, rehydration ratio and low water activity. Chemical parameters such as; titrable acidity, pH and total soluble solid was found between ;2.7±0.01%-1.1±0.003%, 6.1±0.01-4.6±0.007, 11.3±0.04-7.6±0.3 respectively. Some proximate composition of the pumpkin powder values recorded as follow  $8.2\pm0.03$  to  $6.4\pm0.04\%$  moisture content,  $6.2\pm0.006$  to  $4.7\pm0.02\%$  total ash  $4.2\pm0.05$  to  $1.1\pm0.03\%$  fat and 4.2±0.05 to 2.4±0.02% protein. The highest total phenolic content, beta carotene, Ascorbic acid and antioxidant activity were recorded for sample dried at zone II and treated with 2% salt solution. Overall, Pumpkin dried at zone III combined and salt blanched, experienced high moisture removal, short drying time and high effective moisture diffusivity that lead to high shrinkage ratio, rehydration ratio, bulk density and water absorption capacity where only high shrinkage ratio is undesirable. Whereas, Pumpkin dried at zone II and salt treated exhibited better retention of bioactive components.

Key words: pumpkin, pretreatment, zone, salt blanched, citric acid, salt, drying,

#### **1. INTRODUCTION**

#### **1.1. Background and Justification**

Pumpkin (*Cucurbita maxima*) is a fruit vegetable native to South America but have been domesticated in several tropical and subtropical countries (Achu *et al.*, 2005). The crop is rich in nutrients, adapts well to local conditions and grows in a wide range of agro-ecological zones (Thompson *et al.*, 2013). It has a great economic potential for use both as a food and as a cash crop. It is utilized for its leaves, marrow, fruit pulp and seeds (FAO, 2005). It is profoundly rich in minerals, vitamins, pectin, dietary fibres and vital antioxidants like carotenoids, lutein, and other abundant polyphenolic compounds (Aziah and Komathi, 2009). Pumpkin is considered as a traditional crop with high potential to overcome undernourishment (Dutta *et al.*, 2006) especially with its high beta carotene content. Further, the crop has been used as medicine for various human diseases in many parts of the globe. It prevents certain types of cancer, cardiovascular disease and macular degeneration and is recommended for arthrosclerosis and reduction of cholesterol in people suffering from obesity (Danilchenko *et al.*, 2000).

As compared to other perishable crops the fruit is relatively quite stable after harvest for one to three months (Guine *et al.*, 2011). However, it is difficult to store for long period of time because of its big size as well as perishable nature with extended period of storage. Particularly after peeling it is susceptible to moisture loss, softening, color changes and microbial spoilage (Sojak *et al.*, 2014). Moreover, Pumpkins due to its large size (approx 2-35 kg/fruit), have less consumer acceptance as fresh vegetable (FAO, 2005; Mala *et al.*, 2018); difficult for transportation and marketing (Dirim and Caliska, 2012). Such problems made pumpkin underutilized vegetable and made it be as poor's food. To increase the consumption of pumpkin some attempts has been tried. This include, processing to obtain juice, puree, pickles, seeds, and drying that allow longer shelf life and convenience (Que *et al.*, 2008). Despite that, pumpkin having small size can be available for fresh market.

Dried pumpkin powder can increase pumpkin consumption by providing an alternative food source to fresh pumpkins (Roongruangsri and Bronlund, 2015). The use of pumpkin powder as a supplement to cereal flours in bakery products such as bread, cakes, and cookies, in soups, spices, sauces and instant noodles, and as a natural coloring agent in pasta and flour mixes has

been reported. Beside this pumpkin powder can be used to formulate infant weaning due to the fact that it has high beta carotene content (Que *et al.*, 2008). It is also used because of its highly desirable flavor, sweetness and deep yellow-orange color (Cumarasamy *et al.*, 2002).

Drying is one of the oldest and a very important unit operation, it involves the application of heat to a material which results in the transfer of moisture within the material to its surface and then water removal from the material to the atmosphere (Ekechukwu, 1999; Akpinar and Bicer, 2005). It constitutes an alternative to the consumption of fresh fruits and vegetables, and allows their use during the off-production season. Besides giving longer shelf life it brings about substantial reduction in weight, volume, minimizing packaging, storage and transportation cost, and enable storability of product under ambient temperature (Alibas, 2007; Guine *et al.*, 2011).

So far, several methods of drying such as sun drying, solar drying, convective hot air drying, freeze drying, microwave drying and vacuum drying have been studied on quality of pumpkin (Alibas, 2007; Tunde and Ogunlakin, 2013; Workneh *et al.*, 2014; Sojak *et al.*, 2014). To dates, solar drying is attracting many scholars in terms of production of relatively better quality dried products as compared to open sun drying; less expensive running cost as compared to convective, freez and other advanced drying methods. Solar dryers are environmentally sound (reduce the emission of carbon to the environment) and save other fuel or electrical energy to generate heat.

Among many solar drying methods, Solar tunnel dryer is commonly used method to dry fruits and vegetables (Waheed *et al.*, 2014). However, the temperature and relative humidity of drying medium in long solar tunnel driers are not uniform. Variation in these factors determine rate of drying as well as quality of the product at the end of drying. For instance, dried samples at the end of tunnel dryer exposed to high drying temperature and low relative humidity as compared to other zones of drying. If different samples are dried for the same duration in the different drying zones, there will be some over and under drying of samples both of which affects the quality of final products. Therefore, products at different drying zones have different drying rate to reach final drying phase. In order to produce better quality product, it is necessary to determine the drying kinetics of samples at different drying zones and evaluate quality of the products. However, during drying of food, the food may lose heat sensitive nutrients in addition to change in colour and the physical properties, depending on the drying condition such as temperature and drying time (Henriques *et al.*, 2012). Kha *et al.* (2011) reported that, pre-treatment prior to drying are one of the most important factors that has positive effect on the final product quality in terms of physicochemical properties produced whilst drying. Pre-treatments would help to inhibit impact of spoilage enzymes (polyphenol oxidases, peroxidase, catalase, and phenolase), degradation of vitamins and other health promoting bioactive compounds through reducing oxidative degradation (Prothon *et al.*, 2001). Use of pre-treatments such as blanching and dipping in appropriate concentration of chemicals (such as citric acid sodium meta bisulphite and salt), before drying results in minimum quality degradation (Sathiya *et al.*, 2016). Furthermore, pre-treatments can extend product shelf life and reduce drying time of products (Workneh *et al.*, 2014). Therefore, this work was initiated with the purpose to achieve the following objectives.

#### **1.2. Objectives**

#### 1.2.1 General objective

To investigate and characterize solar tunnel dryer zones and pre-drying treatments to produce better quality of pumpkin powder.

#### 1.2.2. Specific objective

- 1. To assess the effect of solar tunnel dryer zones on drying rate and quality of pumpkin powder
- 2.To investigate the effect of pre-treatments on drying kinetics and quality of pumpkin powder
- 3. To establish the combined effects of pre-treatments and solar tunnel dryer zones on drying kinetics and quality of pumpkin powder

### 2. REVIEW OF LITERATURE

#### 2.1. Pumpkin Production and Consumption

#### 2.1.1. Pumpkin production

The pumpkin is a gourd of the genus Cucurbita and the family Cucurbitaceae (Caili *et al.*, 2006; Jedidah, 2017), that grows around the world. Edible parts of the plant include the flowers, fruit, leaves, root and seeds. They typically have a thick orange or yellow shell, creased from the stem to bottom, containing the seeds and pulp. Its fruit range in size from less than 0.45 kg to over 500 kg and it varies greatly in shape ranging from oblate to oblong, they have a moderately hard rind with thick, edible flesh below and a central cavity containing numerous seeds. Although pumpkin fruits are usually orange or yellow, some fruits are dark green, pale green, orange-yellow, white and grey and can be stored without damage for a long time and that due to the thickness of it is wall (Dhiman *et al.*, 2009).

Food and drug association (FDA) reported that world agricultural production has increased annually by 2.2% over the last ten years. Pumpkin production was found to have increased to 25 million tons from 1992 to 2012. In fact, pumpkin production grew faster than the average growth of all agricultural production (FAOSAT, 2013). For instance, the world production of pumpkin is estimated to be 24.62 million MT from an area of 5,10,0000 hectares (Breezy,2016). The crop is rich in nutrients, adapts well to local conditions and grows in a wide range of agro-ecological zones (Moard and Jica, 2000). Table 1 shows list of countries with high production of pumpkin.

Rank	Country	Pumpkin production (metric
		ton)
1	China	7,241,409 m/t
2	India	4,987,123 m/t
3	<b>Russian Federation</b>	1,232,462 m/t
4	Ukraine	1,104,550 m/t
5	United States	863,460 m/t

Table 1.Top five pumpkin producing countries

Source FAOSAT (2013)

#### 2.1.2. Consumption of pumpkin

In recent years, awareness of the nutritional and health benefits of vegetables in Ethiopia has been increasing. The main reason for this is public health advocacy on the role of vegetables in human nutrition and health through its provision of antioxidants such as vitamin A, C and E.Due to the fact that the above mentioned vitamins are important in neutralizing free radicals (oxidants) known to cause cancer, cataracts, heart disease, hypertension, stroke and diabetes (Demissie *et al.*, 2009). The other reason is, partly because of the rising prices of livestock products such as meat, milk and eggs, which traditionally forms a major component of most Ethiopian diets. As such the increasing consumption of vegetables helps to fight hidden hunger, malnutrition (FAO, 2001).

In addition, Pumpkin is one of the foods recommended for postpartum women in Korea. Pumpkin is believed to have health benefits and is often eaten with fat, which aids carotenoid absorption. Therefore, it should be a useful source of provitamin A (Pla *et al.*, 2007). Many other countries, such as the former Yugoslav republics, Argentina, India, Brazil, and America, also use pumpkins traditionally as medicine for diabetes (Fu et al., 2006).

#### 2.2. Utilization of Pumpkin

Consumption of fruits and vegetables has been increased rapidly by people due to awareness regarding their health benefits. Many of the indigenous tropical and temperate fruits and vegetables have still remained underexploited due to the lack of awareness of their potential, market demand and low and erratic bearing in many cases (Sharma and Rao, 2013). Some underutilized species have multipurpose uses as fruits, vegetables and also have therapeutic and medicinal properties (Malik *et al.*, 2010). Pumpkin has received considerable attention in recent years because of the nutritional and health protective values. The presence of magnesium, potassium and folate in pumpkin highlights its heart friendly attributes. The seeds of pumpkin are rich in proteins, iron, zinc, manganese, magnesium, phosphorous, copper, potassium, polyunsaturated fatty acids and carotenoids (Patel, 2013).

In other parts of world, dried vegetables; like, carrot, banana, onion, tomato can found in pieces or powders forms. However, in Ethiopia there are not such type of products in the market. In

our country, pumpkins are widely grown for their fruit utilization that are effectively and efficiently being used for stew preparation to be consumed with Ethiopian traditional spongy thin-layer bread (*Injera*) made from cereal grain called teff. The other most important food product from pumpkin fruit is dried pumpkin which is called '*Duba quanta*' although the effects of drying are not studied. This dried product is used for making delicious stew called '*Duba Wott*' and highly used during the period of food scarcity ((Alibas, 2007).

#### 2.3. Economic Importance of Pumpkin

Pumpkin has numerous nutritional values. Moreover, the low production costs of pumpkin contribute to the fact that it is a relatively inexpensive agricultural product (Jaswir *et al.*, 2017). It is also cheaper as compared to carrots in cost and are abundantly available in market. Carotene content of some Spanish pumpkin varieties was found to be higher than that of carrots (Wu *et al.*, 1998). Hence UNO has given lot of importance to pumpkin due to its rich carotenoid content. Pumpkins due to its large size (approx. 2-35 kg/fruit) have less consumer acceptance as fresh vegetable (FAO, 2005).

#### 2.4. Nutritional Importance of Pumpkin

Pumpkin possesses some really top quality essential nutrients that are required for many processes in the human body. Pumpkin flesh is very low in calories yet contains abundant quantities of extremely good dietary fiber. Many important disease fighting nutrients are also found in large quantities in the pulp and seeds of the pumpkin, including the vitamin pantothenic acid, vitamins C and E. (Aziah and Komathi 2009). Furthermore, pumpkin has an abundance of macro- and micro-nutrients, as well as antioxidants that boost the human body immunity against cancer and other deadly diseases (Oloyede *et al.*, 2013). Pumpkin pulp also is a good source of  $\beta$ -carotene (Dhiman *et al.*, 2009) and the  $\beta$ -carotene is converted to vitamin A in the body which is essential for healthy skin, vision, bone development and many other functions. It acts as a powerful antioxidant for preventing tumor growth, enhancing immune system and inhibiting mutagenesis (Nkosi *et al.*, 2006).).

#### 2.5. Postharvest Problem Associated with Pumpkin

Though pumpkin has been appreciated for high yields, good storage, longer period of consumption, high nutritive value and fitness in transportation yet, like most vegetables, is a perishable crop whose characteristics are changed with time. Due to its bulkiness and large size, there are chances that it may get spoiled early when it is cut open. Further, the large size and heaviness also reduce its consumer acceptance and poses transport problems (Pawar *et al.*, 1985). Moreover, to make it available throughout the year, it is essential to reduce it to desirable shapes and sizes. Preservation methods are required to increase the shelf life, conserve properties and to protect the perishables from insect and microbial growth. There are various methods which are used to preserve fruits and vegetables. One of the most commonly used methods for preservation is drying, which is considered to be the oldest and the most important method of food preservation (Sacilik, 2007).

All pumpkins should be well matured, carefully handled, and free from injury or decay. Recommended conditions for storage of pumpkins are 10 to 13 °C. The RH should be 50 to 70%. Higher RH promotes decay while lower RH causes excess weight loss and texture deterioration. In addition, when stored at low temperature, unfavorable physiological processes occur, resulting in chill damage (Sojak *et al.*, 2014). The fruit surface should be kept dry, and storage rooms should have good air circulation. Postharvest Pathology is also another problem with pumpkin is Decay, in which is the primary cause of storage losses of pumpkins. Numerous fungi cause storage rots including species of Aspergillus, Colletotrichum (anthracnose), Didymella, Fusarium, Mycosphaerella (black rot), Rhizopus, and Sclerotinia (Teotia *et al.*, 2004).

#### 2.6. Preservation and Processing of Pumpkin

Various methods of food processing and preservation can be used today. The methods include dehydration, cold and heat treatment, fermentation, minimal processing, irradiation, additives and packaging to prevent growth of microbes such as bacteria and fungi (Kim *et al.*, 2015). The biggest challenge in processing fresh produce is subsequent nutrient loss. Actual losses depend on various factors such as food type, temperature and cooking time. Nearly all food preparation and preservation methods lead to losses. Drying has been recognized as the most useful

processing technique for prolonging the keeping quality of solid foods including vegetables (Dissa *et al.*, 2010). Food processors and nutritionists need to find ways of minimizing nutritional losses without compromising the health of consumers. Alternatively, to combat losses and improve human health, food fortification may be more widely used (Kim *et al.*, 2015).

Pumpkin needs some way of preservation mainly to reduce or stop spoilage, to make it available throughout a year, to maintain desired levels of nutritional properties for the longest possible time span and to make value added products (Nawirska *et al.*, 2009). One of the biggest advantages of dried foods is that they take much less storage space than canned or frozen foods. Drying is one of the most cost-effective ways of preserving foods of all variety which involves removal of water by application of heat (Horuz and Maskan, 2015).

#### 2.5.1. Drying as food preservation method

For removing moisture and preserving the food, drying technique is one of the earliest techniques (Que *et al.*, 2008). Drying has a vital role in postharvest processing and it has always been of great importance for conserving agricultural products and for extending the food shelf life (Doymaz, 2007). Vegetable drying is generally done either for preserving the perishable raw commodity against deterioration or to reduce the cost of packaging, handling, storing and transporting. The most serious constraint for shelf-life enhancement is the activity of microorganisms. Water in food is reduced to a very low level during drying, thus achieving better microbiological preservation and retarding many undesirable reactions during storage owing to the reduction in water activity. In addition to microbial spoilage retardation; Drying technique also influences other characteristics, such as palatability of food, flavor, aroma, viscosity, hardness, and enzymatic activity (Guine *et al.*, 2011).

#### 2.5.2. Methods of solar and sun drying

In today's world, it seems that the most effective and common form of processing is the convective drying method, because of its ability to reduce the moisture content in food and preserved well with short period of time (Mundada *et al.*, 2010). However, These conventional dryers and drying techniques are not economical due to high energy cost (Gurlek *et al.*, 2009). However, there are many constraints to the convective method that must be observed. It runs

with fuel and electricity, that make it unsuitable for poor farmers where there is no electricity, and it needs optimization of time-temperature combination for every individual food types (Zhang *et al.*, 2011). Another alternative method to consider is the microwave drying. This method provides many advantages in using uniform energy, providing low space utilization, supplying healthy sanitation, and giving better process control. However, this method has some drawbacks. For example, the microwave method can cause uneven heating, can be high investment cost, and can cause damage to the final product (Zhang *et al.*, 2011). Freeze drying is a well-known drying process for obtaining high quality products because it reduces nutritional and sensorial degradation. In the other hand, the freeze drying method also requires a lot of time and is known as the most expensive form of food drying process (Das and Banerjee, 2015).

#### 2.5.2.1. Sun drying

sun drying is a method where food products are spread on mats or raised in clean platforms to be dried by direct radiation of the sun. It is the simplest and cheapest drying technique, which is widely practiced in the tropical region where the outdoor temperature is high enough (usually  $30^{\circ}$ C or higher) to remove moisture from agricultural materials (Teferi *et al.*, 2013). In other word sun drying is the evaporation of water from products by sun or solar heat, assisted by the movement of surrounding air, this method is relatively slow, because the sun does not cause rapid evaporation of moisture. Sun drying also have a negative effect on final product quality in case of food safety. As reported by Akpinar and Bicer (2008) open sun drying caused higher losses beta carotene, due to longer exposure of the drying fruits and vegetables to solar radiation, particularly ultraviolet (UV) rays, which catalyse  $\beta$ -carotene oxidation, leading to the loss of vitamin activity.

Open sun drying of various crops is the widest spread conventional method for food preservation practiced in many urban and rural areas of developing countries. The major disadvantage of this technique is low quality and hygienic problems of the product. The product gets contaminated from dust, insects, rodents, and other animals which seriously degrade the food quality and ultimately results in a negative trade potential and economical worth. Labor requirement, long drying time and direct exposure of the produce to sun and wind are the further difficulties with this method (Waheed *et al.*, 2014). This was confirmed by Workneh *et al.* 

(2014) who found lower Total soluble solid, ascorbic acid, pH value and TSS/TA ratio; higher titratable acidity and longer time of drying in sun dried pumpkin fruit.

#### 2.5.2.2. Solar drying

Solar drying is often differentiated from "sun drying" in that the former operates by the use of equipment to collect the suns radiation in order to harness the irradiative energy for drying applications. In many parts of South East Asia, spice crops and herbs are routinely dried .Solar dryers are far more rapid, providing uniformity and hygiene to the products being dried and are suitable for industrial food drying processes

The reduction of food losses is particularly a problem for small farmers in developing countries who produce more than 80% of the food. Since traditional sun drying is relatively slow process, considerable losses can occur.in addition ,a reduction in the product quality takes place due to insect infestation ,enzymatic reaction ,microorganism growth ,and mycotoxin development (Rajkumar et al., 2007) .With cultural and industrial development ,artificial mechanical drying came into practice .this process is highly energey intensive and expensive ,which ultimately increase product cost.thus solar drying is the best alternative as a solution of all the drawback of natural drying and artificial mechanical drying (Victor and Luis, 1997).

Solar dryers are used in agricultural for industrial food drying are used for industrial drying processes. They are very useful device from the energy conservation point of view. They do not only saves energy but also save time, occupy less area, improves quality of the product quality of product, make the process more efficient, and also protect the environment (Tripathy and Kumar, 2009). Currently, design and development of solar dryer has much attention by food technologists and engineers and various types of solar dryer has been designed such as; natural convection solar dryer, green house type solar dryer, indirect types solar dryer, Indirect multi-shelf solar dryers, cabinet type solar dryer, tunnel types solar dryer, integral type solar dryers, mixed mode natural convection solar dryer , solar and chimney dryer (Bala and Mondol, 2000).

#### 2.5.2.3. Direct solar drying

Direct solar drying is the conventional way of drying the products. In this method the products are directly exposed to the solar radiation and reduce the moisture content to

atmospheric. The air movement is due to density difference. This technique involves the thin layer of product spread over large space to expose to solar radiation (Anupam, 2016).

#### 2.5.2.4. Indirect solar drying

Indirect solar drying or convective solar drying is the new technique of product drying. It is very efficient method than the direct type of solar drying. In this method the atmospheric air is heated in flat plate collector or concentrated type solar collector. The heating process is either passive or active. This hot air then flows in the cabin where products are stored. Therefore, moisture from the product may lost by convection and diffusion. This method of drying is used to avoid direct exposing to the solar radiation (Nimmol and Devahastin, 2010).

#### 2.5.2.5. Mixed mode solar drying

It is combination of direct and in direct solar drying method. Product may dry with both direct exposures to solar radiation and hot air supplier on it. Air may have heated in solar energy collect or first then pass to the chamber where products are stored. In this process product may dry according to convective moisture loss. The same chamber is partially or totally covered with the transparent material to exposure the products to solar radiation (Nimmol and Devahastin, 2010).

#### 2.6. Pre-drying Treatments and Importance

To date, increased attention has been given to the concerns regarding the prevention or minimization of quality degradation of vegetables during drying. These food products contain an extensive collection of phytochemicals, such as vitamins, minerals, antioxidants, pigments and other bioactive compounds, associated with health benefits. However, phytochemicals generally undergo significant degradation during drying, as they are sensitive to heat, light and oxygen (Kumar, *et al.*, 2012). In addition, several nutrient losses are inherent to dehydration, being leached from the vegetable tissue along with the water removal. Colour changes are also often monitored since they can be directly related to the retention of pigment nutrients, such as carotenoids, chlorophylls, phenols, flavonoids and betalains. Different treatments have been applied before the drying process, in order to minimize nutrient losses and thus improve the nutritional value of dried vegetables.

Fruits and vegetables are usually pre-treated for extending the shelf life, preservation of flavor and colour, minimization of nutrients loss, elimination of enzyme activity etc. Pumpkin, like most vegetables, is a perishable food. One way of producing dried products of good quality is to use pre-treatments, which is able to improve product quality (Sathiya *et al.*, 2016). Use of pre-treatments such as blanching and salting before drying results in minimum quality degradation. Sulfiting protects the product against non-enzymatic browning during dehydration (Vashisth *et al.*, 2011). In general, various pre-treatments prior to drying like blanching, chemical treatments viz. sodium/ potassium metabisulphite, citric acid, sodium chloride, calcium chloride, ascorbic acid, osmotic solution etc. are applied prior to drying of food material.

Sathiya *et al.*,2016 investigated the "effect of pre-treatments on the proximate composition of pumpkin flour". they pre-treated pumpkin slice with the; dipping in 0.1% citric acid for 15 minute; hot water blenching at 95°C for 3 minute; steam blanching for 5 minute; blanching at 95°C in 1% sodium chloride for 3 minute; dipping in 0.2% potaium meta bisulphite (KMS) for 45 minute and hot water blanching for 2 minute followed by dipping in KMS for 45 minute prior to drying. Based on this they conclude that The results have shown that blanching of pumpkin slices followed by pre-treatment with potassium metabisulphite (KMS) before drying gave higher colour stability. Blanching prior to dehydration improves the retention of  $\beta$ -carotene during storage of the pumpkin flour, probably due to inactivation of enzymes and sulphite treatment has an enhancing effect

#### 2.6.1. Blanching

Blanching is a unit operation applied prior to freezing, canning, or drying in which fruits or vegetables are heated for the purpose of inactivating enzymes responsible for commercially unacceptable darkening and off flavors (Murthy *et al.*, 2014), modifying texture as well as nutritional value and removing trapped air. There are different methods for blanching the products viz. hot water, hot air, flowing steam and microwave treatment. Steam blanching is more effective than water blanching for the conservation of soluble nutrients (Neelavati *et al.*, 2013). Blanching is definitely the most popular treatment applied to vegetables prior to drying. If applied under optimal conditions, blanching may improve the colour, flavour, texture, nutritional quality and overall acceptability of dried vegetables (Mdziniso *et al.*,2006).

Different researchers investigate on blanching of vegetable for best time temperature combination where the indicator enzymes are inactivating (Sweta *et al.*, 2012). Wu *et al.* (2014) revealed that peroxidase, catalase and pectin esterase enzymes in diced carrots could be inactivated (greater than 97%) after 1 min steam blanching. However, in broccoli, 90 seconds (sec) of steam blanching was sufficient to destroy peroxidase activity. Mousa *et al.* (2004) optimized the blanching method for brinjal slices by using enzyme test method. They treated the slices with boiling water for different time duration (3, 5, 7, 9, 11 min) and reported that blanching of slices at 95 °C for 7 min resulted in efficient inactivation of enzymes in comparison to other treatments.

#### 2.6.2. Citric acid solutions

Citric acid is one of the natural chemical which applied as pretreatment on fruit and vegetables prior to drying or freezing. Chandra *et al.* (2000) have revealed that the pretreated slices of osmotically dehydrated mangoes with citric acid are superior in colour, flavor, texture and taste over the slices which are not treated with citric acid. Shakir *et al.* (2009) have recommended the dipping of apple and pear in 0.20 %t citric acid to prevent browning. For the preparation of pumpkin candy, Muzzaffar (2006) recommended the pretreatment of steam blanching for 4 minutes followed by 1.5% citric acid dip for 20 minutes. Dar *et al.* (2011) used different concentrations (1.00, 1.50 and 2.00 %) of citric acid proved superior with respect to overall acceptability scores in terms of color, taste, texture and flavor. For preparation of osmotically dehydrated wild pear halves, Devi (2014) applied different concentration of citric acid (0.25, 0.5, 1.0 and 1.5 %) for different time intervals (10, 20 and 30 min) and found concentration of 1% citric acid for 30 minutes to be the best by using a concentration of  $70^{0}$ B sugar syrup.

#### 3.6.3. Sodium chloride

Salting is still widely practiced in Africa and other parts of the world. Salting reduces the osmotic tension of cells and increases the stress on bacteria and enzymes that can degrade food and its constituents such as carotenoids (Workneh *et al.*, 2014). Teferi *et al.* (2013) study the thin-layer drying of pumpkin fruit slices. They tried to compare oven drying ( $60^{\circ}$ C) with sun drying pretreated with blanching ( $60^{\circ}$ C for one minute) and dipping in sodium chloride (10%)

for 10 minute) on some chemical parameters; pH, total soluble solid, titratable acidity of pumpkin slices. They conclude that Pre-drying treatments had significant effect on changes in dried pumpkin fruit slices. Salted pumpkin fruit slice sample had the highest pH and total soluble solid value, lower titratable acidity and shorter time of drying.

#### 2.7. Quality Parameters of Pumpkin Affected During Drying

#### 2.7.1. Drying kinetics

Determining the overall quality of dried products and also prediction of the drying kinetics of the food products under various conditions are of importance for the design of the drying systems and for meeting quality specifications and energy conservation (Onwude *et al.*, 2016). One of the most important aspects of drying technology is the modeling of the drying processes. Process modeling is of unquestionable importance for the design and operation of dryers at optimal drying conditions. Drying influences physicochemical and quality characteristics of products; thus, modeling of drying kinetics is one tool for process control (Sturm *et al.*, 2012).

The drying kinetics are greatly affected by air temperature, air humidity, material size (thickness), air speed and drying time, (Rajkumar *et al.*, 2007; Pandey *et al.*, 2010; Kumar *et al.*, 2012). Each of them may have varying degrees of effect on drying processes that must be considered during the drying process. This problem makes manual controlling of dryer systems almost impractical. Thus, it is important to researchers to find a model that incorporates a large number of variables. During the last decades, some theoretical, empirical, and semi theoretical drying models that have been widely used for modeling the drying kinetics of food products are presented in form of models, namely, Fick's second law of diffusion, Weibull distribution function, Page, and logarithmic models (Midilli et al., 2003; Sacilik *et al.*, 2006; Doymaz, 2010; Onwude., *et al.*, 2016).

The underlying chemistry and physics of food drying are highly complicated, so in practice, a drying is considerably more complex than a device that merely removes moisture. However, to understand drying process more effective models are necessary for process design, optimization, energy integration, and control. Although many research studies have been done about mathematical modeling of drying, undoubtedly, the observed progress has limited empiricism to a large extent and there is no theoretical model that is practical and can unify the

calculations (Erbay *et al.*, 2010). Some of the semi-theoretical models which are suitable for solar dryers are indicated in (Table 2).

Table 2: Some of thin layer drying models for the variation of moisture ratio (MR) with time (t)

No	Model name	Model	Description of constants
· 1	Lewis	MR = exp(-kt)	k=drying constant,t=drying time
2	Page	$MR = exp(-kt^n)$	k=drying constant,t=drying time=coefficient
3 4	Modified Page Henderson and Babis	$MR = exp((-kt)^n)$ $MR = a exp(-kt)$	k=drying constant,t=drying time,n=coefficient k=drying constant,t=drying time,a=coefficient
5 6	Logarithmic Two-term exponential	$MR = a \exp(-kt) + c$ $MR = a \exp(-kt) + (1-a)$ $\exp(-kat)$	k=drying constant,t=drying time,a,c=coefficient k=drying constant,t=drying time,a=coefficient
8	Diffusion approximation	$MR = a \exp(-kt) + (1-a)$ $exp(-kbt)$	k=drying constant,t=drying time,a,b=coefficient
9	Modified Henderson and Pabis	$MR = a \exp(-kt) + b \exp(-gt) + c \exp(-ht)$	K,g,h=drying constant,t=drying time,a,b,c=coefficient
10	Midilli <i>et al</i> .	$MR = aexp(-kt^n) + bt$	k=drying constant,t=drying time,a,b,n=coefficient

Source: Sassilic et al. (2006); Midilli et al. (2002); Doymaz (2010), Yaldiz and Ertekin

(2001); Akoy (2014); Rayaguru and Routray (2012); Kaur and Singh (2014)

#### 2.7.2. Physical, functional, chemical and nutritional properties

Functional properties indicate the ability of the proteinaceous material to hold oil or fat and water, to emulsify the same and to form products having a firm consistency upon heating and cooling include viscosity, dispersibility, emulsify, and form gels, foam, produce films and absorb water and /or fat.

#### 2.7.2.1. Physical parameters

#### 2.7.2.1.1. Shrinkage percentage

Drying of agricultural produce is one of the preservative methods which reduce water activity, enzymatic and non-enzymatic actions to enhance food stability and texture. It is an essential unit operation which involves heat and mass transfer phenomena, attributed to physical and structural changes (Dianda *et al.*, 2010). Physical changes, such as structure, case hardening, collapse, pore formation, cracking, rehydration, caking and stickiness can influence the quality of final dried products. Shrinkage of foodstuff during drying is unavoidable because heating and removal of water from the food matrix may cause stresses in the cellular structure, hence leading to structural collapse, changes in volume, shape deformation and capillaries contraction (Mayor *et al.*, 2005). Shrinkage is one of the major physical changes, which influenced the texture, mechanical and rheological properties of the dried food materials. Pretreatments given to foods before drying or optimal drying conditions are used to create a more porous structure so as to facilitate better mass transfer rates. Maintaining moisture gradient levels in the solid, which is a function of drying rate, can reduce the extent of crust formation; the faster the drying rate, the thinner the crust (Talla *et al.*, 2004).

#### 2.7.2.1.2. Rehydration capacity

Most dried food products are rehydrated prior to consumption. It is considered as the percentage of the original weight gained by dried samples during rehydration for a given time at a given temperature in water which depends greatly on the porosity of the material (Pereria, 2014). Rehydration is a diffusion process, during which water moves from the outside of the cells into the interior, and the rehydration capacities of samples depend on the pretreatment and the drying process that were used (Adiletta *et al.*, 2016). In dried products, rehydration behavior must be known to assure the acceptable properties of the rehydrated samples. In the rehydration process, two main cross-current mass fluxes are involved, a water flux from the rehydrating solution to the product and a flux of solutes from the food product to the solution. The pre-drying treatments, drying conditions and rehydration itself, induce structural and compositional changes in the food which affect the product quality. Rehydration behavior has been considered as a measure of the induced damage in the material during drying (Rajkumar, 2007). The rehydration characteristics of the dried product are also influenced by the method of processing, sample constitution, preparation of the sample prior to rehydration and extent of the structural and chemical changes induced by drying (Krokida and Maroulis, 2000).

2.7.2.1.3. Water activity

Water activity  $(a_w)$  has long been considered as one of the most important quality factors for dried products especially for long term storage. Water activity is related with moisture content and responsible for biochemical reactions (Quek *et al.*, 2007). It also affects the shelf life, safety, texture, flavor, and smell of foods. While temperature, pH and several other factors can influence if and how fast organisms will grow in a product, water activity may be the most important factor in controlling spoilage. It predicts stability with respect to physical properties, rates of deteriorative reactions, and microbial growth. Foods containing proteins and carbohydrates, for example, are prone to non-enzymatic browning reactions, called Maillard reactivity increases, reaching a maximum at water activities in the range of 0.6 to 0.7 (Usha *et al.*, 2010). Generally, the values of water activity among 0.20 and 0.40 ensure the stability of the product against browning and hydrolitical reactions, lipid oxidation, auto-oxidation and enzymatic activity (Dirim and Çalışkan, 2012).

#### 2.7.2.2. Functional properties

#### 2.7.2.2.1. Bulk density

Bulk density is defined as the ratio of weight of the flour to the flour volume in gram per centimeter cube(g/mL) (Subramanian and Viswanathan, 2007). Bulk density indicates the behavior of a product in food formulations, for instance, high bulk density is disadvantageous for the formulation of complimentary foods as low density is required in such type of formulations. It is an important parameter that determines the packaging requirement of a product, material handling and application in wet processing in the food industry, and it is generally affected by the particle size and density of the flour. It can also indicate the behavior of a product in dry mixes and it varies with the fineness of the particles (Yenenesh, 2016).

#### 2.7.2.2.2. Water absorption capacity

Water absorption capacity describes flour – water association ability under limited water supply. It gives an indication of the amount of water available for gelatinization. Water binding capacity is a useful indication of whether flour or isolates can be incorporated into aqueous food formulations. Moreover, the oil and water holding capacity could be a function of the protein composition, not only due to the hydrophilic and lipophilic groups exposed but also due to the physical entrapment of oil (Abera, 2009).

#### 2.7.2.2.3. Oil absorption capacity

Ingredients with high oil absorption capacity (OAC) play an important functional role in stabilizing food systems with high fat content, improve viscosity and texture of formulated foods and they can act as emulsifiers (Sangnark & Noomhorm, 2004). In addition, oil absorption capacity is an important property in food formulations because fats improve the flavor and mouth feel of foods.

#### 2.7.2.3. Chemical quality

Browning, lipid oxidation, colour loss and change of flavor in foods can occur during drying and storage. Browning reactions can be categorized as enzymatic and no enzymatic changes (Chandra *et al.*, 2015). Enzymatic browning of foods is undesirable because it develops undesirable colour and produces off flavour. The application of heat, Sulphur dioxide or sulphite and acids can help control this problem. The major disadvantage of using these treatments for food products is their adverse destructive effect on vitamin B or thiamine. Acids such as citric, malic, phosphoric and ascorbic are also employed to lower pH thus reducing the rate of enzymatic browning.

#### 2.7.2.3.1. pH

The acidity or alkalinity of a food is usually expressed as pH (Abera, 2009). The pH is important parmeter to assess the ability of a microorganism to grow in a specific food (AOAC, 2012). The pH of a food can dramatically alter the growth of microbes in food and is a major determinant of the type of food preservation process used for that food. It is considered as safety indicator with combination of water activity, temperature and packaging of the food product.

Yeasts and molds usually grow best between pH 4 and 6 and bacteria usually grow best at pH near 7. In selecting a food preservation process that makes a food shelf stable, the initial pH of that food must be considered to minimize the likelihood of bacterial growth in that food.

#### 2.7.2.3.2. Titratable Acidity

Titratable acidity (TA) sometimes called as total acidity measures the total acid concentration in a food. It is a better predictor than pH of how organic acids in the food impact flavor. Titratable acidity is determined by titration of intrinsic acids with a standard base (Bergveld, 2003). It is expressed in terms of dominant acid found in the product such as mg lactic acid, citric acid, tartaric acid, malic acid eq/g as sample weight depend on the types of food. The concentration of titratable acidity increase when as drying temperature and time increase, since it causes conversion of macronutrient into weak acids (Goyal *et al.*, 2008).

#### 2.7.2.4. Nutritional properties

Fruits, vegetables and their products in the dried form are good sources of energy, minerals and vitamins. However, during the process of dehydration, there are changes in nutritional quality (Suresh *et al.*, 2014). A more number of vitamins such as A, C and thiamine are heat sensitive and sensitive to oxidative degradation. Sulphuring can destroy thiamine and riboflavin while pre-treatments such as blanching and dipping in sulphite solutions reduce the loss of vitamins during drying. As much as 80% decrease in the carotene content of some vegetables may occur if they are dried without enzyme inactivation. However, if the product is adequately blanched then carotene loss can be reduced to 5% Steam blanching retains higher amounts of vitamin C in spinach compared with hot-water blanching (Mala *et al.*, 2018).

Type of nutrients	Possible changes
Calories content	Does not change, but is concentrated into a smaller mass as moisture is
	removed
Fiber	No change
Vitamin A	Fairly well retained under controlled heat methods
Vitamin C	Mostly destroyed during blanching and drying of vegetables
Thiamin ,riboflavin	Some losses during blanching but fairly good retention if water is used to
and niacin	dehydrate is also consumed
Minerals	Some maybe lost during rehydration if soaking water is not used. Iron is
D	not destroyed during drying.
Protein	Can undergo heat denaturation, susceptible to light oxidation and may undergo enzymatic degradation
Lipids	May undergo enzymatic hydrolysis in the initial phase of drying. At low
Carbohydrate	Maillard browning and changes in flavor under high heat. Sugar can be caramelized and give darker color to dried product

Table 3: Some nutritional components of dried products and their change during drying

Source: Sachin et al. (2010)

#### 2.7.2.4.1. Carotenoids in pumpkin

Carotenoids, the natural plant pigments responsible for the orange colour of pumpkin, are intensely investigated because of their health promoting effects. Carotenoids are a primary source of vitamin A for most of the people living in developing countries, where vitamin A deficiency is still common. Pumpkins are poor in total solids and are high in  $\beta$ -carotene, which gives its yellow or orange color (Mitra *et al.*, 2012). Carotenoids are among the phytochemical components believed to reduce the risk of developing some degenerative diseases, and are responsible for the attractive colour of many fruits and vegetables (Hosseini *et al.*, 2010). Thus, Beta-carotene has been used for many years as a food colouring agent, pro-vitamin A in food and animal feed, an additive to cosmetics, multivitamin preparations, and in the last decades as a health food product under the claim 'anti-oxidant (Nakhon *et al.*, 2017).

#### 3.7.2.4.2. Vitamin C

Vitamin C or L-ascorbic acid is an essential exogenous nutrient, mainly available from fruits and vegetables that play an important role in human development and health. This compound is essential for connective tissue formation and maintenance, immune system stimulation, works as antioxidant and enhances iron utilization among other roles (Ndawula *et al.*, 2004).
All drying methods significantly cause loss of vitamin C (Kiremire *et al.*, 2010) and this could be attributed to the fact that vitamin C is highly prone to oxidative destruction in the presence of heat, light, oxygen, enzymes, moisture and metal ions. Pawar *et al.* (1985) observed more loss of ascorbic acid in sun dried unblanched samples when compared with cabinet dried blanched and sulphited sample after 3 months of storage.

#### 2.7.2.4.3. phenolic compounds in pumpkin

Polyphenols are a large group of phytochemicals that are considered responsible for the health benefits associated with fruits and vegetables (Nisha *et al.*, 2009). Plant polyphenols can scavenge free radicals due to their chemical structure. Phenolic or polyphenols have received considerable attention because of their physiological functions, including antioxidant, antimutagenic and antitumor activities. They have been reported to be a potential contender to combat free radicals, which are harmful to our body and foods systems (Nagai *et al.*, 2003). Although, phenolic compounds do not have any known nutritional function, they may be important to human health because of their antioxidant potency. Phenolic are ubiquitous plant components that are primarily derived from phenylalanine via the phenyl propanoid metabolism (Krishan and Naraya, 2011).

#### 3.7.2.4.4. Pumpkin as a source of Natural antioxidant

Vegetables and fruits have been used as natural materials to maintain human health as they help to reduce the risk of many age-related degenerative diseases (Lee *et al.*, 2007). Antioxidants can be defined as substances able to inhibit or delay the oxidative damage of protein, nucleic acid and lipid caused by dramatic increase of reactive oxygen species (ROS) during environmental stress (Lim *et al.*, 2006). Antioxidants act by one or more of the following mechanisms: reducing free radical activity, scavenging free radicals, potential complexing of pro-oxidant metals and quenching of singlet oxygen (Tachakittirungrod *et al.*, 2007). Antioxidants can be classified into primary and secondary antioxidants due to their protective properties at different stages of the oxidation process. Primary antioxidants stop or delay oxidation by donating hydrogen atoms or electrons to free radicals to convert themselves to more stable products. As for secondary antioxidants, they function by many mechanisms, including binding of metal ions, scavenging oxygen, converting hydro peroxides to nonradical species, absorbing UV radiation or deactivating singlet oxygen (Maisuthisakul *et al.*, 2005).

## **3. MATERIAL AND METHODS**

## 3.1. Description of Experimental Site and Materials

The study was conducted at Jimma University college of Agriculture and Veterinary Medicine (JUCAVM), Food Science and Postharvest Technology Laboratory, located at 356 km south west of Addis Ababa at about 70 33''N latitude and 360 57''E longitude and altitude of 1710 meter above sea level (m.a.s.l). The mean maximum and minimum temperature are 26.8°c and 11.4°c, respectively and the maximum and minimum relative humidity is 91.45% and 39.92%, respectively (Bpedors, 2000). The drying experiment was conducted in solar tunnel dryer which found under department of Postharvest Management. Whereas the laboratory analysis was done at postharvest physiology and food analysis laboratories and veterinary postgraduate laboratory and animal nutrition laboratory. Pumpkins (*Cucurbita maxima*) were collected from road side of Woliso, Oromia region, Ethiopia. The selection criteria were based on shape (round) and colour (light green) and texture of the fruit. Therefore, fruits having the same shape, color and texture were collected considering that the selected fruits more or less have the similar genetic makeup and maturity status. In addition, All the chemicals used for analysis were analytical grade.

#### **3.2.** Characterstics of Solar Tunnel Dryer

The solar tunnel dryer has a length of 24 meters and width of 2 meters as indicated in (Figure 1). It is laid on brick stands which have a height of 0.8 meters. The solar absorber is 8-meterslong and the drying zone is 16 meters long. The fan located at the entrance of the solar dryer has a capacity of 75 watts to suck and mix ambient air with air in absorber section to reduce the very hot temperature before it enters to zone one of the drier. The fan operated by power collected by solar panel (WS 80/85 Mono RHA/D, Germany) attached at the top of the front side of the absorber. The absorber is black in color (8 meters long and 2 meters wide). Total dryer zone of 16 meters subdivides into three zones each having 5.33 meters long. According to preliminary data the dryer had an average temperature 46.42, 53.8 and 67.76<sup>o</sup>C at zone I, II & III respectively while the average ambient temperature was 29. 7<sup>o</sup>C.Wheras the average relative humidity were, 29.47, 28.84, 21.82 & 48.6 % for zone I, II, III and ambient respectively (Appendix Table 7).



Figure 1: Picture of solar tunnel dryer with absorber and three zones

## **3.3. Pre-treatments of Pumpkin Pulp**

The experiment was performed by selecting three pumpkins with average weight 37.15 kg. Then the selected ones were washed with sufficient tap water. The clean pumpkin was splinted and the rind, seeds and peeled removed using knife manually. Then pumpkin pulp was uniformly sliced into 2 mm thickness using a vegetable slicer (Chen *et al.*, 2017). Then the slices were treated at a ratio of 1:2 (g of sample/mL of solution) (Aydin and Duigu, 2015); in salt solution (2%) for 20 minute (Workneh *et al.*, 2014); in 1% citric acid solution for 20 minute (Doymaz and Ismail, 2013) and blanched in (1%) salt solution at about 65<sup>o</sup>C (the temperature was checked by glass thermometer) for 2 minute (Sathiya *et al.*, 2016).



Figure 2:Flow diagram of sample preparation for drying pumpkin slice

## **3.4. Solar Tunnel Drying Process**

The drying experiment was conducted between April 16/2019 and April 17/2019, where the condition was full sunny. After preparing the samples and applying pre-treatments; about 0.7 kg of each samples were placed randomly in the three solar tunnel dryer zones for each drying zone. For drying kinetics determination independent representative samples were placed on small wire mesh and weighed using digital balance (ABJ220-4M, WB1151070, Australia) with  $\pm$  0.1 sensitivity at the beginning of drying and in every 30 minute intervals until constant weight was achieved. During drying process temperature, relative humidity and air speed of the solar tunnel dryer and surrounding environment were recorded and expressed in terms of graphs and tables. maximum and minimum temperature (<sup>0</sup>C) and relative humidity (%) for each zones and ambient environment are summarized in Table 5, which was collected during drying using data logger (testo-184H1, Germany). Then after drying stops the samples were cooled to room

temperature overnight; ground into powder; packed in polyethylene bags and stored at ambient atmospheric condition during the study period.

#### **3.5. Experimental Design**

A factorial experiment laid out, considering two factors: dryer zones and pre-drying treatments. Solar tunnel dryer levels were three zone I, zone II and zone III as indicated in Figure 1 assuming variation in drying medium temperature and relative humidity among the zones. Predrying treatments levels were four (untreated (control), 1% citric acid and 2 % salt solutions soaked for 20 minute and blanched at 65<sup>o</sup>C in 1% salt solution). The experiment was laid as 3X4 factorial combination arranged in Randomised Complete Block Design (RCBD) and replicated three times in 36 experimental units.

## **3.6.** Collected Data

## **3.6.1.** Drying characteristics of pumpkin (C. maxima)

#### **3.6.1.1.** Moisture content determination

Moisture contents of fresh and powder pumpkin samples were determined according to AOAC (2000), using the official method 925.05. The dishes used for the moisture determination were dried at  $130^{\circ}$ C for 1 hour in (Leicester, LE675FT, England) and placed in desiccators for about 30 min. The mass of each dishes was measured (M<sub>1</sub>) and about 5 g of the sample was weighed in to each of the dishes (M<sub>2</sub>). The sample was then dried at  $103^{\circ}$ C for 6 hr. After drying is completed, the mass of samples and container was measured (M<sub>3</sub>). The moisture content was then calculated from the Eq. (1):

Moisture(% w/w) 
$$\frac{M_2 - M_3}{M_2 - M_1} *100$$
 (1)

Where  $M_1$  = mass of empty dish  $M_2$  = mass of empty dish plus mass of sample before drying,  $M_3$  = mass of empty dish plus mass of sample after drying

#### 3.6.1.2. Moisture ratio

The moisture ratio (MR) of pumpkin slice during drying experiments was calculated using the following Eq.(2):

$$MR = \frac{M_d - M_e}{M_0 - M_e}$$
(2)

Where  $M_d$ , Mo, and Me are moisture content at any drying time, initial and equilibrium moisture content (kg water/kg dry matter), respectively. The values of Me are relatively little compared to those of  $M_d$  or Mo, the error involved in the simplification is negligible (Goyal *et al.*, 2008), thus moisture ratio was calculated as Eq. (3):

$$MR = \frac{M_d}{M_0}$$
(3)

#### 3.6.1.3. Effective moisture diffusivity (D<sub>eff</sub>)

Fick's second law of diffusion equation, symbolized as a mass-diffusion equation for drying agricultural products in a falling rate period, is shown in the following equation (Doymaz,2010)

$$\frac{\partial M}{\partial t} = Deff\nabla^2 M \tag{4}$$

The solution of diffusion equation (Eq. 4) for slab geometry is solved by Crank (Crank ,1975) and supposed uniform initial moisture distribution, negligible external resistance, constant diffusivity and negligible shrinkage:

$$MR = \frac{8}{\pi^2} \sum_{n=0}^{\infty} \frac{1}{(2n+1)^2} \exp(\frac{(2n+1)^2 \pi D_{eff} t}{4L^2})$$
(5)

where Deff is the effective moisture diffusivity  $(m^2/s)$ , t is the drying time (s), L is the halfthickness of samples (m) and n is a positive integer.

For long drying times, a limiting of Eq. 5 is obtained and expressed in a logarithmic form:

$$\ln MR = ln \left(\frac{8}{\pi^2}\right) - \left(\frac{\pi^2 D_{eff\,t}}{4L^2}\right) \tag{6}$$

From Eq. 6, a plot of ln MR versus drying time gave a straight line with a slope (K) of:

$$K = \frac{\pi^2 D_{eff}}{4L^2}$$
(7)

Where, *MR* is the moisture ratio, *Deff* is the effective moisture diffusivity  $(m^2/s)$ , and *L* is the thickness of slice of the sample (m),

However,  $D_{eff}$  of the pumpkin slices was obtained from the slope (K) of the graph of ln (MR) against the drying time. In (MR) versus time results in a straight line with negative slope and K is related to Deff by Eq.(7)

For drying model selection, drying curves were fitted to 6 well known thin layer drying models which are given in (Table 4). The best of fitted model was determined using four parameters: higher values for coefficient of determination ( $R^2$ ) and lower value for reduced-chi square ( $X^2$ ), root mean square error (RMSE) and mean relative percent error (P) using Equations (8-11).

#### 3.6.1.4. Kinetic models tested

The following thin layer drying models were selected and tested for fitting the models. These were the Lewis, Page, Henderson and Babis, diffusion approach, Mindili, Logarithmic and two term exponential approach. for more details, see Table (4).

No	Model name	Model equation			
•					
1	Lewis	MR = exp(-kt)			
2	Page	$MR = exp(-kt^n)$			
3	Henderson and Babis	MR=aexp(-kt)			
4	Diffusion approximation	$MR = a \exp(-kt) + (1-a) \exp(-kbt)$			
5	Mindili et al	$MR = aexp(-kt^n) + bt$			
6	Logarithmic	$MR = a \exp(-kt) + c$			
7	Two-term	$MR = a \exp(-kt) + (1-a)$			
	exponential	exp(-kat)			

Table 4: Models and their equation considered for fitting of experiment

Source, Midilli et al. (2003); Doymaz (2010), Yaldiz and Ertekin (2001); Rayaguru and Routray (2012); Kaur and Singh (2014)

The drying data obtained were fitted to seven thin-layer drying models detailed in (Table 5) using the nonlinear regression analysis. The goodness of fit for each model was evaluated based on the statistical parameters:  $R^2$ , RMSE,  $\chi^{2a}$  and P. The coefficient of determination ( $R^2$ ) is one

of the primary criteria for selecting the best model to define the drying curves. In addition to  $R^2$ , reduced Chi-square (x<sup>2</sup>) and root mean square error (RMSE), relative mean percent error (P) are used to determine the quality of the fit (Doymaz,2010). For quality fit,  $R^2$  value should be higher and  $\chi^2$ , RMSE and P values should lower. These were calculated as Eq. (8,9.10 &11)

$$R^{2} = 1 - \frac{\sum_{i=1}^{N} (MR_{pre,i} - MR_{exp,i})^{2}}{\sum_{i=1}^{N} (XMR_{pre,i} - MR_{exp,i})^{2}}$$
(8)

$$X^{2} = \frac{\sum_{i}^{N} 1(MR_{exp,i} - MR_{pre})^{2}}{N - n}$$
(9)

$$RMSE = \left[\frac{1}{N} \sum_{i=1}^{N} (MR_{pre,i} - MR_{exp,i}) 2\right]^{\frac{1}{2}}$$
(10)

$$P(\%) = \frac{100}{N} \sum \frac{/MR_{exp} - MR_{pre}/}{MR_{exp}}$$
(11)

Where, MRexp, *i* is the *i*th experimentally observed moisture ratio, MRpre, *i* the *i*th predicted moisture ratio, N the number of observations, n is the number constants and X is mean (Akpinar, 2005).

## 3.6.2 Physical and functional properties

#### 3.6.2.1. Shrinkage ratio

Shrinkage ratio (SR) of pumpkin was determined according to the method described by Disa *et al.* (2010). The percentage of shrinkage of pumpkin flake were calculated as shown in Eq. (12).

SR (%) = 
$$\frac{V_{i-V_f}}{V_i} * 100$$
 (12)

where, SR (%) is shrinkage ratio, Vi (cm<sup>3</sup>) is the apparent volume of the fresh sample before drying, and  $V_f$  (cm<sup>3</sup>) is the apparent volume of the sample after drying.

Both sample volume fresh ( $V_i$ ) and dried ( $V_f$ ) were determined by solid displacement (line seed) The volume of the sample displaced in line seed were measured using a 50 ml graduate cylinder.

#### 3.6.2.2. Rehydration ratio

Method given by Joshi (2009) were followed to determine the rehydration ratio of dried samples. The dehydrated sample (5g) were taken in a 100 mL beaker and 50 mL water was added to it. The contents were heated to boil for 5 minutes. The excess water was taken out and drained using a laboratory tissue paper. Then, weight was recorded by using an analytical balance and ratio was calculated as indicated in Eq. (13).

$$RR = \frac{\text{Weight of dehydrated sample}}{\text{Drained weight of rehydrated sample}}$$
(13)

*Where RR= rehydration ratio* 

#### 3.6.2.3. Bulk density

The bulk density (BD) of the powder was determined according to the method described by Makinde & Ladipo (2012). Ten grams (10g) of each powder sample were measured into a 50 mL graduated measuring cylinder. The volume of the sample was have determined before and after gently tapping the base of the measuring cylinder on a laboratory bench for 10 times. This were have replicated for each sample for consistency and accuracy. The bulk density (g/mL) were calculate as weight of flour (g) divided by flour volume (mL) Eq. (14).

$$BD(\frac{g}{mL})) = \frac{\text{weight of dried sample}}{\text{volume of dried sample after tapping}}$$
(14)

Where BD is Bulk Density, g is gram and mL is milliliter

#### **3.6.2.4.** Water hydration capacity

Water hydration capacity was determined using the method of Robertson (2000). One g of the sample was mixed with 10 mL of distilled water for 5 min on magnetic stirrer. The mixture was centrifuged at 3500 rpm in a centrifuge (800-1, USA) for 30 minute and the volume of supernatant was measured by using 10 mL measuring cylinder from each of the samples. Then WHC was determined using Eq. (14)

*Where WHC -= water hydration capacity, g is gram and mL is milliliter* 

#### **3.6.2.5.** Oil absorption capacity

The oil absorption capacity was determined using the method of Robertson (2000). One g of the sample was mixed with 10 ml of food grade (Sun flower oil) for 5 minute on magnetic stirrer. The mixture was centrifuged at 3500 rpm in a centrifuge (800-1, USA) for 30 minute and the volume of supernatant was measured by using 10 mL measuring cylinder from each of the samples. And the result was expressed as indicated in Eq. (16).

OAC (mL/g) = 10 - Supernatant (16) Where OAC is oil absorption capacity, g is gram and mL is milliliter

#### 3.6.2.6. Water activity (a<sub>w</sub>)

The water activity of the samples was determined by Lab Master- aw instrument (Novasina AG, CH- 8853 lachen, Switzerland) according to Chardelle *et al.* (2005). Where direct measurements were taken at room temperature. Standard cuvett were used in which powder were filled up to the rim and placed below the sensor of the water activity meter, which gave direct reading of water activity of the sample.

#### **3.6.3 Chemical properties**

#### 3.6.3.1. Total soluble solids

Determination of total soluble solid (TSS) was followed the method described by Ranganna (2007). First 2.00 g of pumpkin powder dehydrated to its initial moisture content. Then, the TSS was determined with the help of hand refractometer (DR201-95, Germany) and was expressed as °Brix (°B) at room temperature. The measurement repeated three times and average values were taken.

## 3.6.3.2. рН

The pH of pumpkin powder was measured according to the method described by Nunes and Emond (1999). 2.00 g of powder was rehydrated back to its initial moisture content. An extract

of an aliquot of juice was extracted from the rehydrated pumpkin powder and filtered with cheesecloth. Then, the pH value of the pumpkin was measured using the pH meter (portable CP-500 Taiwan) which was calibrated with pH 7 and pH 4. The measurement repeated three times and average values were taken.

#### **3.6.3.3.** Titratable acidity

Titratable acidity(TA) expressed as percentage of citric acid, was determined by titrating 50 ml of the homogenate samples against 0.1 N NaOH. First the distilled water (1L) used for titration was titrated with 0.1 N NaOH and the volume of 0.1 N NaOH consumed by water titration was considered as a blank. The volume of 0.1 N NaOH used for titration of the sample was noted after correcting the blank and percent of citric acid was calculated using Eq. (18) (Abera, 2009). In all cases triplicate determination was made

Citric Acid (%) = 
$$\frac{V*0.0064*100}{W}$$
 (18)

Where: V=Volume of 0.1 N NaOH used for sample titration; 0.0064=Factor equivalent in which 1ml of 0.1N NaOH =0.009008g C3H6O5; W=Weight in gram of sample in the mixture (Pearson, 1971).

#### 2.6.4. Proximate composition of pumpkin powder

#### 2.6.4.1. Total ash determination

Total ash content was have determined gravimetrically (AOAC, 2000) using the official method 941.12, by taking 3 g of samples in tared silica crucibles. The dried samples were slowly heated over hot plate until the bulk of organic matter was burnt. Then the crucibles were have placed in a muffle furnace (SX-5-12, China) for ashing at 550°C over night to obtain a carbon free white ash. Then ash content of sample was then calculated as given by Eq. (19).

$$Ash(\%) = \frac{Weight \, of \, ash(g)}{Weight \, of \, sample(g)} * \, 100 \tag{19}$$

#### 2.6.4.2. Crude protein determination

Crude protein was determined according to AOAC (2000) by the Kjeldahl method using semiautomatic (VELP SCIENTIFA nitrogen analyzer). About 1.00 g of sample powder and 1.00 g of catalase mixture (10% cupper (II) sulphate and 90 % potassium sulphate) was added to the Kjeldahl flask. Then 12 mL of concentrated sulfuric was added and placed in digesting track for one hour at a temperature of 420<sup>o</sup>C until a clear solution observed. After digestion stopped and cooled, the sample was distilled automatically by adding 50 mL of deionized water and 50 ml of 40% sodium hydroxide solution. Meanwhile The distillated solution was titrated against with 0.2 N hydrochloric acid to a reddish color. Then the result was Calculation follows Eq. (21) and Eq.(22)

Total nitrogen (%)=
$$\frac{\{(V-V_b)*N*14\}}{W}$$
 (21)

$$Crude protein(\%) = (total nitrogen(\%) * 6.25)$$
(22)

Where: V = volume of acid consumed to neutralized the sample; Vb= the volume of acid consumed to neutralize the blank; N = normality of the acid; 14=Eq. wt of nitrogen; 6.25= conversion factor from total nitrogen to crude protein

#### 2.6.4.3. Crude fiber determination

Crude Fiber Content of pumpkin powder was determined according to AOAC (2000), using the official method 920.169. About 1.6 g of the sample was weighed in each of 600 mL beaker. 200 mL of 1.25% sulfuric acid solution was added to each beaker and allowed to boil for 30 minute by rotating and stirring periodically. During boiling the level was kept constant by addition of hot distilled water. After 30 minutes 20 mL of 28% potassium hydroxide solution was added in to each beaker and allowed to boil for another 30 min. The level was still kept constant by addition of hot distilled water. Then after 30 min the solution found in each of the beaker was filtered through crucibles containing sand by placing each of them on Buchner funnel fitted with No.9 rubber stopper. During filtration the sample was washed with hot distilled water, 1% sodium hydroxide solution and finally with acetone. Each of the crucibles with their contents was dried for 2 hr at about  $130^{\circ}$ C and cooled in desiccators and weighed (M<sub>1</sub>). Then, they were ashed for 30 min at  $550^{\circ}$ C in furnace and were cooled in desiccators. Finally, the mass of each crucible was weighed (M<sub>2</sub>). The crude fiber was calculated from the Eq. (23).

Crude fiber (%w/w) = 
$$\frac{M_2 - M_1}{W} * 100$$
 (23)

Where  $M_1$ : mass of the crucible, the sand and wet residue,  $M_2$ : mass of the crucible and the sand and W: sample weight.

## **3.6.5.** Bioactive components determination

#### 3.6.5.1. Beta-carotene

Extraction of total beta carotene content was follow the method described by Sadler *et al.* (1990). First extraction solvent was prepared from 50% hexane, 25% acetone, 25% ethanol, and 0.1% BHT). Then About 0.5g of sample powder were mixed with 0.5 g CaCl2.2H2O in analytical conical flask and 50 mL extraction solvent and gently shaken for 30 min. Then 15 mL of distilled water added and the solution was frequently shaken again for 15 minute. The organic phase, containing the beta-carotene were separated from the water phase, using a separation funnel, and filtered using what man filter paper No.1.

After sample extracted beta-carotene were estimated from absorbance read at 450 nm using UV-Vis spectrophotometer, 124-244, Cambridge and compared with beta-carotene standard. Pure Beta-carotene standard (Sigma Aldrich) were used as a standard and the measurement were compared to a standard solution. To draw the calibration curve (Appendix Figure 5), beta carotene standard stock solution was prepared by accurately weigh 0.01 g beta-carotene standard and dissolved in 20 mL solvent which were similar to extraction solvent used to extract samples (50 % hexane, 25 % acetone, and 25 % ethanol) and made the volume to 100 mL using the same solvent. From the stock solution 0, 2, 3, 4 and 5 were added in to 100 mL flask and diluted to give 0, 0.1, 0.2, 0.4, and 0.8 mg/L of beta- carotene standard in the same solvent. Then 3 mL of each sample were introduce into test tubes and covered cover with aluminum foil and the absorbance were read using (UV-Vis spectrophotometer,124-244, Cambridge). All samples were prepared in triplicate for each analysis.

#### 2.6.5.2. Ascorbic acid

Ascorbic acid content was determined by 2, 6-di-chlorophenol-indophenol Visual titration method (Hassan, 2008). The analysis started by Preparation of extracting solution. Metaphosphoric acid – acetic acid (HPO3 – HOAC) was prepared by weighing 15g of HPO3 sticks and dissolving in 40 mL of HOAC and 200 mL of distilled water. The resulting solution was diluted to 500 mL with distilled water, filtered and stored in the dark for use. Indophenols

solution was prepared by weighting 50 mg of 2, 6-dichlorophenol indophenols powder and dissolved in 50 mL of distilled water containing 42 mg of NaHCO3. The resulting solution was then diluted to 200 mL with distilled water, filtered and stored in the dark for use. Next standard ascorbic acid solution (1 mg/mL) was prepared by dissolving 50 mg of ascorbic acid in 40 mL of HPO3 – HOAC solution and made up to 50 mL in a volumetric flask.

Following preparation of standard solutions; indophenols solution was standardizing with standard ascorbic acid solution by transferring 2 mL aliquots ascorbic acid solution into 50 mL conical flasks. The content of the conical flask was titrated against indophenols from the burette until a distinct rose color persisted for about 5 seconds. Blank titrations were also carried out using 7 mL of PHO3 – HOAC solution against indophenols. Samples were extracted by weighting 2 g of each of the powdered and fresh samples and transferred into conical flasks. 40 mL of the extracting solution was added to each sample and triturated to form a suspension and then allowed to stand for 30 minutes. The volume obtained was noted and designated as V mL. Sample aliquots (7 mL each) were obtained by filtering the suspension. Finally, 7 mL of sample aliquots were titrated against indophenols from the burette until a distinct pink to rose color persisted for 5 seconds. The titration was repeated three times for each sample aliquot and average titre values obtained. The concentration of ascorbic acid in each sample (mg/g of sample) was calculated using the following formula in Eq.(25).

ascorbic acid 
$$\left(\frac{mg}{100g}\right) = (X - B) * \frac{F}{E} * \frac{V}{Y} * 100$$
 (25)

X = Average titre value obtained from sample titration B = Average titre value obtained from blank titration. F = mg of ascorbic acid equivalent to 1ml of indophenols solution. E = No. of grams of powdered fruit sample assayed. V = Volume of initial assay solution Y = Volume of sample aliquot titrated

#### 2.6.5.3. Determination of total phenolic content

Sample extraction for determination of total phenolic content follow described by Wolde *et al.* (2014). First 0.1g of sample were mixed with 20 mL of methanol and shake for 24 hr on a mechanical shaker then filtered using whatman filter paper No.1.Then the samples were stored in a refrigerator ( $4^{0}$ C) until analysis. After samples were extracted total phenolic contents were determined according to methods of Kuyu *et al.* (2016) which involves the reduction of Folin-

Ciocalteau reagent by Phenolic compounds, with an associated formation of a blue complex. Ten mL of the extracts were added with 2 mL of 2N Folin-Ciocalteau reagent. Immediately, 2 mL of 7.5% sodium carbonated solution was added. Then, the mixture was incubated for (Heraells, England) 30 min at 37°C, and the absorbance was read at 765 nm using UV-Vis spectrophotometer,124-244, Cambridge, Gallic acid was used as a standard and the measurement was compared to a standard curve ( $R^2$ =0.99645) prepared with Gallic acid solution (Appendix Figure 4). Total phenolic content of extracts was then expressed as mg gallic acid equivalents per gram of dried basis of samples (mg GAE/g d.w) that was derived from a calibration curve. All The samples were prepared in triplicate for each analysis and the mean value of absorbance was obtained at 765 nm.

To draw the calibration curve gallic acid stock solution was prepared by accurately weigh 0.1 g gallic acid into a 100 mL volumetric flask, dissolved in 10 mL methanol and the solution was made up to the same solvent. Then from the stock solution0, 0.625, 1.25, 2.5, 3.75, 5, 6.25, 7.5 and 8.75 mL added to flask and diluted to give 0. 25, 50, 100, 150, 200 and 250 300 and 350 mg/L of gallic acid in methanol with the final volume 25 mL for each. Then 1 mL of each sample was introduced into test tubes and mixed with 2 Normality Folin- Ciocalteu reagent and 2 mL of 7.5% sodium carbonate. The tubes were covered with aluminum foil and allowed to stand for 30 minutes at room temperature and the absorbance was read at 765nm using (UV/Vis spectrophotometer, 124-244, Cambridge) expressed as milligrams of gallic acid equivalent per g of dry weight (mg GAE/100 g d.w).

#### 2.6.5.4. Determination of DPPH scavenging activity

DPPH (2,2'-diphenyl-1 - picrylhydrazyl) scavenging activity of the methanolic extract of the sample was determined according to the procedure of Wolde *et al.* (2014). First 0.1g of sample were mixed with 20 mL of methanol and shake for 24 hr on a mechanical shaker then filtered with filter paper and mixed again with 20 mL of methanol and shaked for 30 minute. Next A 0.004% solution of DPPH radical solution in methanol was prepared and then 4 mL of this solution was mixed with various concentrations (2–14 mg/mL) of the extracts in methanol in this case 2.5,5,7.5,10 and 12.5 mg/mL of sample extract concentration were taken. Finally, the samples were incubated for 30 min in the dark at room temperature. Scavenging capacity was read spectrophotometrically (UV/Vis spectrophotometer, 124-244, Cambridge) by monitoring

the decrease in absorbance at 517 nm. The percentage of absorbance was calculated according to Eq.(26). The scavenging activity was expressed as the 50% effective concentration (IC<sub>50</sub>), which was defined as the sample concentration (mg) necessary to inhibit the DPPH radical activity by 50% calculated from the graph of DPPH scavenging activity percentage against extract concentration.

Antioxidant activity (%) = 
$$\frac{AB_{(C)} - AB_S}{AC} * 100$$
 (26)

*Where:*  $Ab_{(C)}$  *is absorbance of control*  $AB_{(S)}$  *is absorbance of sample* 

## 3.7. Statistical Analysis

First the drying kinetics model (R<sup>2</sup>, X<sup>2</sup>, RMSE and P) values were estimated by non-linear regression using statistical software (MS, office Excel-2016 and mini tab version 16.). Then effect of solar tunnel dryer zones and pretreatments on drying characteristics, physical and functional properties, chemical and nutritional parameters were analyzed using Minitab version 16 whereas ANOVA of a 3×4 factorial design for mean separation. Result was expressed with  $\pm$  standard error from the three replications for physical, functional, chemical and nutritional parameters. Difference between the samples mean were conducted using Tukey's test at  $\alpha$ =0.05 level of significance.

## **4. RESULTS AND DISCUSSION**

#### 4.1. Variation of Temperature and Relative Humidity in Solar Tunnel Dryer

The temperature and relative humidity of different drier zones which are the most important factors for drying kinetics are presented in Table 5 during drying and Figure 3. The average temperature of zone I, II, III and ambient were  $45.63\pm3.38$ ,  $54.78\pm3.70$ ,  $64.85\pm6.20$  and  $28.9\pm2.5^{\circ}$ C respectively whereas the average relative humidity was recorded as  $34.58\pm3.67$ ,  $31.36\pm3.40$ ,  $24.2\pm9.40$  and  $45.78\pm5.7\%$  for zone I, II, III, and ambient air during drying.

Table 5: Average, maximum and minimum temperature and relative humidity at three zones and ambient recorded during drying.

Temperature and RH		Average	Minimum	Maximum
	Ambient Zone I	28.27±2.5 ( <b>45.73±5.7</b> ) 45.63±3.38 ( <b>34.58±3.67</b> )	22.9 ( <b>36.7</b> ) 40.9 ( <b>28.2</b> )	33 ( <b>57.3</b> ) 51.6 ( <b>42.7</b> )
Temperature ( <sup>0</sup> C)	Zone II	54.78±3.70( <b>31.36±3.40</b> )	48.9 ( <b>25.9</b> )	58.6 ( <b>38.6</b> )
	Zone III	64.97±6.20( <b>24.16±9.40</b> )	56 (21)	70 ( <b>27</b> )

Note: for both temperature and relative humidity the minimum values were observed in the morning (10:00PM) whereas maximum values were observed from 12:00-15:00 AM. Sample mean expressed  $\pm$ standard deviation

# 4.2. Effect of Solar Tunnel Dryer Zones and Pretreatments on Drying Characteristics

Drying behavior of pumpkin slices was studied by analysis of patterns of moisture loss obtained with three zones of solar tunnel dryer and four pre-drying treatments. Drying kinetic, moisture diffusivity and models fitted to the kinetics were presented and discussed as follows.

## 4.2.1. Effect of pre-treatmnts on drying kinetics of pumpukin slices

The characteristics drying curves showing the changes in moisture ratio of pre-treated pumpkin with time at the three zones of the dryer as indicated in figure 4, 5 and 6. According to the results the pre-treatment has an effect on the moisture removal of the pumpkin samples as expected. Among the three pretreatments and control, the salt blanched pumpkin slice shows fast removal of moisture in all cases. For instance, at zone I, salt blanched sample took 390

minute to reached a moisture ratio of 0.069 whereas the salt and citric acid treated samples demanded 480 min to reached a moisture ratio of 0.059 and 0.047 respectively. Further the control sample took relatively more time to dry.



Figure 3: Drying curve at zone I for control, citric acid, salt and salt blanched treated pumpkin slice

Regardless of control, citric acid treated and salted samples; the salt blanched samples experienced the higher moisture removal at zone I and zone III. The probable reason that salt blanched sample dry fast is, that blanching plus salt have disrupt the cell wall and this improve movement of water from internal tissue to the surface of sample, which is supported by Roongruangsri and Bronlund (2015) who said "salt blanching reduces drying time through reducing the firmness of fruit tissue and facilitating moisture diffusion from sample slices"

The result of present study is in a good agreement with the findings of Tunde and Ogunlakin (2011) who studied mathematical modeling of drying of pretreated (water blanched, steam blanched oil water blanched untreated) pumpkin and with Doymaz (2010) reports for apple slices. However, it was not in close agreement with findings of Adepoju *et al.* (2017) who studied the effect of pretreatments and drying methods on some qualities of dried mango fruit, and found no significant effect of pretreatments drying curve.Generally, the finding of this study was supported by reports of Goyal *et al.* (2008) and Doymaz (2010) who observe, various forms of blanching combining with salt pretreatments increase the drying, for apples, tomato slices respectively.



Figure 4: Drying curve at zone II for control ,citric acid , salt and salt blanched treated pumpkin slice



Figure 5: Drying curve at zone III for control ,citric acid , salt and salt blanched treated pumpkin slice

## 4.2.2. Effect of dryer zones on drying kinetics of pumpkin slices

Figure 7 and 8 shows the effect of solar tunnel dryer zones on moisture removal of pumpkin slice. As indicated in Figure 7 and 8, the pattern of drying curve for control and citric acid, salt and salt blanche treated pumpkin slice at the three zones was same. The moisture removal was rapid at zone III and recorded short time to reach to the final moisture ratio. The reason behind that was its average temperature (64.97<sup>o</sup>C) and relative humidity (24.16%) relatively higher and lower respectively, than other two zones. This phenomenon is more explained "a 10 fold increased in temperature can double the rate of moisture removal of product". Moreover, zone II shows relatively better removal of moisture than zone I.This also support that moisture

removal is fast at increased temperature and these conditions were the same for the three pretreatments and control samples.

These result was described well by Prachayawarakorn *et al.* (2008), that the higher capability of removing moisture at high temperatures can possibly be explained by the acceleration produced through the movement of water molecules at higher temperatures which took part in a more rapid decrease of the moisture content. These result was also in a good agreement with report of Taheri *et al.* (2011) for tomato slice. This indicates that diffusion is the dominant physical mechanisms governing moisture movement in the samples. Further, investigating effect of solar tunnel dryer zones for different products and fitted them with different mathematical models to predict the time with same situation is advisable to avoid under or over drying of products.



Figure 6:Moisture ratio versus time at different dryer zones for the control (C) and citric acid (CA) treated pumpkin slices



*Figure 7: Moisture ratio versus time at different dryer zones for the salt (S) and salt blanch (SB) treated pumpkin slices* 

## 4.2.3. Effective moisture diffusivity(*D<sub>eff</sub>*)

The moisture diffusion is considered to be an important transport property, which is needed to calculate and model drying properties of foods. The effective moisture diffusivity and drying constant of the pumpkin slices are presented in Table 6. In the present study, drying constant of the pumpkin slice were found between  $0.0137 (m^{-1})$  and  $0.0047 (m^{-1})$  which have a direct effect on effective moisture diffusivity from the slices (Table 6). It revealed that the lowest moisture diffusivity exhibited  $7.63*10^{-9}(m^2/s)$  at Zone I- for salt (2%) treated slice followed by citric acid treated sample ( $8.28*10^{-9}$ ) in the same zone of dryer. However, the highest moisture diffusivity was  $2.34*10^{-8}(m^2/s)$  for salt blanched followed by citric acid sample  $2.30*10^{-8}(m^2/s)$  at zone III as indicated in Table 6. This means that combination of high temperature and predrying treatment such as blanching in hot water solution containing salt citric acid and facilitate water transport from inside to pumpkin surface.

The  $D_{eff}$  values in the present study was in close agreement with values reported by Perez and Schmalko (2009) for convective drying of pumpkin as influence by pretreatment (blanching for one and two minute) and drying temperature. The values of effective diffusivity obtained from this study lie within in general range  $10^{-12}$  to  $10^{-8}$ (m<sup>2</sup>/s) for drying of food materials (Doymaz, 2011). Amin (2007) reported the effective diffusivity of mango slices varied from  $1.87 \times 10^{-10}$ m<sup>2</sup>/s to  $3.67 \times 10^{-10}$ m<sup>2</sup>/s in temperature range from 50°C. to 90°C, which is slightly lower than current study. In addition, Kongdej (2011) studied the effects of temperature and slice thickness

on drying kinetics of pumpkin slices and found effective diffusivity  $1.359 \times 10^{-10}$  to  $5.301 \times 10^{-10}$  m<sup>2</sup>/s and this also slightly lower than the result in present study. Adeleta *et al.* (2018) indicated the highest value of effective moisture diffusivity of pumpkin slice  $9.39 \times 10^{-9}$  (m<sup>2</sup>/s) for treated and dried at 70°C and the lowest value  $6.75 \times 10^{-9}$  (m<sup>2</sup>/s) untreated and dried at  $55^{\circ}$ C. His finding support that, effective moisture diffusivity increased as drying temperature increased and when applied predrying treatments (0.8%(w/v) trehalose, 0.1% (w/v) NaCl and 0.2% (w/v). In general, from this result we can conclude that high temperature and low relative humidity as well as application of predrying treatments alter effective moisture diffusivity that bring short drying time.

Zone	Pretreatment	Drying constant K (-)	$D_{eff}(m^2s^{-1})$
Ι	Control	0.0061	9.89*10 <sup>-9</sup>
	Citric acid (1%)	0.0054	8.28*10 <sup>-9</sup>
	Salt(2%)	0.0047	7.63*10 <sup>-9</sup>
	Salt blanched	0.0065	1.05*10 <sup>-8</sup>
	Control	0.0097	$1.57*10^{-8}$
TT	Citric acid(1%)	0.0125	2.03*10 <sup>-8</sup>
11	Salt(2%)	0.0093	$1.501*10^{-8}$
	Salt blanched	0.0115	$1.87*10^{-8}$
	Control	0.0102	1.65*10 <sup>-8</sup>
TTT	Citric acid(1%)	0.0137	2.30*10 <sup>-8</sup>
111	Salt(2%)	0.0114	$1.85*10^{-8}$
	Salt blanched	0.0142	2.34*10 <sup>-8</sup>

Table 6:Effective moisture diffusivity  $(D_{eff})$  of pumpkin slice at different zone and pretreatments

## 4.2.4. Fitting the proposed models

Obtaining drying kinetics data and their modeling is necessary to design, simulate and optimize the drying process or drying facilities. Modeling the drying behavior at the determined condition is important to obtain higher-quality dried products, which are provided by controlling and optimizing the process parameters (Clemente *et al.*, 2011). The drying models were fitted to seven common thin layer drying models available in literatures and most recommended for fruit and vegetables drying. However, to see the fitting models for each zone; only zone II was discussed in this section and the rest are given in (Appendix Table 1 & 2).

The best model describing the drying characteristics of samples was chosen as the one with the highest coefficient of determination ( $R^2$ ), the least mean relative percent error (P), root mean square error (RMSE) and chi-square ( $X^2$ ). The values recorded for  $R^2$ ,  $X^2$ , RMSE and P range from 0.88005 to 0.99940, from 0.00013 to 0.01024, from 0.01024 to 0.11743, from 4.56 to 28.09 respectively (Table 7). As indicated in Table 7, the diffusion approximation model achieved the highest  $R^2$  (0.99373, 0.99427, 0.99651 and 0.99940) for citric acid treated, control, salt (2%) treated and salt blanched respectively, with the lowest  $X^2$  and RMSE. However, the Lewis as well as Henderson and Babis models yield lowest  $R^2$  value range from 0.88005 to 0.94332 excluding salt blanched sample.

The diffusion approximation model was found to be the best fitting for describing the drying behavior of control, citric acid and salt and salt blenched treated samples. Further, Considering the mean percent relative error (P) value less than 10, Henderson and Babis model was found suitable for describing the drying characteristics of control and salt blanched samples. Moreover, two term exponential model was found suitable for describing the drying behavior of citric acid and salt and salt blanched samples. Figure 9 and 10 compare experimental data with selected fitted data for pumpkin slices dried at zone II.

Pretreatments	Models	$\mathbb{R}^2$	$\mathbf{X}^2$	RMSE	P(%)
	Logarithmic	0.96643	0.00853	0.08432	19.79
	Henderson and Babis	0.94332	0.00658	0.07793	5.25
	Lewis	0.93227	0.01496	0.12232	22.64
	Page	0.96672	0.00772	0.08412	15.12
	Two term exponential	0.99175	0.00189	0.04163	17.59
Control	Diffusion approximation	0.99427	0.00145	0.03475	4.56
	Mindili <i>et al</i>	0.97255	0.00768	0.07592	18.86
	Logarithmic	0.96718	0.00825	0.08124	15.70
	Henderson and Babis	0.91237	0.01031	0.09186	16.98
Citric acid	Lewis	0.88005	0.01532	0.11743	22.37
	Page	0.97372	0.00588	0.07278	25.58
	Two term exponential	0.99339	0.00147	0.03633	9.59
	Diffusion approximation	0.99373	0.00157	0.03541	8.45
	Mindili <i>et al</i>	0.981705	0.00521	0.06038	24.99

Table 7: Curve fitting criteria for the various mathematical models and parameters for pumpkin pretreated with citric acid, salted, salt blanched and untreated dried at temperatures of zone II

	Logarithmic	0.97481	0.00672	0.07484	21.56
	Henderson and Babis	0.93032	0.00796	0.08594	28.09
Salt (2%)	Lewis	0.94429	0.01287	0.11346	22.34
	Page	0.97572	0.00590	0.07360	15.99
	Two term exponential	0.99479	0.00125	0.03391	8.34
	Diffusion approximation	0.99652	0.00093	0.02779	6.27
	Mindili <i>et al</i>	0.985904	0.00416	0.05582	11.43
	Logarithmic	0.99388	0.00132	0.03251	12.35
	Henderson and Babis	0.98736	0.00139	0.03536	9.11
Salt blanched	Lewis	0.98675	0.00196	0.04424	10.56
	Page	0.99362	0.00122	0.03325	14.49
	Two term exponential	0.99721	0.00053	0.02192	8.40
	Diffusion approximation	0.99940	0.00013	0.01024	6.43
	Mindili <i>et al</i>	0.99033	0.00237	0.04071	8.59

Among the seven models tested four of them achieved  $R^2$  value of  $\ge 0.99373$  (Table 7). In addition to zone II, the Diffusion approximation model scored a highest  $R^2$  0.99844 for zone III control and 0.99920 for citric acid treatment at the same zone (Appendix Table 3). Furthermore, the Logarithmic model fitted for pumpkin slice dried at zone I with pretreatments of salt blanched and salt (2%) and recorded  $R^2$  0.99856 of 0.99656 respectively. Two term exponential fitted for three treatment combination (Zone I-Control, Zone III-Salt (2%), Zone III- Salt Blanched (Table 7). The Henderson and Babis model also fitted to predict the moisture ratio of pumpkin dried at zone I with citric acid pretreatment and achieved  $R^2$ ,  $X^2$  and RMSE value of 0.99717, 0.00067 and 0.02511 respectively. Ergin *et al.* (2016) report  $R^2$ ,  $X^2$  and RMSE, 0.997, 0.0004,0.018 for Two-term Exponential, 0.993, 0.0010 and 0.026 for logarithmic and 0.993, 0.0009 and 0.027 for Henderson and Babis models respectively for freeze dried kiwi slices.

# **4.3. Effect of Solar Tunnel Dryer Zones and Pretreatments on Physical and Functional Properties**

The interaction effect of solar tunnel dryer zone and pretreatments showed significant effect on important physical and functional properties like; shrinkage ratio, rehydration ratio, bulk density, water hydration capacity, oil absorption capacity, water solubility index and water activity as given in Table 8.

#### 4.3.1. Shrinkage ratio (SR)

Shrinkage of agricultural products is one of the unavoidable physical change of dried food products due to loss of moisture and mainly change of physical properties of the products. SR of dehydrated product is an important parameter that determines the packaging requirement as well as consumer perception. A product with lower SR value is better than higher one since the former shows relatively less change from the original product volume after drying as compared to the later one.

As indicated in Table 5 and 8, with an increase in drying medium temperature and decrease of RH from zone I to zone III, the shrinkage ratio increased. This implied that, with an increase in drying potential of the drying medium, more moisture is moved out of the samples and increased the SR. The shrinkage of dried product which depend on structural deformation during dehydration process; is highly affected by drying air temperature, relative humidity and velocity depends on the product nature (Mahiuddin *et al.*, 2018). The cell wall is mostly composed of solid material, but a very small amount of water is present in micro capillaries. This water is referred to as cell wall water. Migration of free water has little effect on material shrinkage; however, transport of intracellular and cell wall water strongly affects the material shrinkage during drying (Onwude *et al.*, 2016). During drying, transport of intracellular water causes cellular shrinkage, pore formation, and collapse of the cell. Finally, overall food tissue is deformed due to the migration of cell wall water (Joardder *et al.*, 2015).

ANOVA result (Appendix Table 9) shows that the interaction of zone of dryer and pretreatments had signifcant effect on shrinkage ratio (P<0.001). When zones of dryer are compared, the SR increased from zone I to III. This might be as indicated in Table 5, with an increase in drying medium temperature, decrease in RH in the dryer, the moisture removal capacity of the medium increased to reduce the dried sample volume. Pre-treatments also result in significant effect on SR in regardless of zone of dryer. Control samples were the less affected in terms of SR as compared with samples subjected to pre-treatments in zone I and II (Table 8). However, there was no signifcant (P $\leq$ 0.05) effects were observed among the control, citric acid, and salt pre-treated samples except significant effect of salt balched sample in zone III (Table 8). The variation among pre-treatments might be because of less impact of pretreatments on the control to modify physical and chemcial properties of the sample.

Results in the present study showed that, drying of pumpkin slice at high temperature and salt blanching cause an increase in shrinkage percentage. This was supported by Seifu *et al.* (2018) for onion powder who observed an increase of shrinkage ratio as drying temperature increased. In contrast Wang and Brennan (1995) found that shrinkage of potato tissue at higher temperature ( $70^{\circ}$ C) was lower than shrinkage at low temperature ( $40^{\circ}$ C). This is may be due to the case-hardening effect that controls the transport of moisture, which ultimately controls material shrinkage.

Further, the increase of shrinkage ratio for salt blanched sample may be due to the fact that blanching lead to cell wall disruption and fast removal of water from internal tissue. Inaddition, blanching with salt solution may prevent the occurrence of case hardening, since case hardening is the main cause of low shrinkage in dried product. Moreover, the removal of water during drying of biological products leads to cellular structural modifications due to reduced tension inside the cells. This phenomenon causes alterations in the shape and dimension of products including volume shrinkage (Brasiello *et al.*, 2017).

#### 4.3.2. Rehydration ratio (RR)

Rehydration is a process of refreshing the dried material in water prior to consumption. Rehydration ratio (RR) is considered as one of the important quality attribute for dried products. The rehydration characteristics indicate the physical and chemical changes during drying as influenced by processing conditions, sample pretreatment and composition (Feng and Tang, 1998). Though, Consumers give first impression for color and volume of dehydrated products, food technologist should consider the RR of dried products as well.

In the present study, rehydration ratio of pumpkin slice was affected by both condition of drying medium (temperature and RH) and pretreatments. But no interaction effect was observed (Appendix Table 9). As indicated in Table 8, RR was increased as air temperature increased and RH decreased, this may associate to shrinkage ratio of the product, the higher the shrinkage ratio result improved in RR. Interms of pretreatments, there was no significant difference at

zone I. This implies that RR of pumpkin was influenced by Temperature and RH than pretreatments. However, at zone II there was no significant different ( $P \le 0.05$ ) between control (6.08±0.3) and citric acid (6.16±0.01) treated samples but these two values differ significantly with the salt and salt blanched pretreated values.

As given in Table RR of pumpkin slice found between 5.91 and 7.06 which is higher than the value of papaya  $4.1\pm0.01$  and mango powder 3.93 dried in solar tunnel dryer (60 °C) as reported by Ghan *et al.* (2014). Furthermore, at zone III, the maximum values of rehydration ratio (7.1±0.01) was recorded for salt blanched pumpkin slice and the minimum was for citric acid (6.43). This may be that high air temperature and low RH combined with salt blanched result in retained cell integrity.

As noted from the result rehydration ratio increased with the increase in drying temperature and application of predrying treatments such salt, citric acid and blanching in hot water containing salt solution. This result was in contradict with reported by Mehta *et al.* (2017) who observed maximum rehydration ratio was obtained for unblanched bitter guard and capsicum. Generally pumpkin slice in this study shows high rehydration ratio with relative other vegetables. For instance, Abdu and Ghanem, (2011) report rehydration ratio of convective and refractance window dried tomato from 2.95 to 3.24 which is lower than the result of this study.

#### 4.3.3. Bulk Density (BD)

Bulk density (BD) is a measure of heaviness or lightness of a powder sample. Both high and low bulk density is required depend on the purpose. For instance, higher bulk density is desirable for the greater ease of dispersibility and reduction of paste thickness during food preparation. Whereas low BD is recommended for product formulation especially for infant weaning.BD of powder affected by drying temperature and physical changes during drying. It is directly related to the shrinkage ratio of dried product. Since both depends on the volume change.

ANOVA table showed, the interaction effect of zone and pretreatment (P<0.004) was significant on the bulk density of pumpkin powder. Table 8 revealed that, the value of bulk density was found in the range of 0.52 to 0.78 (g/mL). This result is slightly lower than the

report of Roongruangsri and Bronlund (2015) who found bulk density of hot air dried pumpkin powder from 0.62 to 0.91(g/mL). However, the value was higher than to bulk density of freez dried (0.33(g/mL)) and hot air dried (0.59 (g/mL)) pumpkin flour as reported by Que *et al.* (2008).

Zones	Pretreat	Slice		Powder			
	ment						
		SR(%)	RR(-)	BD(g/L)	WHC(mL/	(g) OAC(m	$L/g$ ) $a_w$
Zone I	С	$32.58 \pm 0.05^{i}$	5.91±03 <sup>c</sup>	$0.52 \pm 0.006^{g}$	$4.29 \pm 0.04^{h}$	$1.0\pm0.05^{i}$	0.291±0.001 <sup>a</sup>
	CA	$34.6 \pm 0.3^{h}$	5.96±0.01°	$0.68 \pm 0.003^{e}$	$5.55 \pm 0.04^{de}$	$1.3{\pm}0.01^{gf}$	$0.29{\pm}0.0007^{a}$
	S	$41.04 \pm 0.03^{f}$	$6.08 \pm 0.07^{\circ}$	$0.67 \pm 0.009^{e}$	4.69±0.03 <sup>g</sup>	$2.1 \pm 0.06^{\circ}$	$0.274 \pm 0.0008^{cd}$
	SB	46.33±0.1 <sup>e</sup>	$6.15 \pm 0.07^{\circ}$	$0.70 \pm 0.01^{de}$	$5.51{\pm}0.08^{de}$	$1.6 \pm 0.03^{ef}$	$0.282 \pm 0.001^{b}$
Zone II	С	47.09±0.5 de	6.08±0.3°	$0.53 \pm 0.003^{fg}$	$5.12 \pm 0.03^{f}$	2.4±0.03 <sup>b</sup>	$0.263 \pm 0.0006^{ef}$
	CA	37.26±0.3 <sup>g</sup>	6.16±0.01 <sup>c</sup>	$0.72 \pm 0.006^{cd}$	$5.85 \pm 0.04^{\circ}$	$1.7 \pm 0.03^{de}$	$0.267 \pm 0.002^{cde}$
	S	$48.08 \pm 0.4^d$	$6.32 \pm 0.03^{bc}$	$0.69 \pm 0.007^{de}$	$5.70{\pm}~0.02^{cd}$	$1.8 \pm 0.02^{d}$	$0.274 \pm 0.0008^{cd}$
	SB	$54.51{\pm}0.02^{b}$	$7.02{\pm}0.08^{ab}$	$0.74 {\pm} 0.001^{bc}$	$5.81 \pm 0.02^{\circ}$	$2.5 \pm 0.03^{b}$	$0.266 \pm 0.002^{de}$
			1	C	C		
Zone III	С	$52.22 \pm 0.3^{\circ}$	$6.61 \pm 0.02^{abc}$	$0.56 \pm 0.003^{t}$	$5.34 \pm 0.07^{\text{ef}}$	2.5±0.03 <sup>b</sup>	$0.241 \pm 0.002^{g}$
	CA	$51.93 \pm 0.6^{\circ}$	$6.43 \pm 0.02^{abc}$	$0.74 \pm 0.006^{bc}$	$6.15 \pm 0.06^{b}$	$1.1\pm h0.03^{1}$	$0.255 \pm 0.001^{ m f}$
	S	$52.65 \pm 0.2^{\circ}$	$6.62 \pm 0.3^{abc}$	$0.75 \pm 0.003^{ab}$	$6.22 \pm 0.03^{ab}$	$3.6 \pm 0.03^{a}$	$0.257 \pm 0.003^{f}$
	SB	$65.06 \pm 0.9^{a}$	7.06±0.01 <sup>a</sup>	$0.78 {\pm} 0.002^{a}$	$6.41 \pm 0.009^{a}$	$1.5 \pm 0.02^{fg}$	$0.227{\pm}0.002^{h}$
	CV(%)	1.16	2.56	1.34	1.12	3.08	0.92

Table 8: Mean of shrinkage ratio (SR) in, Rehydration ratio (RR), bulk density (BD), water hydration capacity (WHC), water solubility (WSI), oil absorption capacity(OAC) and water activity (a<sub>w</sub>) obtained from the zones and pretreatments

Values expressed are mean values of three replicates  $\pm$ standard error. All mean scores, bearing different superscript in columns differ significantly (P $\leq$ 0.05).C=Control, S=Salt treated, SB=Salt blanched, CA=Citric acid treated

## 4.3.4. Water hydration capacity (WHC)

Water absorption capacity (WHC) gives an indication of the amount of water available for gelatinization. It is a useful indication of whether powder or isolates can be incorporated into aqueous food formulations (Udensi, 2006). Drying can diminish the osmotic properties of cell walls. Therefore, increase in water absorption and volume occurs due to the swelling of hydrophilic materials such as starch, cellulose, and pectin materials (Singh, *et al.*, 2006). Jayaraman *et al.* (1990) pointed out those pretreatments such as blanching in water, sulphiting and salting prior to drying, increased rehydration capacity of dried products.

The interaction effect of zone and pretreatments were significant (P $\leq$ 0.001) on water hydration capacity of pumpkin powder. According to Table 8, the water absorption capacity of pumpkin powder was found in the range of 4.29 (mL/g) and 6.41 (mL/g) which is higher than 3.07 (g water/g) reported by Sevilla *et al.* (2009) for hot air dried (70<sup>o</sup>C) course pumpkin powder. The water absorption capacity (mL/g) of pumpkin powder dried at zone II showed no significant different (P $\leq$ 0.05) between citric acid and salt blanched treated samples where the lowest value observed for control sample (Table 8). The same trend was observed at zone II (Table 8). However, at zone III, there was a significant different (P $\leq$ 0.05) among the values of each pretreatment, where the maximum value (6.41 (mL/g)) obtained for salt blanched sample and minimum (5.34 (mL/g)) for control sample (Table 8).

From the result of this study there was the increase of water absorption capacity as move from zone I to zone III. This is supported by Seifu *et al.* (2018) who observed the increase of water absorption capacity as drying temperature increase from 50 to 90<sup>o</sup>C. However, the result was in contradicted with the value  $2.60 \pm 0.08$  (mL/g) reported by Que, *et al.* (2008) on pumpkin cube dried at air temperature of 70<sup>o</sup>C. The probable reason that pumpkin powder show high water absorption capacity may be due to its good hygroscopic behavior. Thus, food materials having high WHC can act as a functional ingredient in baked products. In general, the result of this study showed that water absorption capacity of pumpkin powder significantly affected by zone and pre drying treatments such as citric acid solution salt blanching and salt solution.

#### **4.3.5.** Oil absorption capacity (OAC)

Oil absorption capacity (OAC) is an important functional property for food product ingredients because it improves flavor retention and the sensation produced in the mouth (Mart'inez-Flores *et al.*, 2006). Ingredient with high OAC play an important functional role in stabilizing food systems with high fat content, improve viscosity and texture of formulated foods and they can act as emulsifiers (Aydin and Gocmen, 2014). The interaction effect of zone and pretreatments was significant on oil absorption capacity (P $\leq$ 0.001). As mentioned in (Table 8) pumpkin powder which dried at zone I and pretreated with salt scored the maximum (2.1 (g oil/g dried sample)) value while the minimum value (1.0 (g oil/g dried sample)) scored for control sample. At zone II there was no significant difference observed between the value of control (2.4 (g oil/g dried sample)) and salt blanched (2.5 (g oil/g dried sample)) the same was true between

salt and citric acid treated (Table 8). Moreover, the maximum and minimum value of OAC (g oil/g dried sample) of pumpkin powder at zone III was obtained for salt (3.6) and citric acid (1) pretreatment respectively (Table 8). Furthermore, without considering pretreatments, the highest OAC (g oil/g dried sample) was observed at zone III whereas the lowest at zone II showing this result is contradicting with values 3.87, 3.97 and 4.42 (g oil/g dried sample), at 70 ,60 and 50<sup>o</sup>C as Roongruangsri and Bronlund, (2015). However, these results are in a good agreement with finding by Aydin and Gocmen, (2015) for freez dried and metabisulphite treated.

#### **4.3.6.** Water activity (a<sub>w</sub>)

Water activity has long been considered as one of the most important quality factors for dried products especially for long term storage with appropriate packaging material (Quek *et al.*, 2007). The values of water activity found in range of 0.20 and 0.40 ensure the stability of the product against browning reactions, lipid oxidation, auto-oxidation and enzymatic activity (Dirim and Caliskan, 2012). According to (Table 8) the water activity value of pumpkin powder was found between 0.291 and 0.227. The pumpkin powder dried at zone I had a water activity 0.274, 0.282,0.29 and 0.291 for salt (2%), salt blanched, citric acid and control pretreatments respectively (Table 8). However, these values were slightly higher than to the rest of two zones. For instance, the minimum water activity at zone I (0.274) was the maximum value at zone II in both case for salt (2%) treatment (Table 8). Furthermore, water activity of pumpkin powder at zone III was found between 0.227 and 0.257 for salt blanched and salt (2%) pretreatments (Table 8).

Shelf life of dehydrated products is highly dependent on water activity values. Lower value is advisable because it inhibit microbial growth, biochemical activities, and no enzymatic browning and lipid oxidation. Generally, water activity of pumpkin powder showed increment as moved from zone I to zone III which directly related to that high air temperature that might have removed the free water since there is fast drying condition and no reabsorption of water. Moreover, all the recorded values prove that product having water activity of less than 0.3 also have moisture content of less than 8%. From the result, pumpkin powder will be safe interms of microbial contamination, browning reactions, auto-oxidation and enzymatic activity since the values of water activity were within the range of recommended value. However, there may

be lipid oxidation and browning reaction. Due to the fact, the result shows lower fat content and the pretreatment applied before drying; it will not be that much a problem.

# 4.4. Effect of Solar Tunnel Dryer Zones and Pretreatments on Some Chemical Properties and Proximate Composition of Pumpkin Powder

#### 4.4.1. Total soluble solid (TSS)

The ANOVA table (P $\leq$ 0.001) shows the interaction effect of zone and pretreatment were highly significant on TSS of pumpkin powder (Appendix Table 4). As indicated in table 8, the result of TSS were found between 7.62 and 11.30. TSS of pumpkin powder for control samples were obtained 7.62,10.12 and 10.14±0.03 for zone I, III and II respectively, showing no statistical different between zone II and III (Table 9). Whereas the citric acid pretreatment exhibited the minimum value (10.2) at zone I and showed an increase at zone II (11.2 and III (11.30) with no statistical different (Table 9). Moreover, salt blanched pumpkin powder also experienced an increase in TSS from 7.69 to 8.92 significantly (P $\leq$ 0.05) as moving from zone I to III (Table 9). Among all pretreatments salt (2%) showed a significant increase (P $\leq$ 0.05) in TSS from zone I to III.

This study was in a conformity with result of Teferi *et al.* (2013) who observed the maximum TSS for salt treated and minimum for untreated different accession of pumpkin powder. In general, the pumpkin powder treated with salt (2%) and citric acid showed relatively higher TSS. This is related to the fact that one of the function of salt pretreatment is to improve the TSS of dried product by preventing the desolation of soluble components.

## 4.4.2. pH

The pH is important parmeter to assess the ability of a microorganism to grow in a specific food and decide the food to store at ambient or refrigerated condition (AOAC, 2012). The pH of dried product is influenced by drying medium temperature and relative humidity as well as air velocity since this conditions affect drying time. The higher the temperature and air velocity and lower RH lead to fast drying so that no chance of oxidation of macromolecules.

The pH of pumpkin powder was significantly affected by zones of dryer and pretreatments ( $P \le 0.001$ ). The values generally found in a range of 4.62 to 6.1 (Table 9). Further, the result

revealed that the pH of pumpkin powder decreased as drying condition (temperature and relative humidity) decreased; this may be associated with the increase in titratable acidity. The pH of pumpkin powder pretreated with citric acid shows relatively lower value, 4.62, 4.8, 4.9 at zone I, II and III respectively compared to others pretreatments (Table 9). These may be due to the fact that citric acid has the acidification effect. In all zones salt treated pumpkin powder showed maximum pH, this may be that soaking in salt solution was enough to arrest activity of microorganisms and enzymes that contribute to the conversation of macronutrients in to weak acids.

The decreased in pH for citric acid treated pumpkin powder is in good agreement with Fana *et al.* (2015), who work on orange fleshed sweat potato flour in which citric acid treated flour show low pH or high acidity value. Generally, the pH value of pumpkin powder in the current study show an increase from zone I to zone III with corresponding pretreatments. This phenomenon can have related with, at low temperature (zone I) with slow drying condition, convertion of starch in to weak acid appeared so that the acidity of product increased.

#### 4.4.3. Titratable acidity (TA)

Titratable Acidity (TA) is an important chemical parameter which strongly related to aroma and flavor of the food. Citric acid is the most dominant acid present in pumpkin and it is significantly decisive factor in consumer acceptance of the processed products since a high value associates to a satisfactory acidic flavor (Joseph *et al.*, 2016; Yusife *et al.*, 2017). High acidity may have allergic effect to some individuals. The TA of dried food is influenced by drying condition (temperature and relative humidity) drying time and pre-drying treatments applied.

The (P $\leq$ 0.001) showed that TA of pumpkin powder significantly different from the fresh value. Increased of TA after drying is related to the conversion of macronutrients in to weak acids. ANOVA (P $\leq$ 0.001) table also showed that the interaction effect of zones and pretreatments was highly significant on TA (%citric acid/g of sample) (Appendix Table 10). TA values at zone I, 1.8,2.09, 2.10 and 2.68 % were observed for, l, salt (2%), control, salt blanched and citric acid pretreatments respectively, showing the maximum for citric acid pretreatment (Table 9). This may be that citric acid treatment has acidification effect on the product. However, TA value at zone II slightly lower as compared to zone I. Furthermore, TA values 1.1 ,1.6, 1.9 and 2.3 for salt (2%), control, salt blanche and citric acid pretreatments respectively at zone III, showed significant difference ( $P \le 0.05$ ) (Table 9).

The decrease in TA moving from zone I to zone III was comparable with convective drying of onion powder as reported by Seifu *et al.* (2017). In addition, the TA value in this study was near to values reported by Workneh *et al.* (2014) where 2.4% for blanched oven dried and 1.7% for pumpkin slice dipped in 10% salt solution. However, contradict with Purkayastha *et al.* (2013) who observed an increased in the titratable acidity that as drying temperature increased in dried tomato. The value of TA is inversely related to the value of pH as confirmed in present study. In general, this study confirmed that concentration of titratable acidity increase as drying time increase and air temperature decrease, since prolonged drying time causes conversion of macronutrient into weak acids (Falade and Olugbuyi, 2010).

#### 4.4.4. Moisture content

Moisture content of the dried product is an indicator of efficiency of dehydration. It is directly related to drying method, drying time and conditions of storage (Sathiya, 2016). The moisture content of the fresh and dried pumpkin under study are presented in (Table 9). According to (Table 9), (P $\leq$ 0.05) shows the interaction effect of zone and pretreatments was highly significant on moisture content (%) of the pumpkin powder. Combination of predrying treatment and zone lead to fast reduction of moisture content of fresh (90.63 %) to pumpkin powder (6.4 - 8.2 %) as indicated in Appendix Table 7 and Table 9 respectively. However, moisture content of pumpkin powder was slightly lower than results reported by Sathiya *et al.*, (2016), which was 6.40 % for untreated and 13.8 % for steam blanched both dried at 55± 2<sup>o</sup>C.

In details moisture content at zone I was statistical different ( $P \le 0.05$ ) for the given pretreatments bearing the maximum value for control  $8.2\pm0.03\%$  and minimum for salt blanched (6.6%) (Table 9). At zone II, also the values were significantly different ( $P \le 0.05$ ) that found in the range of 7.1 to 7.8 % (Table 9). Moreover, at zone III there was no statistical different between the values of control and salt treated samples. From the given pretreatments only the control one show a decrease in moisture content 8.2, 7.8 and 7.0 % for zone I, II &III respectively (Table 9). Generally, the moisture content of pumpkin powder found in between 5.47 and 10.21 % as reported by Roongruangsri and Bronlund (2016) for hot air dried pumpkin powder.

#### 4.4.5. Total ash

Ash refers to the inorganic residue remaining after either ignition or complete oxidation of organic matter in a food sample. Determining the ash content of a food is part of proximate analysis for nutritional evaluation and it is an important quality attribute for some food ingredients (Ismail, 2017). The interaction effect of zone and pretreatment was highly significant on percentage of total ash of the pumpkin powder ( $P \le 0.05$ ). The result found between 4.7 and 6.1 % (Table 9). These values were less than to the value 7.31 % of eggplant flour dried in tunnel dryer and 6.47 % dried in oven as reported by Rodriguez-Jimenez *et al.* (2018). As indicated in (Table 9), citric acid treated pumpkin powder showing a decrease of total ash 6.2 , 5.8 and 5.1 % for zone I, II &III respectively. Excluding control and salt (2%) pretreatments, this pattern also works for salt blanched treated sample (Table 9). This result was also less than to the outcome of total ash 12.56 , 12.61 , 12.64 , 12.97 % for freez dried, metabisulphite freez dried, oven dried and metabisulphite oven dried pumpkin flour respectively as reported.

#### 4.4.7. Crude fiber

Dietary fiber has recently gained much importance since it can reduce the incidence of cardiovascular diseases and certain digestive diseases. The World Health Organization (WHO) has recommended an intake of 22-23 kg of fiber for every 1000 Kcal of diet (Kanwar & Shah, 1997). In current study zone had no significant effect ( $P \le 0.05$ ) on crude fiber. However, pretreatment was highly significant ( $P \le 0.05$ ). Based on this, the result was found in a range between 4.7±0.07% and 5.0% as shown (Table 9). These values were less than study performed by Sathiya *et al.* (2016), where they found crude fiber between 6.58 and 12.to 011% while the former was untreated and the latter hot water blanching, followed by dipping in Potassium meta bisulphite of pumpkin flour. In more detail, crude fiber content of control (4.91%) and citric acid treated (4.88) at zone I, did not show significant different ( $P \le 0.05$ ) the same was true between salt and salt blanched samples (Table 9).

## 4.4.8. Crude protein

The percentage of crude protein of pumpkin powder for the three zones and four pretreatments is given below under Table 9. The values were found between 2.43% and 4.23 % (Table 16). According to (Table 9), crude protein values of pumpkin powder at zone I, observed as 2.43, 2.94, 3.23, 3.7 % for control, citric acid, salt blanched and salt (2%) pretreatments respectively, showing the maximum value for salt pretreatment, were significantly different ((P $\leq$ 0.05). Salt pretreated sample show maximum value at zone II (4.23 %) and minimum at zone III (3.45 %) with significant different (P $\leq$ 0.05) the same was true for control sample (Table 9).
Zone	Pretreatm ent	TSS( <sup>0</sup> B)	pH	TA(%citric acid)	Moisture content(%)	Ash(%)	Protein(%)	Fiber(%)
Zone I	С	$7.62 \pm 0.006^{f}$	5.6±0.02 <sup>e</sup>	2.09±00.04 <sup>d</sup>	8.22±0.03 <sup>a</sup>	5.90±0.06 <sup>b</sup>	3.23±0.01 <sup>e</sup>	4.91±0.03 <sup>cd</sup>
	CA	$10.20 \pm 0.03^{b}$	$4.62{\pm}0.01^{h}$	$2.68{\pm}0.02^{a}$	$6.89 \pm 0.02^{g}$	$6.14{\pm}0.006^{a}$	$2.43 \pm 0.02^{g}$	$4.88{\pm}0.1^{cd}$
	S	9.22+0.08 <sup>c</sup>	$5.9{\pm}0.05^{bc}$	$1.8{\pm}0.02^{ef}$	$7.24{\pm}0.05^{de}$	$5.00\pm0.03^{g}$	$3.70 \pm 0.07^{b}$	$5.03{\pm}0.2^{a}$
	SB	$7.69{\pm}0.04^{\rm f}$	$5.3{\pm}0.03^{\rm f}$	$2.1 \pm 0.04^{d}$	$6.65 {\pm} 0.02^{h}$	$5.72{\pm}0.05^{bcd}$	$2.94{\pm}0.03^{f}$	$5.04{\pm}0.04^{a}$
Zone II	С	10.14±0.03 <sup>b</sup>	5.7±0.04 <sup>de</sup>	$1.40{\pm}0.008^{h}$	7.75±0.02 <sup>b</sup>	$5.62 \pm .05^{cd}$	3.71±0.02 <sup>b</sup>	$4.84{\pm}0.4^{d}$
	CA	11.2±0.02 <sup>a</sup>	$4.8{\pm}0.02^{\text{g}}$	$2.50{\pm}0.003^{b}$	$7.40{\pm}0.06^{cd}$	$5.79{\pm}0.03^{bc}$	$3.59 \pm 0.01^{bc}$	$4.89{\pm}0.1^{cd}$
	S	$10.24{\pm}0.04^{b}$	$6.0{\pm}0.01^{ab}$	$1.3 \pm 0.03^{h}$	$7.14{\pm}0.08^{ef}$	5.6±0.04de	$4.23{\pm}0.05^{a}$	$5.98{\pm}0.09^{ab}$
	SB	$8.21 \pm 0.02^{e}$	$5.39{\pm}0.009^{\rm f}$	$1.7{\pm}0.05^{fg}$	$7.57 \pm 0.02^{bc}$	$5.42{\pm}0.008^{ef}$	$2.98{\pm}0.02^{\rm f}$	$5.96{\pm}0.2^{ab}$
Zone III	С	$10.12 \pm 0.08^{b}$	5.8±0.01 <sup>cd</sup>	1.6±0.05 <sup>g</sup>	$7.00 \pm 0.04^{fg}$	5.57±0.01 <sup>de</sup>	$2.52 \pm 0.02^{g}$	4.69±0.07 <sup>e</sup>
	CA	11.3±0.03 <sup>a</sup>	$4.9{\pm}0.02^{\text{g}}$	$2.3 \pm 0.06^{\circ}$	$6.76{\pm}0.04^{gh}$	$5.06{\pm}0.04^{g}$	$3.21 \pm 0.01^{e}$	$4.89{\pm}0.2^{cd}$
	S	11.13±0.06 <sup>a</sup>	$6.1 \pm 0.03^{a}$	$1.1{\pm}0.04^{i}$	$6.96\pm0.04f^g$	$4.70 \pm 0.02^{h}$	$3.45 \pm 0.02^d$	$4.87 \pm 0.2^{bc}$
	SB	$8.92{\pm}0.03^d$	$5.8{\pm}0.02^{cd}$	1.9±0.02 <sup>e</sup>	$6.38{\pm}0.04^i$	$5.31{\pm}0.01^{ef}$	3.53±0.03 <sup>cd</sup>	$4.87{\pm}0.2^{cd}$
	Fresh	6.72±0.04 (P<0.001)	6.54±0.01 (P<0.001)	0.41±0.03 (P<0.001)	ND	ND	ND	ND
	CV(%)	0.63	0.74	2.79	1.02	1.00	1.20	6.42

Table 9: Mean of chemical properties and proximate of pumpkin powder obtained from combination of zone and pretreatments

Values expressed are mean values of three replicates  $\pm$  standard error. All mean scores, bearing different superscript in columns differ significantly (P $\leq$ 0.05) The p values that show the significance of the fresh value with maximum value of powder are shown in bracket;;C=control, S=Salt treated, SB=Salt blanched, CA=citric acid treated,

However citric acid pretreated pumpkin powder obtained its maximum value (3.59%) at zone II and minimum (2.43%) at zone I (Table 9). Moreover, salt blanched pumpkin powder attained its maximum value at zone III (3.53) but there was no significant different between the values of zone I and II (Table 9). The finding of this study was contradicted with report by Aydin and duigu (2015), in which they report that different pretreatments were had no significant effect on crude protein. In addition, these crude protein values were similar with those obtained by Lydia *et al.* (2017) who studied the effect of pretreatments and drying methods on some qualities of dried mango fruit.

# 4.5. Effect of Solar Tunnel Dryer Zones and Pretreatments on Selected Bioactive Components of Pumpkin Powder

#### **4.5.1.** Total phenolic content (TPC)

Phenolic compounds are currently receiving much attention because of their beneficial health effects related to their antioxidant, anti-inflammatory, cardio protective, cancer chemo preventive and neuroprotective properties (Landete, 2013). Polyphenols are a large group of chemical substances found in plants, characterized by the presence of more than one phenol, formed by the synthesis of derivatives of phenylalanine with acetic acid (Kopec *et al.*, 2013).

ANOVA table showed that the dryer zones and pretreatments were highly significance (P $\leq$ 0.001) on total phenolic content (TPC) of pumpkin powder as indicated in Appendix Table 12. The result was found in the range of 99.59 to 286.43 (mg GAE/100g) (Table 10). The values recorded at zone I were ,99.59 9,152.40 ,164.63 and 182.52 (mg GAE/100g), significantly different (P $\leq$ 0.05) for control, salt blanched, salt and citric acid pretreatments respectively, showing maximum value for citric acid (Table 10). However, at zone II, salt pretreatment achieved the maximum TPC (286.43 (mg GAE/100g) followed by citric acid (241.07 (mg GAE /100g)). Furthermore, control pumpkin powder exhibited its minimum value (131.13 (mg GAE/100g) at zone III compared to other two zones while salt and salt blanched retained better than zone I.

Regardless of pretreatment the TPC showed maximum retention at zone III, followed by zone III. This indicate that the loss in TPC is more at lower temperature and high RH than at increased

air temperature and low RH. In other word low temperature and high RH resulted prolonged drying time that may allowed oxidation of phenolic contents with protein and other components of the product.

The result of present study was comparable with other works, For instance, Dirim and Çalışkan (2012) report total phenolic of 218.47 (mg GAE/100g) for freez dried pumpkin puree powder which is within the range of present study. However, the determined values are much higher than 0.39 mg GAE/ g for freeze dried pumpkin flour given by Que *et. al.* (2008). Moreover, the outcome of this study showed lower value than previous findings of Aydin *et al.* (2014) who report total phenolic content 114 and 899 (mg GAE/100g) for freez dried pumpkin powder (- $65^{0}$ C) and metabisulphite treated-oven dried ( $60^{0}$ C) respectively.

Comparing the total phenolic content of pumpkin powder with the fresh value; the highest lose was obtained at zone I for control (68.36 %) sample, whereas the lowest loss was at zone II salt treated (8.98 %). In general, Pumpkin dried at zone I experienced more loss in total phenolic content in relative to other two zones and control sample from pretreated. Adeleta *et al.* (2018), estimate the highest (91%) reduction of TPC dried at 70°C and untreated whereas the lowest (26%) for pumpkin slice dried at 55°C treated that is higher lose compared to current study. The different may arise from duration of drying since they use 6 mm thickness. This result disagrees with the finding of Bushra *et al.* (2012) who observed loss of total phenolic content 44% in oven dried (80°C) and 20% in air dried (average temperature  $30^{\circ}$ C) for apple. In contrast Mariane *et al.* (2015) observe a drastic increase (81.4 - 96.3%) total phenolic content of dehydrated carrot, eggplant and tomato.

Zone	Pretreat	Total Phenolic mg	β-	Ascorbic acid	Antioxidant activity	
	ment	(GAE/100g d.w)	carotene(mg/100g d.w)	(mg/100g d.w)	% Inhibition	IC <sub>50</sub>
zone I	С	99.59±3.9 <sup>e</sup>	$25.45 \pm 0.8^{i}$	$12.74 \pm 0.07^{hi}$	$44.0\pm0.45^{i}$	5.20±0.2 <sup>b</sup>
	CA	182.52±4.6 <sup>bcd</sup>	38.96±0.7 <sup>e</sup>	17.35±0.02 <sup>e</sup>	$59.6{\pm}0.54^{\rm ef}$	3.16±0.5 <sup>de</sup>
	S	$164.63 \pm 5.5^{cd}$	$42.50\pm0.1^d$	$22.77{\pm}0.2^{\mathrm{b}}$	$72.40 \pm 0.5^{b}$	$2.21{\pm}0.1^{fg}$
	SB	152.40±6.7 <sup>cde</sup>	$31.43 \pm 0.2^{g}$	$18.34 \pm 0.2^{d}$	$66.9{\pm}0.26^{d}$	$2.61 \pm 0.1^{ef}$
zone II	С	237.36±4.6 <sup>ab</sup>	33.08±0.6 <sup>g</sup>	14.61 ±0.2 <sup>g</sup>	57.0±0.1 <sup>f</sup>	3.42±0.3 <sup>d</sup>
	CA	241.07±5.1 <sup>bc</sup>	$47.71 \pm 0.2^{b}$	18.93±0.1 <sup>cd</sup>	61.6±0.12 <sup>e</sup>	$2.62{\pm}0.08^{ef}$
	S	$286.43 \pm 4.8^{a}$	52.36±0.2 <sup>a</sup>	24.15+0.1ª	$79.60{\pm}0.28^{a}$	$1.70 \pm 0.01^{g}$
	SB	208.00±4.9 <sup>bc</sup>	$35.60{\pm}0.1^{\rm f}$	19.57 ±0.07°	70.6±0.36 <sup>c</sup>	$2.30{\pm}0.04^{fg}$
zone	С	131.13±3.0 <sup>de</sup>	29.27±0.6 <sup>h</sup>	$12.17 \pm 0.02^{i}$	$38.8 \pm 0.52^{j}$	6.12±0.2 <sup>a</sup>
111	CA	$207.41 \pm 3.5^{bc}$	44.70±0.3°	$13.11 \pm 0.2^{h}$	$48.0{\pm}0.65^{\rm h}$	$4.47 \pm 0.2^{bc}$
	S	$201.37{\pm}5.1^{bc}$	51.33±0.1ª	$15.33 \pm 0.1^{f}$	$53.5\pm0.12^{g}$	$3.67{\pm}0.03^d$
	SB	177.60±6.9 <sup>bcd</sup>	$42.40 \pm 0.2^{d}$	14.18±0.02 <sup>g</sup>	$52.5\pm0.09^{g}$	$3.72{\pm}0.08^{c_d}$
	Fresh	314.72±3.3(P<0.0 07)	63.4±0.06 (P<0.00)	33.86±0.08 (P<0.00)	82.67±0.18 (P<0.031)	1.15±0.03(P <0.038)
	CV(%)	4.56	1.52	1.2	1.60	6.50

Table 10: Mean of Total Phenolic,  $\beta$ -carotene, Ascorbic acid and antioxidant activity of pumpkin powder obtained from combination of zone and pretreatments

Values expressed are mean values of three replicates  $\pm$  standard error. All mean scores, bearing different superscript in columns differ significantly (P $\leq 0.05$ ). The P values that show the significance of the fresh value with maximum value of powder are shown in bracket C=Control, S=Salt treated, SB=Salt blanched, CA=citric acid treated,

### 4.5.2. Beta-carotene

β-carotene, is a fat-soluble pigment, lipophilic radical scavengers and have a protective function against oxidative damage (Djioua *et al.*, 2009). It is known as a precursor for vitamin A in plant. It is sensitive to heat, oxygen, light, and enzymes (Rawson *et al.*, 2011). The recorded value of beta carotene for pumpkin powder was found between 52.3 (mg/100g) and 25.4 (mg/100g) (Table 10). These values were lower than the findings of Zielinska & Murkowski (2011) who report β-carotine content 96.60 (mg/100g) and 66.85 (mg/100g) of carrot powder at 60<sup>o</sup>C and 90<sup>o</sup>C. Based the data given in Table 10, the  $\beta$ -carotine content of pumpkin powder dried at Zone I were significantly affected by pretreatments (P $\leq$ 0.05) showing maximum value (42.50 (mg/100g) for salt treatment and minimum value (25.45) for control sample. The same trends were observed for the rest of two zone. High loss in beta carotene was observed at zone I (low air temperature and high RH). This may be that long drying time initiate activity of enzymes so that degradation of carotenoid occurs. Further pumpkin dried in zone III (air temperature >60<sup>o</sup>C and relatively low RH) also experienced reduction of beta carotene content when compared to zone III. This may be that some spoilage enzymes activated at high temperature.

The maximum value of  $\beta$ -carotene was recorded for pumpkin dried at zone II for salt treatment. This may be that pretreatments like soaking in salt solution arrest the activity of enzyme that cause degradation of carotenoid and preserve the pigments as well. The outcome of this study showed higher retention of  $\beta$ -carotine when compared to with the previous findings of Sojak (2014), who observe 25.93 % and 29.37% retention on tunnel dried pumpkin flour at 40<sup>0</sup> and 80<sup>0</sup>C respectively. Further report by Prakash *et al.* (2004) observed Maximum  $\beta$ -carotene content was retained in carrots dried by air drying at 50 °C, when compared with the product dried by a microwave oven or a solar cabinet dryer, with the latter presenting the higher loss. Generally, this study show better retention of  $\beta$ -carotene can be obtained by applying pretreatments such as salt and citric acid and at medium drying temperature.

#### 4.5.3. Ascorbic acid

Vitamin C or L-ascorbic acid is an essential exogenous nutrient, mainly available from fruits and vegetables that play an important role in human development and health. This compound is essential for connective tissue formation and maintenance, immune system stimulation, works as antioxidant and enhances iron utilization among other roles (Ndawula *et al.*, 2004). It is also considered as an indicator of food processing quality because of its low stability during thermal treatments (Podsędek, 2007).

The ANOVA (P<0.001) table show that interaction effect of zone and pretreatment was highly significance on ascorbic acid content of pumpkin powder. The values of ascorbic acid of pumpkin powder was found in the range of  $12.17\pm0.01$  -24.15+0.04 (mg/100g d.w) (Table 10). Workneh *et al.* (2014) observed ascorbic acid 3.0-5.1(mg/100g) in pumpkin flour which were

lower than the value of current study. Maximum value (24.15 (mg/100g d.w) of ascorbic acid was obtained at zone II, for salt treated sample. Whereas minimum (12.17 (mg/100g d.w)) for control (untreated) sample at zone III. Ascorbic acid value of dried product is affected by high temperature, oxygen and drying time. Drying of pumpkin at high temperature (>60<sup>o</sup>C) without applying pretreatments can reduce the ascorbic acid content as confirmed by this result.

This study showed that the loss of ascorbic acid during drying of pumpkin was lower than reported by Francisca *et al.* (2015), where they estimated the reduction of ascorbic acid of cucumber 91.3%, 92% and 92.7%, for tunnel drier ( $60^{\circ}$ C), chamber dryer 40°C) and chamber dryer ( $60^{\circ}$ C) respectively. Further, many researchers reported that drying significantly cause the loss of ascorbic acid (Negi and Roy, 2001; Ndawula *et al.*, 2006; Rytel, 2012) which agrees with the findings of the present study. It was also reported that pre-drying treatment significantly reduces the loss of ascorbic acid of other fruits and vegetables during drying (Hiranvarachat, 2011), which was also confirmed by the data presented in this study.

#### 4.5.4. Antioxidant activity

Antioxidant activity is a quality parameter often determined in dried vegetables, being mainly related to the presence of vitamins and polyphenols (Landete, 2013). IC<sub>50</sub> value was determined from the plotted graph of scavenging activity against various concentrations of extracts, which is defined as the efficient concentration of antioxidant necessary to decrease the initial DPPH radical's concentration by 50% and presented together with percent inhibition. The lowest IC<sub>50</sub> indicates the strongest ability of the extracts to act as DPPH radical's scavengers. As obtained from ANOVA (P $\leq$ 0.001) table the interaction effect of zone and pretreatments were highly significance on percent inhibition as well as IC<sub>50</sub> of pumpkin powder.

Based on the ANOVA data given in Table 10, the antioxidant activity was significantly (P $\leq$  0.05) affected by zone and predrying treatments. The maximum (72.40 %) and minimum (44.0 %) percent inhibition values at zone I were observed for salt treatment and control respectively (Table 10). Moreover, at zone II, percent inhibition of pumpkin powder showed a significant different (P $\leq$  0.05) for each pretreatments bearing the maximum percent inhibition for salt treated (79.60 %) followed by salt blanched (70.00%). However pumpkin powder dried at zone III and treated with salt and salt blanched did not show significant difference (P $\leq$  0.05).

The recorded highest value at zone II for salt (2%) treated could be oxidation of bioactive compounds at medium temperature might be lowest as compared with highest (zone III) temperature and salt (2%) treatment might be enough to inactivate the spoilage enzymes. The outcome of this study contradicted with the report of Ghan *et al.* (2014) who observe the increase of antioxidant activity of solar dried mango, papaya and banana. They observe in mango in increases from 68.6 to 86.3 %, in papaya from 64.1 to 80.4 % and in banana from 59.5 to 73.2 % compared to fresh values. Eim *et al.* (2013) evaluated the influence of air drying temperature on the antioxidant activity of carrot, within the range of 40–90<sup>o</sup>C. Decreasing values of antioxidant activity were obtained during drying, this decrease being greater as the drying air temperature increased. In general, the dried pumpkin powder showed a decrease in antioxidant activity from 3.71 to 53.06 % compared to the fresh pumpkin. The maximum values were recorded with the corresponding phenolic, beta carotene and ascorbic acid contents which are considered as a source of antioxidant.

### 5. SUMMARY, CONCLUSION AND RECOMMENDATION

#### 5.1. Summary

Drying of pumpkin can increase its consumption in the form of various value added products. This will be achieved by investigating an affordable and applicable drying methods. Therefore, the present study was conducted to investigate effect of solar tunnel dryer zones and pretreatments on drying characteristic and quality of dried pumpkin. The influence of solar tunnel dryer zones and predrying treatments (namely; 1% citric acid, 2% salt, salt blanched and control) on drying kinetic, physical, functional, chemical and nutritional parameters of pumpkin slices and powder was investigated.

Drying of pumpkin slices occurred in falling rate period; no constant rate period of drying was observed, which implies that moisture removal from the material was governed by diffusion phenomenon. The moisture removal of pumpkin slices at zone III and pretreatment with salt blanched were highest when compared to others. The values of effective diffusivity obtained from this study lie within in general range  $10^{-12}$  to  $10^{-8}$  (m<sup>2</sup>/s) for drying of food materials. The experimental drying data was fitted to seven different mathematical models and compared using statistical criteria. The diffusion approximate was found to be best fitting model whereas the Henderson and Babis, logarithmic approach and two term exponential models were found to be suitable to describe the drying kinetics of pumpkin slices.

Physical parameters such as shrinkage ratio (%), rehydration ratio and water activity of pumpkin powder was found in the range of  $32.58\pm0.05 - 65.06\% \pm 0.9\%$ ,  $5.91\pm0.03 - 7.06\pm0.01$  and  $0.227\pm0.002$  and  $0.291\pm0$ . 001 respectively. From functional parameter of pumpkin powder; for instance, bulk density was found in the range of  $0.52\pm0.006$  (g/ml) -  $0.78\pm0.02$  (g/ml). Further the highest water absorption capacity ( $6.41\pm0.009$  (mL/g)), was recorded at zone III for salt blanched pretreatment. However, the highest oil absorption capacity ( $3.6\pm0.03$  (mL/g) of pumpkin powder was obtained, at zone III for salt (2%) treated.

The total phenolic content of pumpkin powder; the highest lose (68.36 %) was obtained at whereas the lowest lose (8.98 %) was observed at zone II for salt treated. The retention of betacarotene was found between 40.14 and 82.59 % showing maximum retention at zone II for salt treatment and minimum retention at zone I for control. Further the highest ascorbic acid retention (71.32%) was obtained at zone II for salt treatment. Moreover, the highest antioxidant activity was observed at zone II for salt treatment followed by zone I with same treatment. In general, this study showed the presence of variability among the three drying zones and predrying treatments on drying kinetics, physical, functional, chemical, nutritional and some bioactive components of solar tunnel dried pumpkin slice and powder.

### 5.2. Conclusion

The diffusion approximation model was found to be best fitting to describe the drying behavior of pumpkin slice dried at zone II. Thus, with same situation of temperature and relative humidity, slice thickness and pretreatments, the drying time with required moisture content can be calculated using diffusion approximation model. However, models fitted for zone I and zone III were affected by temperature and pre-drying treatments so that no constant model was found to describe the drying behavior at these zones. Moreover, Pumpkin dried at increased temperature (zone III) combined with salt blanche treatment experienced high moisture removal, short drying time and high effective moisture diffusivity that lead to high shrinkage ratio, rehydration ratio, bulk density and water absorption capacity where only high shrinkage ratio is undesirable. Further, the moisture content and water activity of pumpkin powder were low enough to prevent microbial growth and biochemical deterioration. In general, solar tunnel dryer zone with medium temperature (zone II) and salt (2%) treatment showed highest retention of total phenolic content, beta-carotene, ascorbic acid and antioxidant activity of pumpkin powder.

#### **5.3. Recommendation**

- Beside its appreciated nutritional values, pumpkin is not given attention by the agricultural sector as well as by the scientific community in Ethiopia. Thus, both sectors should focus on such underutilized crops and explore the information so that small holder farmers, producers as well as consumers could be benefited.
- As a future line of work it will be better to investigate physical and chemical parameter of the pumpkin powder with its peel and rind since more attention are given for its pulp and seed only.

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# 7. APPENDICES

# **Appendix A: Tables and Figure in kinetic parameters**

Appendix Table 1: Curve fitting criteria for the various mathematical models and parameters for pumpkin slice dried at zone I

Sample code	Models	<b>R</b> <sup>2</sup>	$\mathbf{X}^2$	RMSE	<b>P(%)</b>
	Logarithmic	0.98919	0.00287	0.05018	23.43
	Lewis	0.96158	0.00918	0.09585	18.8
Zone I-Control	Page	0.99029	0.00242	0.04761	24.86
	Henderson and Babis	0.93780	0.00593	0.07468	17.88
	Two term exponential	0.99834	0.00041	0.01963	9.79
	Diffusion approximation	0.98652	0.00363	0.05639	17.53
	Mindili et al	0.99826	0.00049	0.02014	3.66
	Y '.1 '	0.00/707	0.00070	0.00500	0.20
Zone I Citric acid	Logarithmic	0.996/0/	0.00072	0.02528	9.30
	Lewis	0.99549	0.00088	0.02959	11.06
	Page	0.99527	0.00098	0.03035	/.34
	Henderson and Babis	0.99727	0.00067	0.02511	4.65
	Two term exponential	0.995645	0.00090	0.02910	10.02
	Diffusion approximation	0.99507	0.00109	0.03102	11.87
	Mindili <i>et al</i>	0.99536	0.00109	0.03102	5.10
	Logarithmic	0.998557	0.00035	0.01758	4.73
	Lewis	0.99753	0.00053	0.02302	7.23
	Page	0.99777	0.00051	0.02184	5.10
	Henderson and Babis	0.99628	0.00031	0.01714	5.88
	Two term exponential	0.99792	0.00047	0.02107	5.32
Zone I-salt(2 %)	Diffusion approximation	0.99785	0.00052	0.02147	4.89
	Mindili <i>et al</i>	0.99786	0.00056	0.00023	4.69
		0.00	0.000=6	0.00	
	Logarithmic	0.99656	0.00076	0.02560	9.27
	Lewis	0.99543	0.00093	0.02953	8.65
	Page	0.99538	0.00093	0.02954	8.66
<b>– – – – –</b>	Henderson and Babis	0.99159	0.00078	0.02703	8.60
Zone I- Salt	Two term exponential	0.99538	0.00094	0.02949	8.64
blanched	Diffusion approximation	0.99538	0.00102	0.02951	8.65
	Mindili et al	0.99412	0.00140	0.03321	6.14

 $R^2$  = Coefficient of determination,  $X^2$  = Reduced chi-square, RMSE = Root mean square error; P=Relative mean percentage deviation

Sample code	Models	<b>R</b> <sup>2</sup>	X <sup>2</sup>	RMSE	P(%)
	Logarithmic	0.98994	0.00257	0.04534	21.19
	Lewis	0.97312	0.00569	0.07544	17.45
	Page	0.99157	0.00190	0.04156	21.35
Zone III-Control	Henderson and Babis	0.96619	0.00351	0.05623	13.17
	Two term exponential	0.99774	0.00051	0.02144	12.96
	Diffusion approximation	0.99844	0.00039	0.01782	9.59
	Mindili et al	0.99083	0.00112	0.02806	7.32
	Logarithmic	0.98227	0.00457	0.05856	25.06
Zone III-Citric acid	Lewis	0.96959	0.00613	0.07830	13.33
	Page	0.97449	0.00552	0.06946	26.59
	Henderson and Babis	0.97300	0.00331	0.05425	13.65
	Two term exponential	0.99530	0.00103	0.03004	9.45
	Diffusion approximation	0.99920	0.00021	0.01239	7.59
	Mindili et al	0.96406	0.01088	0.08247	10.33
	Logarithmic	0.99104	0.00198	0.03985	18.03
	Lewis	0.98088	0.003498	0.05914	12.56
	Page	0.99306	0.001367	0.03508	11.45
	Henderson and Babis	0.97780	0.00238	0.04626	9.93
	Two term exponential	0.99750	0.00049	0.02100	8.44
	Diffusion approximation	0.99810	0.00042	0.01832	7.14
Zone III-Salt (2 %)	Mindili et al	0.99585	0.00105	0.02706	11.13
	Logarithmic	0.99908	0.00017	0.01134	5.01
	Lewis	0.99919	0.00011	0.01062	4.96
	Page	0.99908	0.00015	0.01136	5.14
	Henderson and B.	0.99859	0.00015	0.01157	4.56
Zone III- Salt blanched	Two term exponential	0.99960	6.861*10 <sup>-5</sup>	0.00775	3.40
	Diffusion approximation	0.99912	0.00016	6.123*10 <sup>-5</sup>	4.84
	Mindili et al	0.99813	0.00042	0.01107	5.07

Appendix Table 2: Curve fitting criteria for the various mathematical models and parameters for pumpkin slice dried at zone III

Appendix Table 3: Model constants for tested models at Zone I

Sample code	Models	Model constants
Zone I-Citric acid	Logarithmic	a= 1.04756, c= -0.01661, k=0.0051
	Lewis	k=0.00549
	Page	n= 0.993884

	Henderson and Babis	a=1.04253
	Two term exponential	a= 1.23268
	Diffusion approximation	a= -1.23660, b=0.99629
	Mindili.et al	a= 1.09506, b= 0.00004, n= 1.01556
Zone I-Control	Logarithmic	a=0.03362,c=0.0697479,k=0.0061
	Lewis	k=0.00609
	Page	k=0.0061, n=0.938821
	Henderson and Babis	a=1.0299
	Two term exponential	a=1.7082, k=0.0061
	Diffusion approximation	a=-15.765, b=0.990578, k=0.0061
	Mindili <i>et al</i>	a=1.06982, n=0.913461, b=-0.000352054
	Logarithmic	a=1.03512, c=- 0.00227734
	Lewis	K=0.00469
	Page	n=0.995076
Zone I-Salt(2 %)	Henderson and Babis	a=1.0299
	Two term exponential	a= 1.19536
	Diffusion approximation	a= -2.00076, b= 0.992597
	Mindili <i>et al</i>	a=1.07225, b= 0.00006, n= 1.01708,
		k=0.0047
	Logarithmic	a= 1.05030, c= -0.01453
	Lewis	k=0.00649
	Page	n= 1.00048, k=0.0065
	Henderson and Babis	a=1.02543
Zone I- Salt blanched	Two term exponential	a=1.08552
	Diffusion approximation	a= -4.22610 ,b=0.99913
	Mindili et al	a=1.10540,b=0.00008,n=1.02952

Appendix Table 4: Model constants for tested models at Zone II

Sample code	Models	Model constants
	Logarithmic	a=1.09905, c= 0.05339
	Lewis	k=0.010299
	Page	n = 0.939254
Zone II-Control	Henderson and Babis	A=1.17605
	Two term exponential	a= 1.86339
	Diffusion approximation	a=1.56798, b= 2.89883
	Mindili et al	a=1.22022, b=-0.00031 ,n= 0.94402
Zone II-Citric acid	Logarithmic	a= 1.05041 ,c=0.06769 k=0.0125
	Lewis	K=0.012499
	Page	n=0.933899
	Henderson and Babis	a=1.1674
	Two term exponential	a= 1.84265
	Diffusion approximation	a= 1.69296, b= 2.16407
	Mindili et al	a=1.15316, b=-0.00050, n= 0.91637
Zone 2-Salt(2 %)	Logarithmic	a=1.07243, c=0.06214
	Lewis	k=0.0092
	Page	n = 0.940650
	Henderson and Babis	1.17788
	Two term exponential	a=1.81700

	Diffusion approximation	a=1.54311 ,b=2.70822
	Mindili et al	a=1.15898,b=0.92535,n=-0.00042
Zone 2- Salt blanched	Logarithmic	a=1.04035,c=0.02073
	Lewis	k=0.01149
	Page	n=0.973267,k=0.0115
	Henderson and Babis	a=1.07466
	Two term exponential	a=1.47660
	Diffusion approximation	a=1.17197,b=5.19267
	Mindili et al	a=1.12487, b=-0.00008, n=0.98773

Appendix Table 5: Model constants for tested models at Zone III

Sample code	Models	Model constants
Zone III-Control	Logarithmic	a=1.02136,c=0.05255
	Lewis	k=0.01019
	Page	n=0.956064
	Henderson and Babis	a=1.10852
	Two term exponential	a=1.61624
	Diffusion approximation	a=1.36744, b=2.45235
	Mindili	a=1.3, b=2.3,n=0.87
Zone III-Citric acid	Logarithmic	a=1.04440,c=0.04634
	Lewis	k=0.01439
	Page	n=0.923628
	Henderson and Babis	a=1.10373
	Two term exponential	a = 1.68565
	Diffusion approximation	a=1.32106,b=4.78565
	Mindili et al	a=1.23140,n=0.97764,b=-0.00019
	Logarithmic	a=1.02462,c= 0.03513
	Lewis	k=0.01139
	Page	n=0.964683
Zone III-Salt (2 %)	Henderson and Babis	a=1.0828
	Two term exponential	a= 1.54308
	Diffusion approximation	a= 1.31006,b= 2.33796
	Mindili <i>et al</i>	a=1.06723, b=-0.00026,n=0.95260
Zone III- Salt	Logarithmic	a=0.990263,c=-0.003414
blanched	Lewis	k=0.01419
	Page	n=1.00640
	Henderson and Babis	a=0.9848
	Two term exponential	a=1.24041
	Diffusion approximation	a=4.16455,b=0.99344
	Mindili <i>et al</i>	a=0.959760,b=0.000012 ,n=0.999209

Appendix Table 6: Drying time, initial moisture content and final moisture content

Sample code		Drying time (min)	Initial moisture content	Final moisture	
Zone	Pretreatment	_			
	С	510	90.8±2.01 <sup>bcd</sup>	8.2±0.03ª	

	CA	480	90.1±0.9 <sup>ef</sup>	$6.9 \pm 0.02^{g}$
	S	480	$90.3 \pm 1.01^{cdef}$	$7.2 \pm 0.05^{de}$
Zone I	SB	390	$90.5 \pm 0.8^{cde}$	$6.6 \pm 0.02^{h}$
	С	330	90.7±0.7 <sup>cd</sup>	$7.8 \pm 0.02^{b}$
	CA	270	$89.8 \pm 1.01^{f}$	$7.4 \pm 0.06^{cd}$
	S	330	$90.8 \pm 0.5^{bcd}$	$7.1 \pm 0.08^{ef}$
Zone II	SB	270	91.5±0.4 <sup>a</sup>	$7.6 \pm 0.02^{bc}$
Zone III	С	270	$90.9 \pm 0.8^{abc}$	$7.0\pm0.04^{19}$
	CA	240	$90.2 \pm 0.2^{def}$	$6.8 \pm 0.04^{ m gh}$
	S	240	$90.6 \pm 0.8^{cde}$	$7.0{\pm}0.04f^{g}$
	SB	210	$91.4{\pm}0.2^{ab}$	$6.4{\pm}0.04^{i}$

*C*=*control*, *S*=*Salt treated*, *SB*=*Salt blanched*, *CA*=*citric acid treated*, *Pr*=*pretreatment* 



Appendix Figure 1: Air speed of the inlet, zones and outlet of the solar tunnel dryer

Appendix Table 7: A	NOVA (P≤0.05) s	shows the sig	nificance of	f the main a	nd interaction	effects
of Zone and pretreatr	nent on functiona	l property of	pumpkin p	owder.		

Source of variation	RR	SR	WHC	OAC	BD	a <sub>w</sub>
Block	0.412	0.291	0.967	0.608	0.297	0.666
Zone	0.00	0.001	0.00	0.001	0.00	0.00
Pretreatment	0.00	0.00	0.00	0.001	0.00	0.00
Zone*pretreatment	0.210	0.001	0.001	0.001	0.004	0.001

*BD*=*bulk density, SR*=*shrinkage ratio, WAC*=*water hydration capacity, OAC*=*oil absorption capacity, RR*=*Rehydration ratio* 

Source of variation	TSS	pН	ТА	Total ash	Protein	Fiber	Moisture content
Blocks	0.890	0.703	0.473	0.266	0.151	0.583	0.375
Zone	0.00	0.00	0.00	0.001	0.00	0.007	0.00
Pretreatment	0.00	0.00	0.00	0.006	0.00	0.00	0.00
Zone*pretreatment	0.00	0.001	0.001	0.00	0.001	0.859	0.001

Appendix Table 8: ANOVA ( $P \le 0.05$ ) shows the significance of the main and interaction effects of Zone and pretreatment on chemical property of pumpkin powder.

*TSS=Total Soluble Solid in <sup>0</sup>Brix, TA=Titrable Acidity in citric acid a<sub>w</sub>=water activity* 

Appendix Table 9: ANOVA ( $p \le 0.05$ ) shows the significance of the main and interaction effects of Zone and pretreatment on bioactive component of pumpkin powder.

Total	β-carotine	Ascorbic	Antioxidant	
Phenolic		acid	% Inhibition	IC <sub>50</sub>
0.382	0.732	0.473	0.450	0.848
0.001	0.00	0.00	0.00	0.001
0.001	0.00	0.00	0.00	0.00
0.058	0.001	0.001	0.001	0.001
	Total           Phenolic           0.382           0.001           0.001           0.058	Total Phenolicβ-carotine0.3820.7320.0010.000.0010.000.0580.001	Total Phenolicβ-carotine acidAscorbic acid0.3820.7320.4730.0010.000.000.0010.000.000.0580.0010.001	Total Phenolicβ-carotine $2$ Ascorbic acidAntioxidant $\%$ Inhibition0.3820.7320.4730.4500.0010.000.000.000.0010.000.000.000.0580.0010.0010.001



Appendix Figure 2:Graph showing Galic acid standard



Appendix Figure 3: Graph showing beta carotine standard