College of Natural and Computational Sciences
Center for Food Science and Nutrition

Processing effect of drying methods on the nutrient retentions, sensorial quality, and shelf-life stability of papaya (*Carica papaya* L.)

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March 2021

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Declaration

I, the undersigned, declare that this thesis entitled "**Processing effect of drying methods on the nutrient retentions, sensorial quality, and shelf-life stability of papaya (*Carica papaya* L.)**" is original work, has been conducted, and written by Masresha Minuye Tasie, in the canter of food Science and Nutrition, Addis Ababa University, Addis Ababa, under the supervision of Dr. Kaleab Baye and Dr. Paulos Getachew. The research has never been presented in any other university as well as research institutes previously. All the source material used for this research has been fully acknowledged.

____________________________ ________________________

Masresha Minuye Date;

The thesis has been approved for submission by advisors undersigned

Name: Kaleab Baye (Ph.D.)	Name: Paulos Getachew (Ph.D.)
Signature: __________________________	Signature: ________________
Date: ______________________________	Date: _________________________

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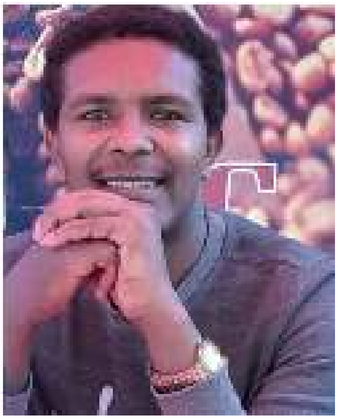

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Table of Contents

List of Tables

List of Figures

List of Annex

List of Abbreviations

VA	Vitamin A
FVs	Fruit and Vegetable
VAD	Vitamin A Deficiency
DALYs	Disability Adjusted Life Years
YLLs	Years of Life Lost
LMICs	Low Middle-Income Countries
BCO	Beta--Carotene 15–15’-oxygenase
TSS	Total Soluble Solids
WHO	World Health Organization
FAO	Food Administrator Organization
FMoH	Federal Ministry of Health.
EPHI	Ethiopian Public Health Institute
VAD	Vitamin A Deficiency
CSA	Central Statistical Authority
GAE	Galic Acid Equivalent
QAE	Quercetin Acid Equivalent
∆E	Colour Change
RH	Relative Humidity
SPSS	Statistical Packaging for Social Sciences
IU	International Unit
CIE	Commission of International Illumination

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Abstract

Dietary guidelines show that more frequent consumption of fruits can prevent nutrient deficiencies and promote health. However, the perishability and unaffordability of fruits had led to very low levels of fruit consumption in low and middle-income countries (LMICs). Despite papaya fruit is one the best nutritious fruit, it is classified as a highly perishable/ low shelf-stable fruit. Therefore, to improve the shelf stability, and accessible, affordable papaya fruit, drying technologies are playing an irreplaceable role. The present study aimed to evaluate the retention of nutrients and bioactive compounds of papaya fruit (*Carica papaya* L) with/without ascorbic acid pretreatment, drying under different drying techniques, shelf stability of dried papaya products, and also estimate the vitamin A intakes for vulnerable populations. Yellow ripped papaya fruits (n=14), with and without ascorbic acid pre-treatment were dried using i) solar drying: open-air, tray driers, and glass house; ii) refractance-window drying; iii) oven-drying, and iv) freeze-drying (control). The concentration of total carotenoid, polyphenols (TP), flavonoids (TF), and B-carotene were determined using spectrophotometry and high-performance liquid chromatography (HPLC). The fresh fruit had high moisture content (87%) and an acidic pH. The dried papaya had a water activity of 0.5-0.6. The highest TPC, TFC, total carotenoids, and carotene was found in freeze-dried papaya samples, followed by refractance-window, and solar-glass house ($P<0.05$). The highest retention in total carotenoids (81.5%), lycopene (78.8), and β-carotene (61.9%), relative to freeze-drying was for the refractance-window; 25 g of dried-papaya could contribute to 38% of the retinal equivalent's requirement for young children. Whereas highest retentions of Vitamin C (47.86), bioactive compounds; total phenolic (35.5), and total flavonoid (72.75) was for the oven and refractance window dryer. Ascorbic acid pretreatment increased the retention of total carotenoids, β-carotenes, TP, and TFC ($P< 0.05$). The sensory attributes of dried papaya did not show a significant difference ($p < 0.05$), as well dried papaya can be stored for up to six months brought without a significant change of microbial load, and served as an eatable product. Refractance-window and solar-glass house drying can improve diets and constitute a promising food systems' intervention that can increase year-round availability, accessibility, and affordability of vitamin A-rich fruits like papaya.

Keywords; Solar drying,Vitamin A,Refractance Window, Beta-carotene, Polyphenol

1. Introductions

1.1 Background and Justification

People in the world are affected by one or more forms of malnutrition. About 800 million are undernourished, 1.9 billion adults are overweight or obese (WHO, 2016) and two billion people worldwide are anemic and suffer from micronutrient deficiencies (Camaschella, 2015). Principally, the driving force of all forms of malnutrition is an unhealthy diet (Pradeilles *et al.,* 2019). Over three billion people cannot afford even the cheapest healthy diet (SOFI, 2020). Poor nutrition is now considered the leading cause of morbidity and mortality putting people at a greater risk than unsafe sex, tobacco, drug, and alcohol use combined. Although what constitutes a healthy diet is context-dependent, there is consolidated evidence that diverse diets with consumption of nutrient-dense foods like whole grains, legumes, nuts, fruits, and vegetables (FVs) are associated with healthier outcomes (Herforth *et al.,* 2019).

Fruits and vegetables are one of the best food crops and their consumption is muscularly connected with several health benefits due to their high nutritional value and medicinal properties (Ames *et al.,* 1993). As stated by WHO,(2005) reports low fruit and vegetable consumption places, among its twenty risk factors in global mortality, just behind the most known killers such as tobacco and high cholesterol levels (Demissie *et al.,* 2009; Wada & Ou, 2002). Therefore, increased consumption of fruit and vegetable are required for maintaining better health (Lim & Tee, 2007). These benefits of fruit and vegetable have been primarily attributed due to the anti-oxidant characteristics of the fruit (Palozza & Krinsky, 1992). Among antioxidants, carotenoids (provitamin A) are the most interesting and had given special attention besides their antioxidant properties due to their uses as provitamin A (used as Vitamin A source) (Yahia, 2010).

Despite irrefutable evidence of the benefits of frequent consumption of fruits, their consumption is very low in low and middle-income countries (Miller *et al.,* 2016). The WHO/FAO, (2003) "Diet, Nutrition and the Prevention of Chronic Diseases “recommends a population dietary intake goal of more than 400 g per day of FVs. A recent analysis of children’s diet in 49 LMICs revealed that very few consume vitamin-A-rich FVs (Baye & Kennedy, 2020). In Ethiopia, for example, the average household consumed 45 kg of FVs per adult equivalent (Worku *et al.,* 2017). This level is among the lowest in sub-Saharan Africa and is far from meeting the WHO recommendation of 146 kg per year (Ruel *et al.,* 2005).

A recent review has also shown that only about 2.4% of adults meet the WHO recommendation of five servings of fruits and/or vegetables per day, leading to increased risk of nutrient deficiencies (e.g. Vitamin A) and chronic diseases (Baye *et al.,* 2019). The highest (~11-12%) disability-adjusted life years (DALYs) and years of life lost (YLLs) was related to this low consumption of fruits (Melaku *et al.,* 2016)

In the areas of widespread vitamin A deficiency, people obtain vitamin A almost exclusively as provitamin A (carotenoids) (West,1996) and then enzymatically converted to retinal (vitamin A aldehyde) by the enzyme Β-carotene 15–15'- oxygenase (Harrison, 2012). In developed countries, provitamin A carotenoids provide 30% of daily vitamin A intake, whereas preformed vitamin A provides 70% daily vitamin A intake (Tang, 2010). In contrast, in developing countries, provitamin A carotenoids provide 70% of daily vitamin A intakes (Tang, 2010). Therefore, among many health and nutrition benefits of consumption of fruits and vegetables, the prevention of vitamin A deficiency appears to be the most important one, especially in developing countries due to the inaccessibility of livestock products for the vitamin A source.

As a result, papaya fruit (*Carica Papaya L.*) is a targeted crop for nutrient enrichment to be used in sustainable programs to combat vitamin A deficiency in developing nations (Organization, 2007; Rodriguez-Amaya, 2003) due to its highest carotenoid content, pro-vitamin A rich fruit. It is considered as a source of vitamin A and as well calcium, and vitamin C (ascorbic acid) which is being widely used in diets (Souza *et al.,* 2008). Therefore, the consumption of papaya fruit can be an effective alternative way to reduce the prevalence of vitamin A deficiency in developing countries. However; papaya is a highly perishable fruit having moisture contents of >80% (Sagar & Kumar, 2010), causes large post-harvest loss.

Drying should be able to be applied, to produce a shelf-stable product of fruit and vegetable. Drying denotes the removal of moisture/ reduce water activity of fruit with the primary aim of reducing microbial activity, produce shelf-stable and easily handled products (Fellows, 2009; Jangam *et al.,* 2010). Along with the preservation of papaya, reduced weight and bulk of dehydrated products, decrease packaging, handling, and transportation costs, and storage place(Araya-Farias & Ratti, 2008; Demarchi *et al.,* 2013). Very limited work had been reported in the drying of the papaya fruit with a different drying technology, which is probably might not be affordable, and accessible for LMICs. However, a comprehensive evaluation of solar drying technologies relative to more common drying methods such as oven and freeze-drying remains scant, and in this research study, another locally adapted eco-friendly drying technology (refractance window) is also included in addition to common drying methods.

Therefore, this research work is targeted to bridge this gap by (1) evaluating the nutrient retention (total carotenoids) of papaya fruit (*Carica Papaya L.*) with/without ascorbic acid pre-treatment and under different drying techniques, including i) solar drying (open-air, tray driers, glass-house); ii) refractance drying; iii) oven-drying, and iv) freeze-drying (control). Alternatively, the study will help for (2) reducing post-harvest loss of papaya through the removal of water (3) increasing the accessibility of shelf-stable, nutrient-rich papaya fruit as a dried product,(4) increasing the consumptions of papaya fruit throughout the country since limited consumption of fruit is present, and (5) to make available dried papaya products when it is off-season.

1.2 Statement of The Problem

Globally about 30% of children < 5 years of age are Vitamin A (VA) deficient, and about 2% of all deaths are attributable to VAD in this age group (Stevens *et al.,* 2015). In Ethiopia, nearly 40% of children are vitamin A deficient (FMoHE, 2011). Accordingly, the (EPHI., 2016) micronutrient survey reports the prevalence of subclinical vitamin A deficiency was 14%, 10.9%, and 3.4% in preschool-age children, school-age children, and women of reproductive age. In general, nationally, 37.7% of children (35.6% to 39.9%) had deficient serum retinol levels. Since in developing countries including Ethiopia, 70 % of Vitamin A source is fruit and vegetable it should be advisable to increase the consumption of horticultural crop.

Despite sustained nutrition education through the health system, consumption of fruits has remained very low (Baye & Hirvonen, 2020; Baye *et al.,* 2019). The high price of fruits, their perishability, and seasonality are among the underlying factors influencing the consumption of fruits (Baye & Hirvonen, 2020). Although this is recognized, little or no food systems' innovation has been put in place to reduce the price of FVs by decreasing loss and reducing transaction costs related to transportation, as well as increase the safety and shelf-life of fruits.

To overcome the prevalence of Vitamin A deficiency, introducing beta-carotenoid-rich and economically feasible food is critical. Provitamin A (carotenoids) is very interesting and can be used in both anti-oxidant and vitamin A sources. Moreover; it is also very important to prevent exposure to vitamin A toxicity because they only convert to vitamin A when the body is needed (Dutta *et al.,* 2005).

Papaya fruit (*Carica Papaya* L.*)* is believed to be the most effective alternative way to reduce the prevalence of vitamin A deficiency (WHO, 2007), because it realizing that (1) it is important, as an economical and highly nutritious foodstuff (2) it has high content of beta carotenoid, (3) availability throughout the year,(in the growing potential area) and (4) cheaper than the other fruits having a higher beta-carotenoid source. But (1) papaya fruit is highly perishable, having > 80 % moisture content (Sagar & Kumar, 2010), (2) cannot easily transport due to its large size (leads to high cost for transportation), (3) exposure to high post-harvest loss, (4) is not available as the required amount for purchasing. In addition to this, it is understandable that in Ethiopia, there are no post-harvest technologies that can be used as transportation, storage condition, and handling fruits and vegetables to reach the consumers safely and keeping their quality.

Therefore, to overcome such a problem, it is worthwhile to use drying technologies. Papaya fruit industrialization through drying is a significant role in minimizing these losses, prolong fruit shelf life, and use fruits which is not fulfill the export standard. Selecting suitable drying methods to preserve papaya nutritional content is one of the ways to supply the population with healthy and beta-carotenoid-rich nutritious processed foods. So, drying is the method that is used for the industrializations of the fruit and it is believed necessary to make preserved products of fruit for human consumption throughout the year.

1.3 Research Questions

- Which drying methods can effectively retain the nutrients and bioactive compounds of papaya?
- Does pre-treatment of papaya drying has significantly retain nutrients than untreated drying?
- For how long the dried papaya product possibly shelf-stable and for how long it will stay without much nutrient loss?
- Is the dried product of papaya fruit will sensorial acceptable for the consumer?

1.4 Objectives

1.4.1 General Objective

- To evaluate the retention of nutrients and bioactive compounds of papaya fruit (*Carica Papaya* L.*)*, and shelf-life stability under different drying techniques.

1.4.2 Specific Objective

- To investigate the effect of solar (open, tray, and glass house), oven, and reflectance window dryers on the nutrient retention of papaya fruit.
- To identify the better drying methods of the papaya fruit with minimal loss of nutrients, bioactive compounds as well as better sensorial quality
- To evaluate sensorial acceptability and shelf-life stability of papaya dried product.

1.5 Significance of The Study

It is well known that most fruit and vegetables are perishable commodities and seasonally available, as a result, they are exposed to high post-harvest loss of 40-50 % (Urge *et al.,* 2014). So, to reduce these post-harvest losses of the horticultural crop, simple, cost-effective, and environmentally friendly drying technology should be available.

In this study ripened yellow (>75%) pulp papaya was subjected to drying using six drying technologies as solar (open, tray, glass house), refractance window, oven and freeze dryer (control). As a remark; solar -tray, solar glass house, and refractance window dryer were locally adapted drying technologies. The study was aimed to evaluate the effect of different drying technologies on the papaya nutrients retentions, and also for shelf stability of dried papaya products. At the same time, the efficiency of locally adapted drying technologies was also evaluated.

The outcome of the research will significantly contribute to;

- The community, through supplying with nutrient-rich dried fruit products.
- Reduces post-harvest loss, by changing into a shelf-stable dried product.
- Increases papaya accessibility and affordability to the community by reduces its weight, transportation cost, storage material cost.
- Increases farmer's income generation, through increasing papaya production.
- Improve community nutrition diversity.
- The people through reducing the prevalence of vitamin A deficiency.
- Selecting the appropriate papaya drying technologies.

2. Literature Review

2.1 Descriptions of Papaya (*Carica papaya* L.) Fruit

The fruit is cherished for its sweetness and soft pulp (Fabi *et al.,* 2007), and regularly consumed ripened in nature. Its original location is not well defined, evidence suggests the American tropics as the main source of this fruit (Garrett, 1995). Papaya is a climacteric fruit, which cultivates year-round, and an elongated berry of various sizes with smooth thin skin and a greenish-yellow colour (Fagundes & Yamanishi, 2001; Fuggate *et al.,* 2010). It is usually about 15 - 50 cm long, 10 - 20 cm in diameter, and weighing up to 9 kg (Ojike *et al.,* 2011). Papaya trees yield fruits within 5 months and can live up to 4-5 years (Orwa *et al.,* 2009) and have numerous seeds, small, black, and covered with gelatinous aril. It is rich in orange pulp and often has orange-red, yellow-green, and yellow-orange hues (Aravind *et al.,* 2013). Its flesh is thick with the colour varying from yellow to red and gives a pleasant, sweet, mellow flavor (Devitt *et al., 2*006; Fuggate *et al.,* 2010). The different flesh color of papaya is the result of the accumulation of carotenoids in fruit cell chromoplasts, primary lycopene in red flesh, and b-carotenoids in yellow flesh, which provide antioxidant activity and vitamin A nutrition, respectively. The growth environmental conditions of papaya in both tropical and subtropical regions within the temperatures range of 21 and 33 °C. It does not tolerate cold weather (less than 15 °C) (Crane *et al.,* 2005; Fuggate *et al.,* 2010; Rivera-Pastrana *et al.,* 2010). It has the maximum postharvest life (days)/shelf life of 7-21 days at an optimum storage temperature (°C) of 8-12 (Wakjira, 2010).

2.2 Papaya (*Carica papaya* L.*)* Production

2.2.1 Papaya (*Carica Papaya* L) Production in Ethiopia

India ranks the first world producer of papaya whereas the 2nd,3rd, 4th, and 5th are Brazil, Indonesia Nigeria, and Mexico, respectively. Ethiopia ranks the 6th (six) world producer, and the second largest producer in the continent after Nigeria (https://www.selinawamucii.com). It produces 2.34% of the global tonnage. Papaya is the most producing fruit in Ethiopia next to the three most popular and most consuming fruits of bananas, mangoes, and avocados (CSA,2019/2020). There are three varieties of papaya is used for exporting standards such as (1) Maradol papaya matures in seven months, (2) Solo papaya (yellow pulp), and (3) 'Local.' (matures faster than Solo or Maradol).

In Ethiopia, papaya is produced in home gardens and semi-commercial levels by farmers as well as commercial level by state farms for home consumption and local market (for fresh fruit and juice making). For exporting standards, the main growing areas include Tigray, both the Raya Alamata and Raya Azebo woreda. There are also other commercial farms of papaya like upper Awash agro-industry(Tibila and Awara, Melka farms) and Zeway farm) (https://www.selinawamucii.com). As clearly presented in figure 1, fruit production and area coverage are increasing therefore since papaya is a highly perishable, cause for post-harvest loss, it should have to improve the post-harvest management system to use a full product of the crop.

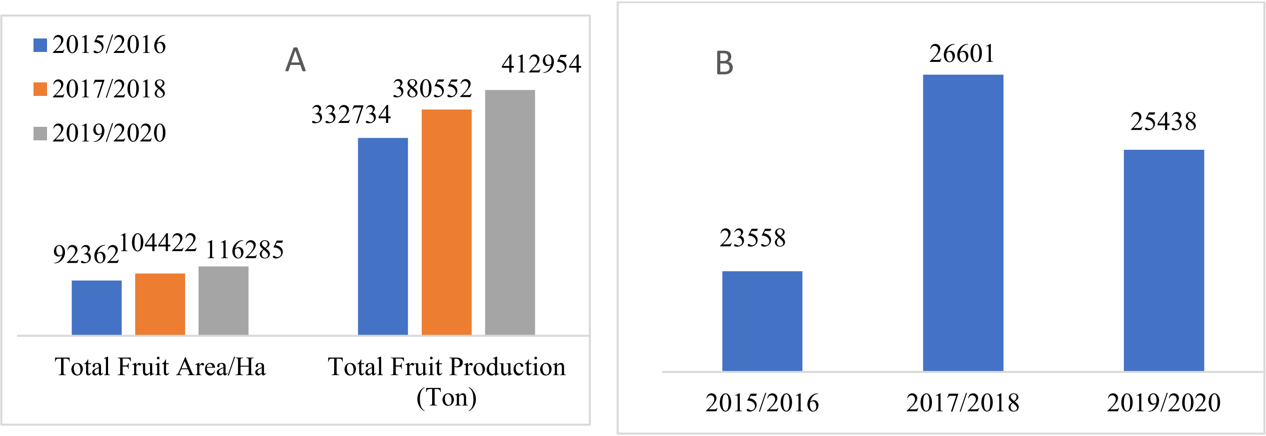


Figure 1; (A), Fruit area coverage and production(ton) & (B), Papaya production (ton)

2.3 Papaya (*Carica Papaya* L.) Nutritional Value

Papaya has been graded one of the tops nutritional scores among 38 common fruits (Ming *et al.,* 2008), and every part of the fruit served a different medical purpose (Hewitt *et al.,* 2000; Silva *et al.,* 2010). It is a tropical and sub-tropical crop fruit that is known for its high nutritional values (Krishn *et al.,* 2008; Yamamoto, 1979), and also its popularity is due to the fruit being low in calorie, as well as rich in antioxidant compounds (Prajapati *et al.,* 2017). It has been reported that per 100 g of the edible portion of papaya contains about 2000 IU of vitamin A, 46 IU of vitamin C, some riboflavin (250 IU), and niacin (200 IU) and is a good source of calcium (38 mg), phosphorous (1 mg) and iron (1.1 mg) (Chaudhari *et al.,* 2000). In papaya fruit above 85 % of (Samson, 1986) the fruits are covered by moisture content, in which the fruits rapidly deteriorate. Next to moisture/water, carbohydrate covered the major part of papaya fruit nutrient content. The major carbohydrates present in the papaya fruit are glucose, sucrose, and fructose, with glucose being the most carbohydrate present in the initial phases of development (Zhou & Paull, 2001), but the sucrose content increases during ripening and can reach up to 80% of the total sugars (Nwofia *et al.,* 2012; Paull, 1993), when the percent of sugars varies between 10 and 13% (Chan Jr *et al.,* 1979; Zhou & Paull, 2001).

In general, the nutritional value of fruit depends on the variety, growing conditions, and ripeness upon consumption (Mitra, 1997) but in papaya fruit, the nutritional content is strongly related to ripening (Chonhenchob & Singh, 2005). The ripening process is assisted by respiration and is associated with ethylene production (Alexander & Grierson, 2002). Accordingly (Zuhair *et al.,* 2013) when the fruit of papaya ripens more, it becomes more nutritious. It increases physicochemical characteristics, antioxidant activity, total phenolic content, and total flavonoid content. Also, more ripened papaya fruit showed more redness and yellowness. Besides nutritional improvement, while in papaya ripening, fruit rapidly decreases in firmness after separating from the tree (Chonhenchob & Singh, 2005; Karakurt & Huber, 2003), which shows that faster respiration/deterioration.

Different physicochemical properties, including pH, Titerable Acidity, Total soluble solids, moisture, and fruit colour, depended on different ripening stages. Even the overall sensorial acceptance of the papaya increasing with the progress of ripening stages of papaya fruit depending on colour, flavor, sweetness, and sourness. The papaya's sensory characteristics (principally taste and aroma) arise from the volatile compounds of (benzyl isothiocyanate, terpenes, hydrocarbons, esters, aldehydes, ketones, alcohols, and organic acids) (Almora *et al.,* 2004; Fuggate *et al.,*2010). Among the volatile alcohols responsible for papaya taste and aroma, linalool is the papaya's most abundant volatile compound (Flath & Forrey, 1977).

Papaya is a rich source of antioxidants such as vitamin A, E, B complex, ascorbic acid compared to carrots and oranges (Tietze, 2002) and also used as the cheapest source of carotenoids, thiamine, riboflavin, niacin, vitamin B-6, and vitamin K (Bari *et al.,* 2006). Antioxidants such as vitamin C, A, and E, phenolic, and carotenoids, which reduce the oxidative stress produced by free radicals (Dosildíaz *et al.,* 2008). They are believed to control/reduce the oxidative impairment in foods and biomolecules through suspending or inhibiting the oxidation process produced by reactive oxygen species and thus enhancing the shelf-life quality of the products as well as protecting the biological systems (Duthie *et al.*, 1996).

Antioxidant compounds such as (β-carotene, ascorbic acid, and phenolic) play therapeutic and preventive roles against several diseases such as aging, inflammation, and certain cancers (Heliövaara *et al.,*1994; Vivekananthan *et al.,* 2003). Among the antioxidants, carotenoids are the most interesting and had given special attention besides their antioxidant properties due to their use as provitamin A (used as Vitamin A source) (Yahia, 2010). Nearly 50 knowns active provitamin A carotenoids are present of which β-carotene makes the largest contribution to vitamin A activity in plant foods (Chandrika *et al.,* 2003). Consuming Provitamin A carotenoids are very useful for our body to control Vitamin A toxicity because provitamins are converted to vitamin A when only the body is needed.

Vitamin A

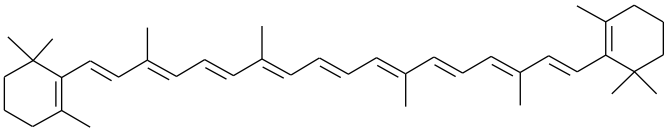
Vitamin A is one of the vital micronutrients like iron, zinc, and iodine that can be used for the promotion of general growth, development, and survival of children (Organization,2002), maintenance of visual function, regulation of differentiation of epithelial tissues, and embryonic development (Underwood & Arthur, 1996). On the other hand, its deficiency is the major health problem prompting children to increase the risk of morbidity, mortality, disability (McLaren & Frigg, 1997), which affects immune function and vision problems (Ezzati *et al.,* 2004). However; various studies revealed that improving vitamin A status can reduce mortality among children by 23% (Beaton, 1993) and pregnancy-related mortality among women by as much as 40% (Orwa *et al.,* 2009; West Jr *et al.,* 1999). Vitamin A is provided in the diet as (1) preformed vitamin A from animal origin (liver, milk and milk products, fish, and meat), and (2) As carotenoids, biologically transformed to vitamin A (provitamins A), from plant foods (dark green leafy vegetables, red/yellow vegetables, and fruits).

Carotenoids

Carotenoid is a group of the whole class of natural pigments and is responsible for the different colors of yellow, orange, and red fruits, roots, and vegetables (Chandrika, 2009; Ruiz-Rodriguez *et al.,* 2008). The most common dietary carotenoids are α-carotene, β-carotene, β- cryptoxanthin, lycopene, lutein, and zeaxanthin; α-carotene, β-carotene, and β-cryptoxanthin are precursors of vitamin A, while lycopene, lutein, zeaxanthin have no vitamin A activity but can also act as antioxidants (Shen *et al.,* 2019).

Provitamin A also has the advantage of being converted to vitamin A only when needed by the body; thus, avoiding potential toxicity from an overdose of vitamin A. The accumulation of carotenoids starts from fruit ripening, resulting in modifications in tissue pigmentation. Generally, the carotenoid biosynthesis pathway begins with the condensation of isopentenyl diphosphate (IPP) (C5) and its isomer, dimethylallyl diphosphate (DMADP), generating a molecule of geranyl diphosphate C10 (GPP) (G. Britton *et al.,* 1998).

A.

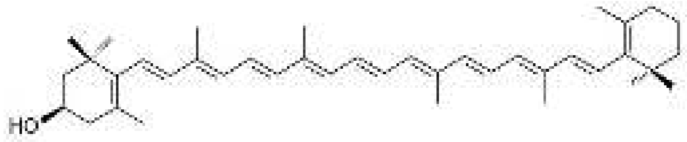


α-carotene, yellow color

B.

ß-carotene, orange color.

C.



β-cryptoxanthin (oxygenated)

Figure 2; Structures of Common Food provitamin A Carotenoids. Source;(Dutta *et al.,* 2005)

The distinguishing structural feature of carotenoids is the wide-ranging conjugated double bond system, which contains alternating double and single carbon-carbon bonds, which is called polyene chain. This part of a molecule, identified as the chromophore, is responsible for the ability of carotenoids to absorb light in the visible region, hence their strong coloring capability. Carotenoids are aquaphobic, lipophilic substances, and are nearly insoluble in water. The polyene chain of the carotenoid is the cause of the instability of carotenoids including their susceptibility to oxidation (combination with oxygen) and geometric isomerization (change of geometry about a double bond). Heat, light, and acids encourage isomerization of trans- carotenoids, their usual configuration in nature, to the cis-form (Dutta *et al.,* 2005).

Oxidation, the major cause of carotenoid losses, depends on available oxygen, the carotenoids involved, and their physical condition. Oxidation is stimulated by light, heat, metals, enzymes, and peroxides and is inhibited by antioxidants, such as tocopherols (vitamin E) and ascorbic acid (vitamin C). Epoxides and apocarotenoids (carotenoids with the carbon skeleton shortened) are believed to be the initial products (Marty & Berset, 1988). Subsequent fragmentations result in a series of low-molecular-weight compounds similar to those obtained in fatty acid oxidation. Conditions necessary for the isomerization and oxidation of carotenoids are likely to exist in home preparation, industrial processing, and storage of foods. The consequences are loss of color and vitamin A and other biological activities. Degradation of carotenoids has also been associated with the development of offflavor in foods, such as in dehydrated carrot and sweet potato flakes (Arya *et al.,* 1979).

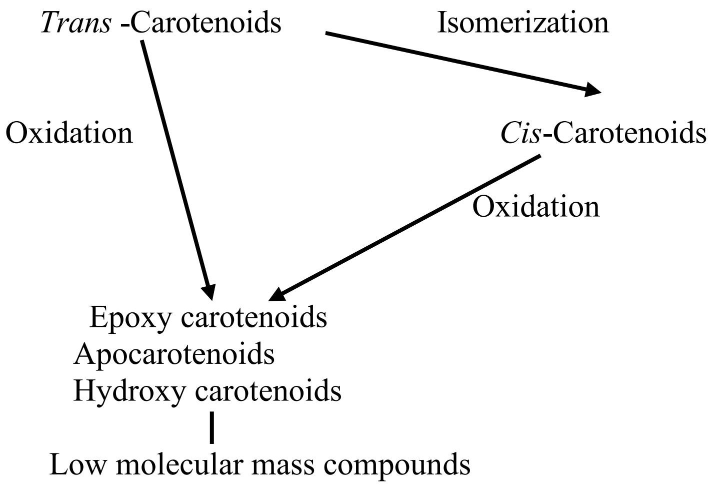


Figure 3; Possible scheme for carotenoid degradation.

Source; (Dutta *et al.,* 2005)

Health-promoting Functions or Actions Attributed to Carotenoids

Carotenoids have been linked with the enhancement of the immune system and decreased the risk of degenerative diseases such as cancer, cardiovascular disease, age-related macular degeneration, and heart disease (Bertram & Vine, 2005; Bruno & Medeiros, 2001). These biological effects are independent of the provitamin A activity and have been attributed to the antioxidant property of carotenoids, through deactivation of free radicals (atoms or groups of atoms possessing an odd, unshared electron), and singlet oxygen quenching (Burton, 1989; Palozza & Krinsky, 1992). The ability of carotenoids to quench singlet oxygen is related to the conjugated double bond system, and maximum protection is given by those having nine or more double bonds (Foote *et al.,*1970).

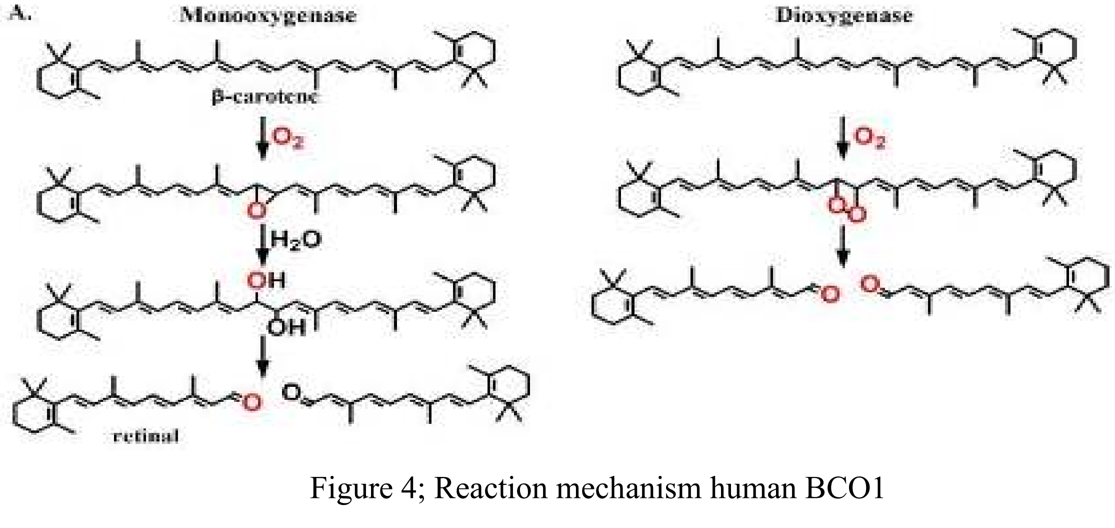


Figure 4; Reaction mechanism human BCO1

Source ; (Foote *et al.,*1970)

Beta--Carotene 15–15’-oxygenase (BCO1) catalyzes the oxidative cleavage of dietary provitamin A carotenoids to retinal (vitamin A aldehyde). Aldehydes readily exchange their carbonyl oxygen with water. BCO1 has been supposed to be a monooxygenase, integrates an oxygen atom from O_2 in one retinal molecule and an oxygen atom from water into the other. A dioxygenase combines only atoms from O_2 into the cleavage products (Delaseña *et al.,* 2014).

2.4 Varieties of Papaya (*Carica papaya* L.)

There are two categories of papaya, red-fleshed and yellow-fleshed color which is a product of the accumulation of carotenoids in fruit cell chromoplasts. Predominantly lycopene carotenoid is present in red flesh papaya whereas beta-carotenoids and β-cryptoxanthin are in yellow flesh, which provides antioxidant activity and vitamin A nutrition, correspondingly (Saengmanee *et al.,* 2018; Wall, 2006). The lycopene is responsible for the red flesh (Blas *et al.,* 2010) whereas β- carotene is responsible for orange/yellow color. Red flesh papaya softens sooner and has a shorter shelf life, but some consumers prefer red flesh papaya, often called “strawberry papaya” in the market. The carotenoid alignments of red and yellow-fleshed Hawaiian Solo papayas (Yamamoto, 1964) displayed a strong accumulation of lycopene (approximately 63% of the total carotenoid content) in red-fleshed fruit, while none was detected in yellow-fleshed fruit. Yellow-fleshed fruit exhibited mostly b-cryptoxanthin and b-carotene derivatives, up to 75% of the total carotenoid content, whereas red-fleshed fruit contained about half that amount.

During ripening in cultivars such as the yellow papaya, lycopene is rapidly converted into β-carotene by the action of lycopene beta-cyclase, which is, in turn, converted into xanthophylls via β-carotene hydroxylase (Blas *et al.,* 2010) whereas cultivars with red pulp, the conversion of lycopene in cyclic carotenoids are suppressed or even inhibited, leading to lycopene accumulation (Yan *et al.,* 2011). β-Carotene is present in green leafy and yellow-orange fruits and vegetables. β-carotene content of fruits (peach, papaya, apricot, and tangerine) may be influenced by the growing conditions, maturity index, post-harvest handling conditions, as well as variety or cultivar (Mangels *et al.,* 1993).

2.5 Post-Harvest Loss of Fruits

Papaya is a highly perishable fruit due to the presence of a high amount of water, mostly consumed as fresh fruit, and is much appreciated for its sensory characteristics, (Durigan *et al.,* 2004). The perishability’s/limited shelf-life characteristics of the fruit are the main cause for fruit post-harvest loss and lack of accessibilities of the fruit for those which are not a potential area for production (Amin & Hossain, 2012; Arah *et al.,* 2016). Accordingly, (Wonduwossen & Bekabil, 2014) data report post-harvest loss of fruit in Ethiopia including papaya covered in the range of 40-50%.

In general, an estimate of 15 to 70% of post-harvest losses of horticultural crops in Ethiopia was observed *(Urge et al.,* 2014) due to different reasons such as the perishable nature of the products, poor postharvest handling, and marketing conditions, and lack of cheap and appropriate post-harvest technology (Brett *et al.,* 1996; Sagar & Kumar, 2010). As a result, these post-harvest losses have several adverse impacts on the sales of tropical produce farm, consumer prices, national income and nutritional quality (Wu, 2010), and fundamental factor leading to food insecurity in many parts of the world, so it is imperative to process freshly harvested fruits and vegetable into shelf-stable fruit. Therefore, using dryer technologies for producing a shelf-stable horticultural crop with a minimal loss of nutrients is the best way.

2.6 Post- Harvest Loss Reduction Technology

Controlled atmosphere storage

Controlled atmosphere storage consists of placing a commodity in a gas-tight refrigerated chamber and allowing the natural respiration of the fruit to decrease the oxygen and increase the carbon dioxide content of the atmosphere in the chamber (Yahia E., 2009). High humidity retards wilting and maintains the product in better condition. Most horticultural products store best in an atmosphere that has a relative humidity of 90% (Lutz and Hardenburg, 1968).

Packaging

Product packaging is a system of preparing goods for transport, distribution, storage, retailing, and end-use, and a means of ensuring safe delivery to the ultimate consumer in sound conditions at optimum cost, and a techno-commercial function aimed at optimizing the cost of delivery while maximizing the sale. Most food packaging is made of paper and paperboard, rigid plastic, and glass (Muncke, 2012).

Waxing

Waxing treatment is used for extending the shelf life through coating the surface of horticultural products. The application of the surface coating on fruits is considered as one of several treatments developed to reduce post-harvest losses and to prolong the shelf-life of fruits (Hassan *et al.,* 2014). It retards the rate of moisture loss, and maintains turgor and plumpness and may modify the internal atmosphere of the commodity, and is performed primarily for its cosmetic effect; the wax imparts a gloss to the skin and gives the product a more shiny appearance than the unwaxed commodity.

Drying

Drying is the oldest approach of food preservation (Lau & Taip, 2011) and it is a process of removing moisture through simultaneous heat and mass transfer. It is a classical method of food preservation that provides longer shelf life, reduced weight and volume (Doymaz, 2005), minimizes packaging, storage, and transportation costs, and also enables product storability under ambient temperatures (Lau & Taip, 2011; Sobukola *et al.,* 2007). Drying can discharge approximately 80 - 90% of the water from the fresh product and preserve large amounts of the nutrients (Kaleem *et al.,* 2016). It causes a reduction in water activity to lower the moisture content of foods, prevents the growth of microorganisms, and hence reduces the rate of chemical reaction that causes spoilage (Lau & Taip, 2011). In food industries, drying methods and dehydration techniques enable the preparation of widespread dried products and foods from fruits and vegetables. However, drying has a tremendous advantage for different foods, it has also some disadvantages that can reduce /eliminate essential vitamins, antioxidants and reduce consumer acceptability (taste and color change) if the proper drying technology cannot be applied.

Product quality of dehydrated fruits is crucial, which should have to take into consideration while the optimization of innovative drying technologies consisted of the appropriate pre-treatments and techniques of dehydration. Likewise, it's important to determine the appropriateness of dryer in the drying of fruits as the physical properties of fruits may change when various drying practice is applied. Selecting appropriate/innovative drying technologies for fruit and vegetable should be a major concern because the dried product may not be good in terms of acceptability and nutrient value for the consumer if appropriate drying technology cannot be applied. The innovative dryer technology must be able to minimize the physical properties change of fruit to increase the dried product marketability.

Table 1; Nutrient retentions at different drying methods.

Research Conditions	Summary of findings	Reference
Fresh papaya fruit was analyzed (n=6) for beta-carotene determination using HPLC.	From six samples of fresh papaya, the beta carotene was ranged from 153- 219 µg/100 g	*(*Pritwani & Mathur, 2017*)*
Golden' and Sunrise Solo' papaya varieties at two different ripening stages	Carotenoid levels increased during ripening, with all-trans-lycopene varying from 0.73 to 1.58 µg/g in the 'Golden' and from 0.68 to	*(*Martins *et al.,* 2016*)*

	1.67 µg/g in the 'Sunrise Solo', and All-trans-β- cryptoxanthin content varied from 1.29 - 3.0 µg/g in the 'Golden' and 0.28 -5.13 µg/g in the Sunrise Solo'	
Two papaya fruit (Tainung (Formosa') & solo (Golden cultivar)) at present 75%, and 100 % yellow color maturation stage of the skin surface.	Results revealed that during the ripening of papaya in both varieties, the Vitamin C and beta- carotenoid content were increasing.	*(*Souza et al., 2008*))*
At different ripening stages of (Honey Dew) papaya varieties. 1) light yellow ripe and 2) deep yellow ripe. Deep yellow ripe fruits were further studied for storage at room temperature for 24 and 72 h.	The beta-carotenoid content (mg/100g); Light yellow ripe; 1.25; Deep yellow ripe; 3.71; Deep yellow ripe after 24 hours; 2.93; Deep yellow ripe after 72 hours;2.41. Fruit maturity studies stated that total carotenoids content was nearly doubled (22 mg/100 g) while β-carotene content showed increment about three-fold through ripening when compared to contents of light-yellow ripe fruit. In 24 h storage, the total carotenoids content was not altered significantly ($p<0.001$). After 72 h, these two carotenoids as well as the total carotenoids content of the fruit was diminished. Vitamin A activity reduced as the storage time was extended from 24 to 72 h.	*(*Bhaskarachary, 2008*)*
Effect of blanching, and temperature Raw papaya was blanched in water with 0.2% Calcium lactate at different temperature and time (100^{O}C, 5second;95^{O}C,10seconds; 90^{O}C,15seconds;85^{O}C,20seconds). Then treated samples were dried heat pump at 50^{O}C until 12% moisture.	Treated papaya at 95^{O}C for 10 seconds in the presence of Calcium lactate 0.2% and then being dried by a heat pump dryer at 50^{O}C were the effective methods to retained more vitamin C and Beta- carotenoid.	*(*Minh *et al.,* 2019*)*
Drying effect Fresh ripe papaya fruits were sliced in different thicknesses (3mm,5mm, and 7mm) respectively, for drying, then dried at 60° C in the oven and in lyophilized. The drying times were found as 7 to 9 h and 10-12 h for the	The drying time increased with the increase in sample thickness. Total carotenoid and ascorbic acid content in freeze-dried papaya powder was 15,535µg/100g and 54.07 mg/l00g, respectively whereas in oven-dried total carotenoid and ascorbic acid content was 1509 µg/100 g and 7.13 mg/l00g respectively.	(Hemlata *et al.,* 2014)

oven and freeze-drying, respectively.	Freeze-dried has more retention of nutrients than oven-dried. Sensory evaluation of papaya powder revealed that freeze-dried papaya powder had better quality than oven-dried.	
Papaya fruit was cut into (2 × 2 × 2 cm3) cubes and using freeze-drying frozen at −20 ± 1 °C for 24 h.	Beta-carotene (Fresh; 243.26 ± 28; Freeze-dried; 223.42 ± 24.08 (µg/100 g); for Ascorbic acid (Fresh; 16.57 ± 0.36; Freeze-dried; 16.84± 2.31 mg/100g). Freeze-drying did not exert any considerable effect on β-carotene and ascorbic acid concentration of papaya fruit.	(Shofian *et al.,* 2011)
Fresh papaya with 11-12 ºBrix samples cut into cubes of 1.5 cm3. As osmotic treatment solution (60%(w/w) sucrose, 0.1M $CaCl_2$, and 0.1M lactic acid), fruit/solution ratio of 1:10 was used & immersed for 24 h. Hot air drying (HA) at 60 °C and air velocity at 1.5 m/s for 18 h (untreated) and for 32 h (osmotic treated) to achieve a moisture content of 17% dry basis.	Fresh papaya; 9.36±0.659(µg/100 g); Untreated papaya in (HA);6.80±0.48(µg/100g); Osmotic treatment; 4.59±0.22 (µg/100 g); Osmotic treat-HA;3.87±0.19 (µg/100 g). In all treatments, the beta-carotenoid content is decreased.	(Siriamornpun *et al.,* 2015)
1. subject to Sun dried at least 8hours). A minimum temperature of 30 - 35 ºC is required with humidity below 60% 2. Samples were pre-frozen in a -70 °C freezer overnight. 3. Oven Dray method, 60 ºC for 24 hours to reach 10% moisture content 4. Deep Freeze method, at -70 and 80 °C for 24 hours.	Fresh; 5.84 mg/100g without drying; Freeze-dried; 8.80 mg/100g; Sun-dried; 2.96 mg/100g; Oven-Dried; 3.44 mg/ 100g; Deep freeze; 4.56 mg/100g. The result showed that Freeze-Dried samples had the highest vitamin C levels (5.84 ± 0.83 mg/100g) while Sun-Dried has the least value of vitamin C (2.96 ± 0.47 mg/100g). In conclusion, the Freeze-Dried method resulted in the highest vitamin C retention. The highest retention of vitamin C will indicate the highest retention of other nutrients because vitamin C is easily lost.	(Mustapa & Ahmad, 2019)).
Effect of drying/methods of drying	The beta-carotenoid contents of (µg/100 g); Freshly cut fruit cubes; 7616; Sun-drying; 1602; Solar cabinet drying 3130 whereas the total carotenoid content of (µg/100 g); Freshly cut fruit cubes; 27440; Sun-drying; 10373; Solar cabinet drying;13316. Papaya pulp dried in solar cabinet drier retained carotenoids better than sun drying.	(Bhaskarachary, 2008)

3. Material and Methods

3.1 Study Area and Materials

The study was conducted at Melkassa Agricultural Research Center (MARC) of the Ethiopian Institutional of Agricultural Research. The center nationally coordinates the Horticulture Crop Research Program (Lowland fruit & vegetables) and it is found in the Ethiopian rift valley, 117 km away from Addis Ababa in the southeast direction located at 8024'N and 39 012'E and an altitude of 1550 meter above sea level. The mean minimum and maximum temperatures of the environment are 13.8ºC and 30.6°C respectively. The research centers might be suitable for drying of horticultural crops because the area is classified as hot. The center gets a mean of the total annual rainfall of 825.9 mm with erratic distribution, having a high coefficient of variation in amount, and the soil pH that horticultural crops grow ranging from 7 to 8.2.

Driers such as Oven, Solar-tray, Refractance window, solar-open, solar- Glass house, and Freeze (control) drier were used.

Instruments; High-Performance Liquid Chromatography (HPLC), UV-visible spectroscopy, Hunter Lab chromameter (colour).

Equipment; pH meter, magnetic stirrer & stir bar, automatic titrator, colony counter, Digital burette.

Reagent and Chemicals; Standard β-Carotene and All other analytical grade chemicals were purchased and used.

3.2 Experimental Design

A completely randomized design (CRD) of two factorial experiments with three replications was implemented. The research was conducted with two factors such as drying methods (oven, solar, glasshouse, sun, and window Reactance dryer) and treatment (pre-treated, and untreated) on the retention of papaya nutrients with a total of 2*5 treatments with one control was used.

3.3 Study Design

The study was conducted in Melkassa Agricultural Research Center in Food Science and Nutrition Research Laboratory. In this research, a completely randomized design (CRD) with the factorial experiment of three replications was used. For this investigation samples of papaya were collected from the personal farm area which is around Melkassa Agricultural Research Center using a purposive sampling method. The collected yellow pulp papaya samples were stored at room temperature until fully ripened cheeking via skin color (> 75 %

yellow), total soluble solids (TSS), and P^H value, and then prepared for drying with appropriate slicing (diameter of 5-6 mm). Sliced papaya samples were homogenized and distributed for each drier of the oven, solar-tray, refractance window, solar-open, solar-glass house, and freeze (control). Then dried papaya samples were subjected to nutrient, microbial, and sensorial analysis using a recommended methods and instruments. Finally, the results were analyzed via SPSS-23 software using analysis of variance (ANOVA) and independent T-test, and $P < 0.05$ value considered as statistically significant.

3.4 Sample Collection and Preparation

Matured papaya (*Carica papaya* L.) with yellow pulp fruit were collected from farmers growing areas. The papaya samples were allowed to uniformly ripe for 4-7 days of storage until 75% of the skin color changed to yellow (Purposive Sampling Technique).

Figure 5; Matured papaya fruit (left), and ready for drying (right).

Besides, the color of skin, the ripening index of the papaya was further evaluated by analyzing the total soluble solids (TSS) measured with a portable digital refractometer (China, Mainland) and pH measured using a portable pH meter (baoshishan, China). Peeling and slicing of the papaya were conducted by hand with proper slicing, a diameter of 5-6 mm, checked with a digital calliper (kotapro, China). The sliced portion of the papaya sample was divided into two portions, where half was treated by soaking in ascorbic acid solution (34g prepared in 1 L water), and the other half was left untreated. The ascorbic acid treatment was according to (Kendall & Sofos, 2007). Pre-treatment of fruit drying prevents discoloration of the fruit’s flesh before and during the drying process as well also can slow oxidation reactions and prevent browning (Osae et al., 2020).

Figure 6; Papaya sample preparations for drying

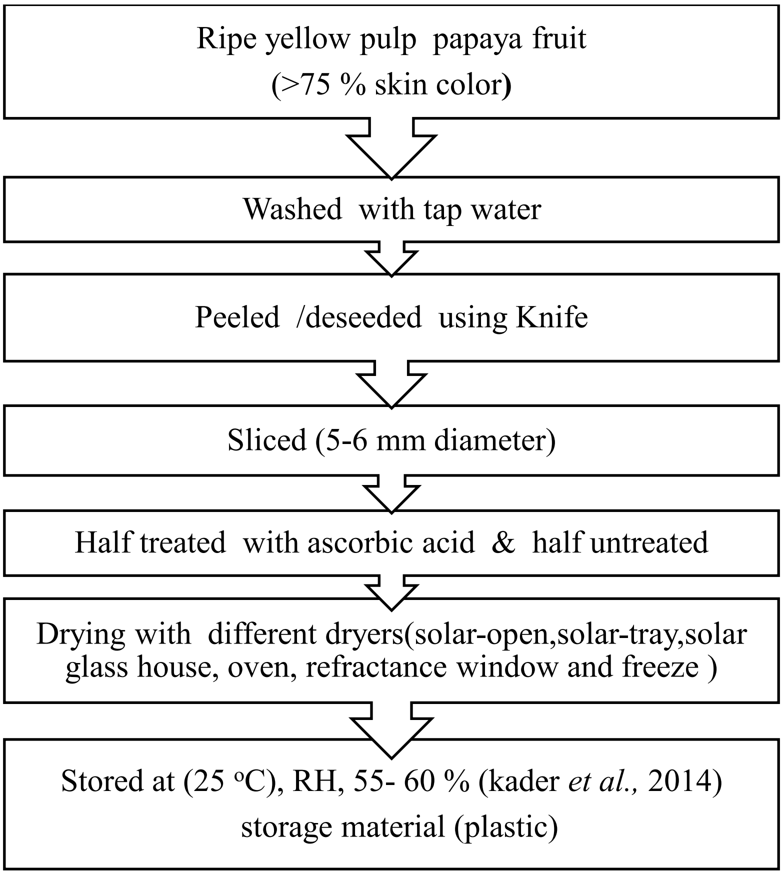


Figure 7; Processing flow chart for papaya fruit drying

3.5 Methods

Drying techniques

Apart from the freeze and oven dryer, all the others were locally adapted technologies.

(1) Drying Materials; Plastics with a sieve size of 5 millimeters (made in china) and resistance to heat up to 80 °C were used for all the dryers except for window refractance dryer.

Figure 8; Papaya drying materials (plastic, sieve size 5-mm diameter, china)

(2) Solar-Open Drying (Direct); It was conducted by laying the sliced papaya on a plastic covered with a plastic mesh. The drying was based on direct exposure to the sun, it is the most ancient method of drying foods and still in use in many parts of the world (Sagar & Kumar, 2010). Drying in the sun is cheaper as it has little or no equipment costs and the product has to spread on suitable surfaces and allowed to dry in the sun. Continuous follow-up throughout the drying period is mandatory because it is exposed to wind, dust, or rain and domestic animals. In this experiment, a maximum of 18 hours was taken to dray papaya slice chips with a moisture content of 12.34 %.

Figure 9; Papaya drying with direct sun (solar-open) and its dried product

(3) Solar-Tray Drying (Indirect); It was designed and constructed at the Melkassa Agricultural research center, Agricultural Engineering Research Process. Its temperature range (37-53 °C) is almost similar to (Vegagálvez *et al.,* 2019) which is locally constructed. Conducted on a drier that has inclined tray holders with a black sheet background for the absorption of solar rays. The tray holders are then covered by a glass. solar drying is similar to sun drying, in which the sun is used as a source of energy to dry the products. In direct sun drying, the sliced fruits were placed in the open air which has a chance to contaminate dried products, and efforts to improve sun drying have led to solar drying. Solar drying is an efficient system for utilizing solar energy (Janjai *et al.,* 2009). The sliced papaya took 16 hours for drying with a moisture content of up to 13.01%.

Figure 10; Papaya drying with solar-tray drier and its dried product

(4) Solar- Glass House Drying (green-house); This is a green-house whose walls and roof are made from glass. Freshly sliced papaya fruits were placed, spread evenly on a plastic mesh, the temperature ranges from 35-55 ºC. The place where the papaya slice is placed massive, that the hot air accumulated inside the room is easily moved, it can be used for large-scale processing. Sliced papaya samples were drying for a maximum of 17 hours with a moisture value of 12.90 %.

Figure 11; Papaya drying with solar-glass house(Indirect) and its dried product

(5) Oven drying; It was conducted in a ventilated laboratory oven (DHG-9123A Zenith Lab, China), hot air-drying method, freshly sliced sample was spread evenly on plastic mesh and placed in a conventional laboratory oven at a constant temperature of 60 ºC for 21 hours to reach 10% -12 % moisture content (Workneh *et al.,* 2014). The basic principle involved in the oven drying technique is the transfer of heat energy by convection from the hot air to the product surface (Castro *et al.,* 2018). However, conventional thermal treatments function at a higher temperature in the falling rate period and have prolonged drying time. This afterward leads to thermally degraded end-products that are unwelcome (Demiray *et al.,* 2017).

Figure 12; Papaya drying with oven and its dried product

(6) Refractance Window Drying; The technology was locally adapted by the Ethiopian Institute of Agricultural Research, Melekassa Agricultural Research Center, Agricultural Engineering Research Process. This drying works on the principle of heat transmittance from boiling water. Reflectance window drying is a recent non-thermal method for drying products (Forero *et al.,* 2015). In this drying technology, the samples were taken~1:45 hours with a moisture content of 10.50 %.

Working Principles of Reflectance Window Dryer

The sliced papaya fruit over a thin infrared transparent material polyethylene film (such as Mylar® film, 0.03 mm) (brought from abroad) resting over the surface of water gets heated.

Figure 13; Papaya drying with refractance window and its dried product

Thermal energy carried by hot water (maintained 94- 98 ^{0}C) transmits sensible heat through the film to the food material by conduction and radiation and then water in the food is quickly evaporated. Heat gets transferred to the water molecules directly and product temperatures can reach up to 74 ºC (Castoldi *et al.,* 2015).

(7) Freeze Drying(Control); Sliced papaya samples were also dried using a laboratory-scale lyophilizer (freeze dryer) (Scientz-10N, China), which yields maximal retention of nutrients and bioactive compounds (Marques *et al.,* 2006). The results of the other dried papaya nutrients were calculated relative to freeze-drying.

Figure 14; Papaya drying with freeze drier and its dried product

Weight loss and Yield

The collected matured papaya samples were placed at room temperature until full ripening (>75%) / ready for drying, during this process the weight of the papaya fruit right after harvest (day 1) till ripening (days 4-7) were recorded. After ripening, the weight losses related to peeling, removal of seeds, slicing, and drying were recorded to calculate the average yields (%).

Temperature and relative humidity

Temperature and relative humidity during drying were measured using a portable device (Vici 288B-CTH, Guangdong, China)

Analytical procedures

Total soluble solids (TSS)

Total soluble solids were evaluated by direct putting the papaya juice to a digital refractometer optical prism (Type ATAGO, Model-9099) and the results were expressed in Brix (Horwitz, 2000).

The pH

The pH of the fresh juice papaya sample was measured in a pH meter (baoshishan, China) formerly calibrated with buffer solutions of pH 4 and 7 at 20°C to estimate the ripeness.

Titratable Acidity

Titratable acidity (TA) was determined by the alkaline titration method of (AOAC, 2006) with 0.1 N NaOH to an endpoint of pH 8.2. The endpoint is indicated by a change in the color of the sample to pink. The pH electrode was calibrated using standard solutions of pH 7.0 and 9.0 before use. The amount of acid in milligram per hundred grams (mg/100g) is calculated as stated below.

$$\% \, Acid = \frac{[\text{NaOH used}] * [0.1 \text{ N NaOH}] * [\text{milliequivalentt factor}] * 100}{grams \; of \; sample \; used} \text{---------------------(1)}$$

Moisture Content

The moisture content was measured before and after drying by oven drying at 105 °C to constant weight (protocol no: AOAC. 925.10; AOAC International, 2007). About 2 g of papaya samples weighed in an Aluminium tin and a sample containing tin placed in the drying oven and until the constant weight of the sample is maintained. Then the dried samples were removed and placed in desiccators to cool until maintaining the heat and then reweight.

$$Moisture(\%) = \frac{(W1-W2)*100}{Sw} \text{--------------------------------(2)}$$

Where; W1; a weight of Aluminium tin and a sample before; W2; a weight of the dry sample and Aluminium tin and SW; sample weight

Water Activity (Aw)

The water activity (Aw) values of dried papaya powder were measured according to the method described by (Koç *et al.,* 2011) with a water activity measurement device (Wert-Messer, Germany), with a ±0.001 sensitivity at 25˚C by direct reading.

Rehydration of Papaya

Rehydration experiments were carried out in distilled water at 45ºC as described by (Ranganna, 1986). Fruit samples (10 g) were added to 100 mL of water and mixed well. Samples were allowed to rehydrate for 5 h, and the rehydration temperature was kept constant using a water bath with adjustable temperature control. After the rehydration period, the excess water was drained out.

$$\text{Rehydration Ratio (Rr)} = \frac{\text{Wr}}{\text{Wd}} \text{-----------------------------------}(3)$$

Rr was expressed as a ratio of water absorbed by the dried sample (Wr) to the weight of the dried sample (Wd) (Horwitz, 2000).

Vitamin C

Methods of Vitamin Assay Third Edition 1966 (Freed, 1966) using UV-visible spectroscopy (Shimadzu -UV-1800, Japan) was used. Five grams of papaya sample extracted with 100ml of 6% trichloroacetic acid mashing with mortar & paste for 2-5 minutes, centrifuge the extracted solutions and then removed suspended solids through filtrations. Two droplets of saturated bromine solution were added in a sample containing flask and then Aeration. In 10ml aliquot, 10ml of 2% thiourea was added, and then pipette 4ml from the mixture into two different test tubes and one as a blank. To each of the remaining tubes, 1ml of 2,4-DNPH was added and let them put all test tube in the water bath at 37ºC for 3 hours and cool in an ice bath for approximately 5 min and then added 5ml 85% H_2SO_4 slowly while the tubes are in an ice bath. Add 1ml of 2% DNPH to the blank and mix all tubes and then standing all tubes at room temperature for 30 min. Finally, the absorbance of the standards, blanks, and test samples at 515 nm was recorded, and calculated as follows.

$$Ascorbic\ Acid\ (mg/100g) = \frac{[(As - Ab) * 10]}{[A10\mu g\ Std - Ab]} \text{----------------------------}(4)$$

Where: As =Absorbance of samples; Ab = Absorbance of blank;

A10 µg Std. =The absorbance of 10 µg AA standard

Total Carotenoids

Total carotenoids were performed following methods described by the Harvest Plus handbook as described by (Rodriguez & Kimura, 2004). Briefly, 5 g of dried papaya samples were ground in 40 ml acetone using mortar and pestle until turn out to be colorless. The extract was vacuum-filtered using a Buchner funnel, partitioned with 60 ml of petroleum ether, and then each fraction was washed with distilled water for complete acetone removal. The extracts were made up to a volume of 50 mL with petroleum ether. All of the procedures were performed in dim light, and the absorption of the extract was read at 452 nm using a UV spectrophotometer (Shimadzu UV-1800, Japan). The total carotenoids concentration was calculated by applying the following formula.

$$TC(\mu g/g) = \frac{(\mathrm{A} \times \mathrm{volume\ (mL)} \times 10000)}{(\mathrm{A1cm1\%} \times \mathrm{sample\ weight\ (g)})} \text{-------------------------------------}(5)$$

Where; TC= Total carotenoids; A = absorbance; volume = total volume of extract; A1%1cm=absorption coefficient of β-carotene in petroleum ether (2592).

Beta- Carotenoids

Extraction: For the extraction of β-carotene, the procedure outlined in AOAC Official Method 941.15- 'Carotene in Fresh Plant Materials and Silages' as mentioned by (Pritwani & Mathur, 2017) was followed. Briefly, 5g of dried papaya sample was mixed with 40 ml acetone, 60 ml petroleum ether, and 0.1 g magnesium carbonate. The extract was filtered using a suction pump and decanted in a separator funnel. The residue was washed with 25 ml acetone, then with 25 ml petroleum ether and the extracts were combined and evaporated to dryness. The residue was further dissolved in acetone. The extract solution was made up to 5 ml using acetone, filtered through syringe (0.45µm), and then injected into the high-performance liquid chromatography (HPLC; Shimadzu, Japan, Kyoto) with a C18 column (5 µm C18, 4.6 × 250 mm, USA) equipped with a UV detector. The peak responses of β-carotene were measure at wavelengths of 450 nm (Sungpuag *et al.,* 1999). The following conditions were set for the HPLC reading: mobile phase: acetonitrile 60%, methanol (30%) and acetone (10%); injection volume: 20 µl; flow rate: 2ml/min; wavelength: 450 nm. The β-carotene concentration (µg/g) was calculated using the following formula.

$$\beta - \mathrm{carotene}\ (\mu g/g) = \frac{\mathrm{AX} \times \mathrm{CS}\ (\mu g/ml) \times \mathrm{total\ volume\ of\ extract\ (ml)}}{\mathrm{AS} \times \mathrm{sample\ weight\ (g)}} \text{----------------}(6)$$

Where: Ax = peak area of carotenoid of a sample; Cs = concentration of the standard; As = peak area of the standard;

Retinol Equivalent (RE)

The β-carotene (μg) was converted to retinol equivalent (RE) by multiplying by 0.167 and was compared to estimated needs from complementary foods (Lutter & Dewey,2003) and daily requirements for lactating and pregnant women (Organization, 2004).

Standard Preparation of Beta Carotene

Standard of beta carotene (1g enclosed in a vial) (Sisco Research Laboratories Pvt. Ltd. (India) was purchased. The standard was prepared by acetone which is extracted solvent for the sample and also the mobile phase. A stock solution of beta-carotene was prepared by taking 10mg in 100ml acetone with the concentration of the stock solution was equal to 100 ppm. A series of standard solutions were prepared from known concentrations of stock solution e.g., 15, 30,45, and 60 ppm dilutions with 5 ml of each acetone solution.

Lycopene

Lycopene was determined as per (Barrett & Anthon, 2000). In brief 0.1 g papaya sample was mixed with 7 mL of 4:3 ethanol/hexane in a tube and covered with aluminum foil, and then the sample containing the tube was placed in crushed ice and shaken for 1 h. After which, 1 mL of distilled water was added and shaking was continued for a further 5 min. Organic (hexane) phase, a sample containing was read at 503 nm UV-Visible (Genesis 10 UV-Vis spectrophotometer (Thermo Electron Scientific Instruments LLC, Madison, WI, USA). Pure hexane used as a blank, and Lycopene in the hexane extract calculated according to;

$$\text{lycopene}\left(\frac{\text{ug}}{\text{g}}\right) = \frac{(\text{Abs} \times 537 \times 2.7)}{(0.105*172)} \text{--} (7)$$

Where; 537 g/mole is the molecular weight of lycopene, 2.7 is the volume (mL) of the hexane layer, 0.1 g is the weight of sample added, and 172 mM^{-1} is the extinction coefficient for lycopene in hexane.

Colour Measurement

The color of dried papaya samples was measured by reflectance measurement using Hunter Lab, (Aeros, Dual-beam Non-contact Reflectance Spectrophotometer (USA) as described by (Almeida *et al.,* 2014). The reflectance of the whole visible spectrum (420 to 700 nm) was recorded at a wavelength interval of 10 nm. D65 lamp, used as a reference light source, and the detector was fixed at an angle of 101 concerning the light source. The equipment was calibrated before use with a standard white tile and a black box for 100 and 0% reflectance, respectively.Color parameters used were CIE L∗(lightness/whiteness), a∗(redness/greenness), b∗(Yellowness/blueness) uniform color space. Dried papaya color results reported in terms of 3-dimensional color values based on the following rating scale:

L* value whiteness 100 white, 0 black

a* value positive values (red color), negative values (green color)

b* value positive values (yellow color), negative values (blue color)

The total color change difference of the dried papaya along with lyophilized (Maskan, 2001) was also calculated as follows.

$$\Delta E = \sqrt{(Lo - L)^2 + (ao - a)^2 (bo - b)^2} \text{-----------------------------------(8)}$$

where subscript "o" refers to the color reading of lyophilized dried papaya. Lyophilized dried papaya was used as the reference and a larger ΔE denotes greater color change from the reference.

Bioactive Compound Analysis

Sample Extraction

Extraction was done as described by (Zuhair *et al.,* 2013). Two grams of dried papaya sample was dissolved with 30 ml of 80 % of acidic methanol (with 1% HCl) and extracted for 2 hours at 35 ^oC using an electrical shaker. Then the extracted sample was centrifuge at 5000 g/ min and then the supernatant was collected for further analysis.

Total phenolic content

The total phenolic compounds of extracts were determined with the folin-ciocalteus method (Singleton *et al.,* 1999). Crude extract of 100 µL (10 mg/ml) was mixed with 0.2 ml folin-ciocalteus reagent (1: 9 ml distilled water ratio), 2 ml purified water, and 2 ml of 7.5 % Na_2CO_3. The mixture was incubated for two hours at room temperature, before reading, then the absorbance was recorded at 765 nm against Gallic acid standard, using UV-Vis spectrophotometer (Genesys-10 UV, USA). The total phenolic compounds concentration was calculated and expressed as Gallic Acid Equivalent (GAE), as follows:

$$C\left(\frac{mg}{g}, in\ GAE\right) = \frac{C1 * V}{m} \text{------------------------(9)}$$

Where, C = total phenolic concentration in mg GAE/g sample; C1 = concentration of Gallic acid established from the calibration curve in mg/ml, V = volume of extract in ml; and m = the weight of the papaya extract in g.

Standard Preparations

The standard gallic acid solution was prepared by dissolving 10 mg of it in 10 mL of methanol (1 mg/mL). Various concentrations of gallic acid solutions in methanol (5, 10, 20, 40, 80, and 10 mg/ml) were prepared from the standard solution. To each concentration, 0. 2 mL of 10% Folin–Ciocalteu reagent, 2 ml purified water, and 2 mL of 7.5 % Na_2CO_3 were added making a final volume of 4.3 mL. The total phenolic content was expressed as gallic acid equivalents using the linear equation based on the calibration curve (Gallic equivalent (mg of GAE /g of sample).

Total Flavonoids

The total flavonoid concentration was determined using the spectrophotometric method described by (Quettier-Deleu *et al.,* 2000). Two (2ml) of the extracted sample (10mg/ml) were mixed with an equal amount of 2% $AlCl_3$ solution in methanol. The mixed solution was incubated for 1 hr at room temperature and the absorbance was read at 415 nm against a quercetin standard, using a UV-Vis spectrophotometer (Genesys-10UV- USA). The concentration of flavonoids was expressed as quercetin equivalent (mg of QAE /g of sample), using the following equation:

$$C\left(\frac{\mathrm{mg}}{\mathrm{g}}, \text{in QE}\right) = C1 * \frac{V}{m} \text{ -----------------------(10)}$$

Where; C = Total flavonoid content in mg/g, in QE (quercetin equivalent), C1 = concentration of quercetin established from the calibration curve in mg/ml, V = volume of extract in ml, and m = the weight of the papaya extract in g

Standard Preparations

Stock solution (1 mg/mL) of quercetin was prepared by dissolving 10 mg of quercetin in 10 mL of methanol and then the standard solution was diluted serially to make various concentrations of 0.5, 1, 2,3,4, 5, and 6 mg /ml) solutions. The total flavonoids content was expressed as quercetin equivalents using the linear equation based on the calibration curve (quercetin equivalent (mg of QAE /g of sample).

Organoleptic Evaluation of Dehydrated Papaya

Organoleptic evaluation for the dehydrated papaya chips was carried out in this experiment using rating acceptance sensorial evaluations of a 7- hedonic scale (where 1 indicates “extremely dislike” and 7 represents “extremely like” as mentioned by (Addai et al., 2016). Dried papaya samples were evaluated for their sweetness, color, flavor, texture, and overall acceptability by 13 semi-trained panellists. Sensorial analysis of dried papaya chips was conducted in Melkassa Agricultural Research Center in Food Science and Nutrition lab. The panellist also from Melkassa Agricultural Research Centre, who has experience in doing sensorial analysis in Melkassa Agricultural Research Center in Food Science and Nutrition lab. Panellist are BSC as well M.Sc. holders, and also not addicted to any drug and medication.

Microbiological Tests

Total Viable bacteria and fungus count of dried papaya fruit were conducted according to (Bolton, 1990), using recommended method. A 10-gram sample was added with 90 ml sterile peptone water and blended for 1 min. The aliquots were further diluted to obtain 10~^{1}, 10~^{2}, and 10~^{3} for both bacteria and fungus. From each dilution, 1.0 ml was transferred aseptically to Petri dishes, poured with plate count agar for total bacteria, and acidified potato dextrose agar for total fungus (mold, and yeast), and incubated for 2-5 days at 37 and 30°C, respectively. Then using the colony counter, colonies were counted, reported as colony-forming units per gram (CFU g−1).

Shelf Life study

The shelf life study of dried papaya was evaluated every month for six months of storage. Samples were stored at a controlled oven which was set a temperature of 25°C and relative humidity of 55- 60 %. Shelf life study was evaluated for the total carotenoid, beta-carotene, water activity, moisture content, total phenolic, total flavonoid, color change, and microbial loads of dried papaya products. For each parameter, similar methods like as mentioned previously were used.

3.6 Statistical Analysis

The nutrient retentions, polyphenolic, physio-chemical, and color of the dried papaya chips mean comparisons for drying methods and storage shelf-life stability were performed using analysis of variance (ANOVA), Tukey-HSD Post-Hoc test whereas mean comparisons between treatments (ascorbic acid-treated and untreated) samples, and microbial loads (between month for each drier) were performed using an independent t-test. All analyses were performed using SPSS software version 22.0 (SPSS Inc. Illinois, USA), and values are presented as means ± standard deviations (SD). P-values < 0.05 were considered statistically significant.

4. Result and Discussion

Dried fruit product quality is critical, which has to be taken into consideration during drying. Therefore, determining the appropriateness of a dryer in the drying of fruits is a critical issue due to the physical and chemical characteristics of fruits may change, if a diverse drying practice is implemented. At present, the degradation of dried fruit product nutrients is due to the application of drying which is the major concern. It must be able to minimize the change of physical properties of fruit to increase the dried product marketability, and to produce a desirable product. The present study aimed to evaluate the nutritional impacts of papaya through different drying techniques, and shelf stability of dried papaya products. Of which solar -open, solar-tray, solar-glass house, oven, and refractance window dryer are among the drying materials used for this investigation.

4.1 Characteristics of Fresh Papaya

In this study, fresh yellow papaya samples were collected and allowed to uniformly ripe, and then the fresh ripened papaya samples were subjected to analyze their pH value, total soluble solids (TSS), titratable acidity, and moisture contents before drying. The variety, maturity, moisture content, and pH can all affect the nutritional quality of the papaya fruit. The characteristics of the fresh papaya fruits are presented in Table 2. In the existing study, the papaya fruit had high moisture content (87%), which is classified under highly perishable fruit as reported by (Sagar & Kumar, 2010) which stated that fruit and vegetable having moisture content > 80 considered as highly perishable. Along with slightly acidic pH, and the TSS values (10.3-11.2) indicated that the papaya was ripened at a physiological maturity level of 4 (75% yellow) and was ready for consumption (Barragán *et al.,* 2018). The fresh papaya characteristics such as moisture content, total soluble solids, pH, and titratable acidity values of the present study is in with the research findings of Masresha and Mulate ., (2020). Yellow color in the fruit skin and TSS value has been used as a harvest index criterion to assure adequate ripening and maximum shelf life for consumption.

Noticeably, different values of physio-chemical, proximate composition and other anti-oxidant properties of fresh papaya may present because it depends on cultivar variation, growing location, sunlight exposure, agricultural practices, stage of ripeness, and postharvest handling (Ikram, *et al* 2015).

Table 2; Selected characteristics of the fresh papaya

Fresh Papaya characteristics	Mean ± SD
Moisture	87.2 ± 1.6
pH	5.3 ± 0.1
TSS (°Brix)	10.3 ± 0.5
TA (Citric Acid) %	0.14±0.01
Fresh weight (g)	
Harvesting date	1407 ± 260
After ripening (7 days of ripening)	1292 ± 256

❖ Data are expressed as mean + SD (n =3). TSS, total soluble solids, TA, Titerable acidity

4.2 Fruit Weight Loss (During ripening & drying) and Yield

Matured yellow pulp papaya fruit was placed at room temperature and the fresh weight was taken and their weight until 6-7 days of ripening also recorded. Some papaya fruits were ripened completely after 4 and 5 days and while others were delayed until 6 -7 days, and then the fruit goes to more ripened and juicier. Part of water was lost during the ripening process as fruit can sustain significant weight loss due to transpiration and respiration with only a minor reduction of food quality (Ferris, 1991), but their weight loss was different for different fruits. In this study, the maximum, fruit weight loss during storage for uniform ripening (>75 % yellow skin color) was found up to 8.47 ±1.8 % as shown in Figure 15.

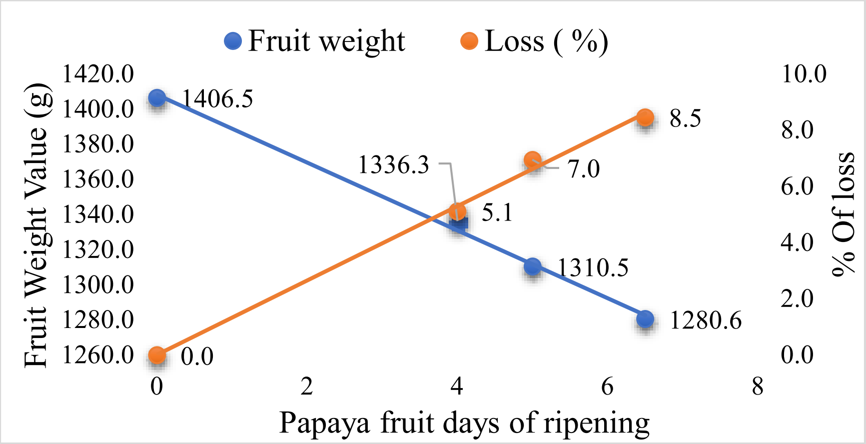


Figure 15; Weight loss during ripening of matured papaya.

On the other hand; yield loss was recorded during sample preparation (peeling, slicing, and weight of seed), and drying with different dryers. Currently, consumption of papaya fruit is increasing, but it has a greater size than most fruits and heavier, and as a result, a significant number of wastes, in terms of peels and seeds are expected. Thus 20 -25% of the product constitutes papaya fruit weight, which consists of 12% peels and 8.5% seeds lost (Pavithra *et al.,* 2017). Most of the papaya fruit contains more seeds while others have low seeds, which could have a negative impact on the weight loss of the papaya product. The peel of papaya also one of the discarded parts during drying beside the seed, and its final weight was covered in the range of 84 - 403 grams from 1406.5 gram.

During the drying of fruit, the highest percentage of fruit loss was observed because the greater portions of the fruit are water, and the water is easily removed when it gets heat. It discharges approximately 80 - 90% of the water from the fresh product and preserves large amounts of the nutrients (Kaleem *et al.,* 2016). Pandey *et al.,* (2014) found that from 1 kg fresh ripe papaya yielded, 150 g and 190 g of freeze-dried and oven-dried papaya powder. Findings are in agreement with the result of Sunita (2005) who reported that drying causes a significant loss of weight due to the removal of moisture content. From the pulp for drying, 10.9 ±1.4 % of the result was covered dried product while 89.1±1.4 % was lost. The papaya fruit peel and seed weight coverage and pulp discarded and pulp dried product is presented in figure 16.

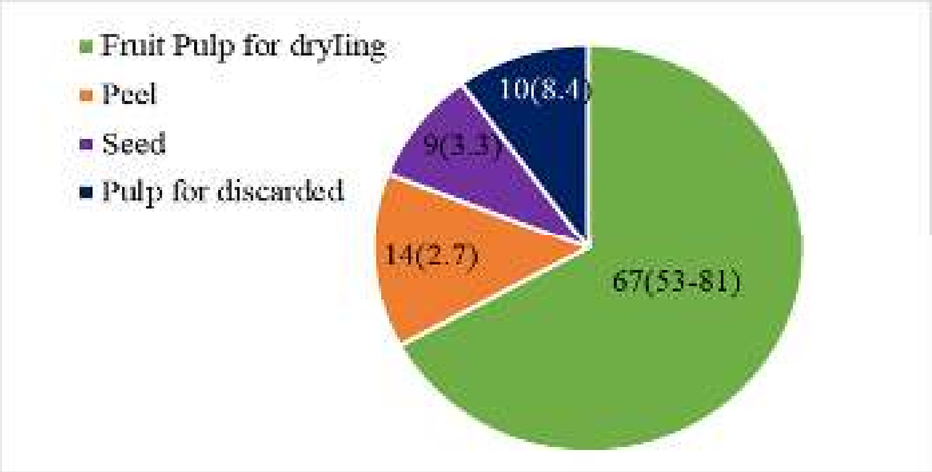


Figure 16; Proportion of peel, seed, and pulp in hand-prepared fresh papaya

Values are percentages (standard deviations); the proportion of the pulp for drying is calculated based on values of the peel, seed and pulp discarded; Values in parenthesis represent the expected range.

Environmental Conditions

Recording and measuring the environmental conditions of temperature and relative humidity is a very critical aspect for drying technology because it proved (1) the data produced with existing environmental conditions (2) the environmental conditions operating properly and producing the desired conditions (3) affect the quality of the resulted dried product. In this research, the environmental conditions of temperature and relative humidity for solar-energy dryers and time taken for drying of papaya sample were recorded, the values are the mean value of two (2) days drying time-temperature and relative humidity, and presented below in Table 3.

Table 3; The average drying time and environmental conditions (^{O}C & % RH)

Dryer type	Drying Time (hrs.)	Environmental Conditions				Temperature
		Temperature (^{O}C)		Relative Humidity		
		Morning	Afternoon	Morning	Afternoon	
Solar-Open	18	29	43	46	16	29 – 43 °C
Solar-Tray	16	37	53	40	16	37- 53 °C
Solar-glass house	17	35	55	35	15	35 – 55 °C
Oven	21	NA				60 °C
Refractance window dryer	1:45	NA				74-80 ^{O}C
Freeze dryer	20	NA				

NA; not applicable

The highest drying time was for oven drying, which took 21 hours to reach a dry matter (DM) of 90% (Table 3). The solar (open, tray, and glass house) drying procedures, all took 16-18 hours to dry, and its dry matter covered in the range of 87 – 89 %, whereas refractance window drying only took 1;45 hours for drying to 90% dry matter. In fact, for solar drying, a longer time is expected due to fluctuating sunlight (ambient temperature) over the product during the drying period (Babu *et al.*, 2018), but in the case of oven drying, it took a long time, this may be probably a load of one-time drying. Indeed, in the refractance window, three modes of heat transfer (conduction, convection, and radiation) occur at the same time (Raghavi *et al.,* 2018); hence, accelerating the drying process.

4.3 Physical Characteristics of Dried Papaya

Physical characteristics such as moisture, water activity, hygroscopicity, and rehydration ratio for dried papaya were estimated. The moisture content of the food matrix and water activity are the two critical factors of food to determines its shelf life, influence how fast organisms will grow in a product, and maybe the most important in a product factor in controlling spoilage. The water activity scale extends from 0 (bone dry) to 1.0 (pure water).

Most food commodities contain sufficient moisture to permit the activity of inherent enzymes and microorganisms, and drying is required to decrease their water activity and prevent microbial spoilage (Ahmed *et al.,* 2013). As a result, papaya fruit was dried through different drying technologies to reduce its water content and water activity to make it shelf-stable. In this research findings, depending on the drying method, the lowest moisture content was observed for oven-dried pre-treated papaya exhibited as 9.34, followed by oven untreated while the highest was for freeze-dried (13.33), which was used as a control (Table 4).

Table 4; Moisture and water activity value of dried papaya (treated and untreated)

Dryer	Moisture		Water Activity	
	Untreated	Treated	Untreated	Treated
Solar-open	$12.34^{aB}\pm1.41$	$12.19^{aB}\pm1.69$	$0.58^{aA}\pm 0.01$	$0.57^{aA}\pm0.01$
Oven	$9.86^{aA}\pm0.48$	$9.34^{aA}\pm0.74$	$0.57^{aA}\pm 0.01$	$0.58^{aA}\pm0.00$
Solar-Tray	$13.01^{aC}\pm1.02$	$12.63^{aB}\pm1.13$	$0.56^{aA}\pm 0.01$	$0.57^{aA}\pm0.02$
Solar- Glass house	$12.90^{bC}\pm0.12$	$11.28^{aAB}\pm0.47$	$0.58^{aA}\pm 0.01$	$0.57^{aA}\pm0.01$
Refractance window	$10.13^{aAB}\pm0.53$	$10.50^{aAB}\pm0.66$	$0.56^{aA}\pm 0.01$	$0.56^{aA}\pm0.00$
Freeze drier (control)	$13.33^{b}\pm0.34$		$0.55^{a}\pm0.01$	

❖ Data are expressed as mean± SD (n=3). The different lowercase letters in the same row and different capital letters in the same column denote a significant difference ($P < 0.05$).

There was no statistically significant difference ($P< 0.05$) between treated and untreated dried papaya for each drier. But differences were observed for both pretreated and untreated dried products of driers ($P< 0.05$) as presented in Table 4. The range of the moisture contents of the dried product was found to be below 15 %. The recommended final values of moisture content for dried fruit are 15% for conventionally dried fruits, and 20-25% for osmotically dried (sugar-treated fruits) (FAO-AGS, 2007). The present research findings of all dried papaya products of moisture content were found below 15%, which is supporting with the reports, and such a low level of moisture content is not favored for microbial growth.

For dried food products to ensure that it is microbiologically stable, the water activity should be lower than 0.600 (Samoticha *et al.,* 2016). A water activity between 0.5-0.6 was achieved for all the dryings of the current research for both treated and untreated dried products, and significant differences ($P< 0.05$) were not observed among the dried products of papaya (treated and untreated)as viewed in Table 4. With such low levels of water activity, the growth of pathogenic and spoilage microorganisms is not favored (Shafiur *et al.,* 2007). The different operating procedures of the dryers explain the different moisture contents and water activities in the dried samples of papaya, even though water activity is not statistically different. Supporting with the current research output, similar research (Vegagálvez *et al.,*

2019) was reported with different drying techniques (freeze-drying, vacuum drying, solar drying, convective drying, infrared drying), that reviled water activity was varied between 0.318 and 0.631, and the moisture content for the dried papaya varied between 7.25 (freeze-drying) and 21.57 g 100 g−1 D.M (solar drying).

In general, both moisture content and water activity values for dried fruit products should be low enough to assure the microbiological stability of dehydrated products. Previous studies report that pathogenic bacteria do not grow in media with lower (0.85) water activity values, whereas molds and yeasts are more tolerant even to water activity values as low as 0.80 (Sagar & Kumar, 2010). Therefore, the dried papaya obtained in this study can be considered as a microbiologically stable product.

Table 5; Hygroscopicity and rehydration ratio of dried papaya (treated and untreated)

	Hygroscopicity %		Rehydration Ratio	
Dryer	Untreated	Treated	Untreated	Treated
Solar-open	$6.51^{aA}\pm0.36$	$13.45^{bC}\pm0.43$	$6.42^{aA\text{-}C}\pm1.0$	$7.53^{aA}\pm0.12$
Oven	$6.18^{aA}\pm0.30$	$6.94^{aA}\pm0.94$	$4.92^{aA}\pm0.82$	$4.64^{aC}\pm0.16$
Solar-Tray	$11.50^{aC}\pm1.13$	$12.41^{aBC}\pm0.33$	$5.80^{aA\text{-}C}\pm0.31$	$4.95^{aC}\pm0.51$
Solar- Glass house	$11.03^{aB}\pm0.43$	$11.74^{aB}\pm0.23$	$7.62^{aC}\pm0.84$	$5.9^{bB}\pm0.15$
Refractance window	$12.22^{aC}\pm0.55$	$11.72^{aB}\pm0.30$	$5.26^{aAB}\pm0.41$	$3.59^{bD}\pm0.44$
Freeze (control)	$9.48^{B}\pm 0.46$	-	$6.85^{BC}\pm0.34$	-

❖ Data are expressed as mean± SD (n=3). The different lowercase letters in the same row and different capital letters in the same column denote a significant difference ($P < 0.05$).

The rehydration index and hygroscopicity of the dried fruit are the two most important physical parameters that can provide valuable information about the final quality of dehydrated products. Rehydration ratio is defined as the water absorption and reconstitution capacity of dried fruits which is aimed at the restoration of previously dried materials in contact with water. The rehydration process is also important for the evaluation of sensory properties (Dadali *et al.,*2008). The degree of rehydration of the dried product is dependent on the degree of cellular and structural disruption (Falade & Abbo, 2007). It is noticeable that dehydration of fruits may bring changes in chemical compositions, bioactive compounds and functional properties, and physical characteristics (Kubola *et al.,* 2013). Shrinkage and hardening are the two most vital physical changes taking place during dehydration because of alteration of tissue microstructure and chemical changes, and they can negatively affect the rehydration ability of dehydrated fruits (Lewicki & Technology, 2006; Sagar & Kumar, 2010).

As presented in Table 5 rehydration ratio for the six drier dried papaya products was evaluated and values were found between 4.92 – 7.62 for untreated dried papaya whereas pre-treated varied from 3.59 – 7.53 and showed a statistical difference ($p < 0.05$) in between dried product. For both solar-glass house and refractance window hydration ratio was displayed statistically significant difference ($p < 0.05$) in between pre-treated and untreated dried product but the rest was not. The higher rehydration ratio was obtained from solar-glass house drier dried papaya products, untreated (7.62) whereas the lowest was found in refractance window dryer for treated dried papaya products. The difference in rehydration characteristics could be caused by differences in surface hardening, the degree of structural damage, and cell shrinkage induced by dehydration (Vegagálvez *et al.,* 2011; Wang *et al.,* 2011). As reported by (Abrol *et al.,* 2014) rehydration of three dried fruits of papaya, mango, and banana varied from 3.1 to 5.0 which is comparable with the present findings. Alternatively (Abrol *et al.,* 2014) also reported that the rates of rehydration of dehydrated materials using rotating tray drying were ranging from 3.7–4.8 followed by hot-air drying (< 4.5). Moreover; the range of rehydration ratio in commercial samples was found to 1.0–6.9 (Megías-Pérez *et al.,* 2014) and the results of the present research output are completely fulfilled commercial criteria. Dried papaya products induced through the heat for both treated and untreated (oven, and refractance window drier) have got low rehydration ratio than solar-dried papaya products, which could be a possible reason that heat makes dried papaya products harder. Dried products that have a higher rehydration ratio is suitable for making a composite product with other ingredients and easily mix because of losing their integrity. As a general applicability of rehydration ratio depending on the end use, high or low rehydration efficiency may or may not be desirable.

Hygroscopicity of dried products indicates that, the rate of change in moisture content (Chiou & Langrish, 2007) within a given time. It is preferable to below as high hygroscopicity indicates the higher tendency of the dried product to absorb moisture and cause stickiness (Tonon *et al.,* 2008). The hygroscopicity value of the current research being differed from 6.18 (untreated, oven) to –13.45% (solar-open, treated), and statistical variations were observed ($p < 0.05$) for both treated and untreated dried products in between driers (Table 5).

Exceptional, only in solar-open, drier method, substantial difference ($p < 0.05$) was observed in between treated and untreated dried papaya. A lower hygroscopicity test was observed for the oven in both treated and untreated dried papaya products, which might be the effect of heat that makes harder/compactness of dried product.

4.4 Nutritional Quality of Dried Papaya Fruit

It is reasonable, drying affects the food nutrients of dried products, but the effect depends upon the food staff and the drying methods. Even though the fact that drying brought a loss of nutrients and other physical properties but it is possible to minimize losses by applying suitable pre-treatments, selecting appropriate drying methods, and optimization of drying conditions (Sablani, 2006). Dried Fruits and vegetables are currently amazingly appreciated by consumers, not only for their high nutritional value and pleasant organoleptic properties but also for their content in bioactive compounds (vitamins and antioxidants, among others), directly related to health benefits (Giampieri *et al.,* 2012) because nutrients are concentrated and make the product is shelf-stable.

Vitamin C, and Bioactive Compounds (Phenolic, and Flavonoid)

The current research evaluated five drying technologies and found them to have variable effects on the nutrients of papaya. As mentioned in Table 6 vitamin C, and polyphenols (total flavonoid and phenolic) were determined. (**Annex 2;** Disclosed the values of vitamin C and polyphenols in between treated and untreated dried papaya).

Vitamin C is one of the very essential nutrients found in fruit and vegetable, functions as an anti-oxidant, and an enzyme cofactor that maintains the iron ion in the reduced ferrous (Fe2+) state (iron absorption), required for enzyme activity (Schlueter *et al.,* 2011). Nevertheless, vitamin C can be degraded during the drying of fruit, but it depending on variables (temperature, pH, light, storage, exposure to oxygen, and contact with minerals (iron and copper). Its degradation in foods is directly proportional to temperature as a prolonged thermal treatment increases favor for oxidation (Svagzdiene *et al.,* 2010). Thus if vitamin C is well maintained during the drying process, other nutrients are probably also preserved (Marques *et al.,* 2006) because it is the least stable nutrient during processing; highly sensitive to oxidation and leaching into water-soluble media during processing. In this study, all processing methods resulted in a significant decrease in vitamin C ($p < 0.05$) as relative to freeze drier. The greatest retention of vitamin C was observed in the freeze dryer (control) followed by oven and solar-open. Results of vitamin C in this research were obtained from 14.33 (Refractance window) – 44.61mg/100g (freeze dryer), being freeze-dried as higher retention as revealed in table 6. It is profound that drying causes great losses in vitamin, heating at a higher temperature for a short time has less effect on vitamin C losses but if drying is prolonged, there will be more losses, (Pandey *et al.,* 2014). But the present study is not similar to this research report because the reflectance window dryer is much lower than the oven which takes more time to dry, this might be due to the higher temperature of the refractance window drier. Overall Vitamin C loss during most drying approaches might be attributed to the oxidation of ascorbic acid under high temperature drying conditions, as well as the reduction of this compound due to its utilization for protecting the oxidation of polyphenols during drying (Joshi et al., 2011; Toor & Savage, 2006).

Fruits and vegetables contain various anti-oxidants which are valuable to human health through lowering the occurrence of degenerative diseases (cancer, heart diseases, and aging process (Lim et al., 2007). This is due to the availability of antioxidants to scavenge free radicals in the human body and thereby decrease the amount of free radical damage to biological molecules (DNA) (Wu *et al.,* 2004). Polyphenols (total phenolic and flavonoids) are one of the antioxidants available in fruit and vegetable and are considered in this investigation as presented in Table 6. The total flavonoid and phenolic contents of dried papaya which was dried with five driers were found to be 0.84 - 1.89 mg/g QE, and 6.6 - 41.57 mg/g GAE respectively, and statistical differences ($P < 0.05$) among the implemented drying methods were observed (Table 6). In both total flavonoid and phenolic content, the solar- open drier had shown a lower value, while the freeze drier (control) had a higher value, following with oven (for phenolic) and refractance window (for flavonoid) respectively.

Table 6; Vitamin C, and bioactive compounds

Drying type	Vitamin C (mg/100g)	Total Flavonoid (mg/g QE)	Total phenolic (mg/g GAE)
Solar-open	17.22^{c}±0.92	0.84^{d}±0.03	6.56^{d}± 0.12
Oven	21.35^{b}±0.73	1.33^{b}±0.06	14.78^{b} ± 1.25
Solar-tray	17.00^{cd}±0.32	1.06^{c}±0.05	11.05^{c} ± 1.04
Solar-Glass house	15.33^{de} ±0.43	1.28^{b}±0.03	12.01^{bc}± 0.62
Refractance window	14.33^{e} ±0.33	1.38^{b}±0.02	13.40^{bc} ± 1.86
Freeze drying	44.61^{a}±0.78	1.89^{a}±0.13	41.57^{a}± 2.5

❖ *Data are expressed as mean± SD (n=3). Mean values within the same column with different superscripts are significantly different at $P<0.05$; GAE-Gallic Acid Equivalent; QE-Quercetin Equivalent*

It is expected that the highest polyphenol (total phenolic and flavonoid) was found in freeze-dried papaya, followed by refractance window, and solar-glass house. Exceptionally, among other driers of the dried product except for a control (freeze drier), the highest total phenolic content was observed for oven-dried papaya products, this could be attributed to the release of polyphenolic compounds from the food matrix during drying (Annegowda *et al.,* 2014). As a result of heat, may have the ability to break down covalent bonds and thus facilitate the liberation of bio-compounds (phenol, and flavonoid) from repeating polymers (An *et al.,* 2016) resulting in higher quantification of flavonoids, and phenolic contents of the oven than other driers.

Carotenoid (lycopene and β-carotene)

Carotenoids (β-carotene, lycopene, and β-cryptoxanthin), flavonoids, and phenolic compounds are primarily served as an antioxidant and also contributes to the fruit sensory characteristics (color, taste, and texture) (Zielinski *et al.,* 2014). Among the carotenoid class, Beta-carotene has given a special emphasis due to its advantage of being converting to vitamin A, contained within the present research report. Beta-carotene theoretically possesses 100% vitamin A activity and provides 80% of the vitamin A value of fruit and vegetables, while a-carotene possesses only 52% of vitamin A activity (Desobry *et al.,* 1997). (**Annex 1**; Revealed the carotenoid contents of (treated and untreated) dried papaya products).

Lycopene is carotenoids which are present in different concentrations in fruit and vegetable, found in higher concentration in tomato and other red pigment fruits because it is responsible for the red color pigment in the food (Wawrzyniak *et al.,* 2005). It is not classified under provitamin A carotenoid but it has a potent antioxidant capacity, which is 31-55% higher than the provitamin-A (β-cryptoxanthin, β-carotene) or even the α-carotene (Shi *et al.,* 2005). In this finding lycopene value was found to be 3.91 (solar-open) – 15.84 (µg/g) (freeze dryer), as accessible in Table 7, and the statistical difference was observed among the driers at $p < 0.05$. Freeze-dried had better nutrient retention than others, as a result, more lycopene retention was observed in freeze drier following with Refractance window dryer. The least was observed in the solar-open drier which may be due to both light and heat sensitivity of lycopene. Despite processing conditions such as high temperature, light, and oxygen have been shown to affect lycopene degradation, it has exhibited that a very high level of stability during the drying process compared with other anti-oxidants (Zanoni *et al.,* 1998). The degradation of lycopene strongly affects the attractive color of the final products, and their nutritional value (Muratore *et al.,* 2008).

Total carotenoid and ß-carotenes contents of dried papaya which was dried with different driers were obtained from 45.10 - 103.74 µg/g, 5.16 - 33.66 µg/g, and showed a statistical significance difference ($P < 0.05$) among the implemented drying methods. Solar-open drying has a recorded as the lowest retained of nutrients of total carotenoid and ß-carotenes, whereas freeze-drying exhibited a higher following with refractance window and solar-glass house as revealed in Table 7. It is expected that solar-open dryer (direct sun) would be the lower nutrient retentions (Sagar & Kumar, 2010) because the papaya samples are directly exposed to light, heat, and oxygen, as a result, the sensitive nutrients of dried papaya were found to be lower as compared to others. Those factors (light, heat, and oxygen) and with longer drying times exposed, impairment to even sensory characteristics alongside with nutritional properties of foods, oxidation of pigments, destruction of vitamins (Reyes *et al.,* 2010).

The high nutrient retention in freeze-dried samples is not surprising as it has been reported to be one of the best drying methods to minimize loss of nutrients and bioactive compounds (Marques et al., 2006; Saini *et al.,* 2014). However, freeze-drying is operationally expensive and thus not cost-effective, particularly in Low Middle Income Country (LMICS) settings (Ratti, 2001). Consequently, drying methods that perform as close as freeze-drying and environmentally friendly are needed, and those could be solar-energy and recently developed reflectance window driers.

Table 7; Carotenoid contents of dried papaya

Drying type	lycopene (µg/g)	total carotenoids (µg/g)	ß-carotenes (µg/g)
solar-open	3.91^{e}±0.28	45.1^{e} ± 1.8	5.16^{e}±1.12
oven	8.03^{c}±0.49	52.46^{d} ±2.81	6.40^{de}±0.23
solar-tray	6.34^{d}±0.63	49.97^{de} ± 1.45	8.24^{d}±0.48
solar-glass house	6.80^{cd}±0.40	71.62^{c}± 1.60	15.02^{c}±0.26
refractance window	12.50^{b}±0.68	84.55^{b} ± 1.00	22.55^{b}±0.01
freeze drying	15.84^{a}±0.40	103.74^{a} ± 1.11	33.66^{a}±0.23

❖ Data are expressed as mean± SD (n=3). Mean values within the same column with different superscripts are significantly different at $P<0.05$.

4.5 Nutrient Percentage Retentions Relative to Freeze Drier

Retention of nutrients is highly dependent on cultivar, production location, maturity stage, season, and processing conditions (Howard *et al.,1*999). Figure17 contains the percentage retention of total carotenoids, beta-carotene, and lycopene relative to freeze-dried samples (control). In this finding, the total carotene retentions of five driers were displayed as varied 43.4 (solar-open) – 81.5 % (Refractance window), whereas others such as beta-carotene, and lycopene retentions differed from 15.31 – 66.99 and 24.66 - 78.89 % respectively. Statistical differences ($p < 0.05$) of total carotenoid, beta-carotene, and lycopene retention relative to freeze dryer among the dryer were observed.

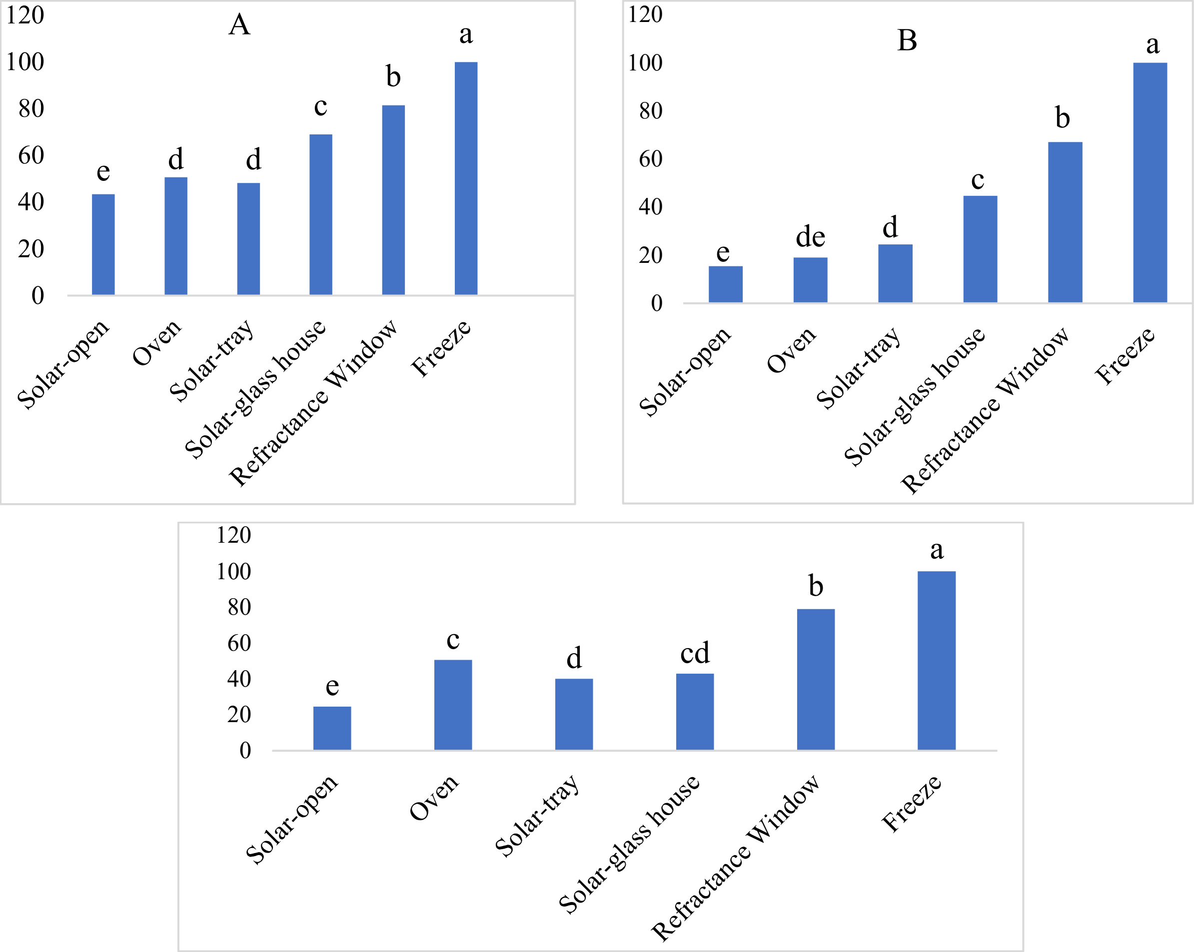


Figure 17; Retention (%) of total carotenoid (A), beta-carotene (B), and lycopene (C) relative to freeze-dried

Carotenoid retention is vital in determining the final quality of the dehydrated products, However; they are sensitive to heat, light, oxygen, and enzymes (Onwude *et al.,* 2017), they can be easily lost. More than 80% of the total carotenoids, 60% of the B-carotene, and 78 % of lycopene were retained after refractance window drying. In contrast, the lowest retentions of total carotenoids (< 50%), lycopene (< 30%), and beta-carotene (< 20%) were observed for the oven, solar-tray, and open solar drying. In line with earlier reports from drying of different fruits, refractance window drying had the best retention, followed by solar glass-house (Bernaert *et al.,* 2019; Shende *et al.,* 2019). Solar dried papaya showed the lowest retention of in β-carotene when compared with other drying technologies, this can be attributed to two reasons, the photosensitive and epoxide forming nature of carotenoids and the enzymatic degradation by lipoxygenase (Sehrawat *et al.,* 2018), which might be due to the longer residence time of the fruit at a low and fluctuating temperature. Similar research findings were also reported by (VegaGálvez *et al.,* 2019). Additionally, Udomkun et al.,(2015) reported that from tested several drying temperature combinations (50˚C, 60˚C, 70˚C, and 80˚C) of the papaya dehydration process, found 5.7% to 75 % loss of β-carotene, and 34.66% to 76.41% of lycopene lose which is a supportive idea with the present research findings. Previous studies have shown that solar-glass house leads to better retention and safety than open-air drying (sample exposed to different environmental pollutants as well fluctuating temperature) (Singh *et al.,* 2018).

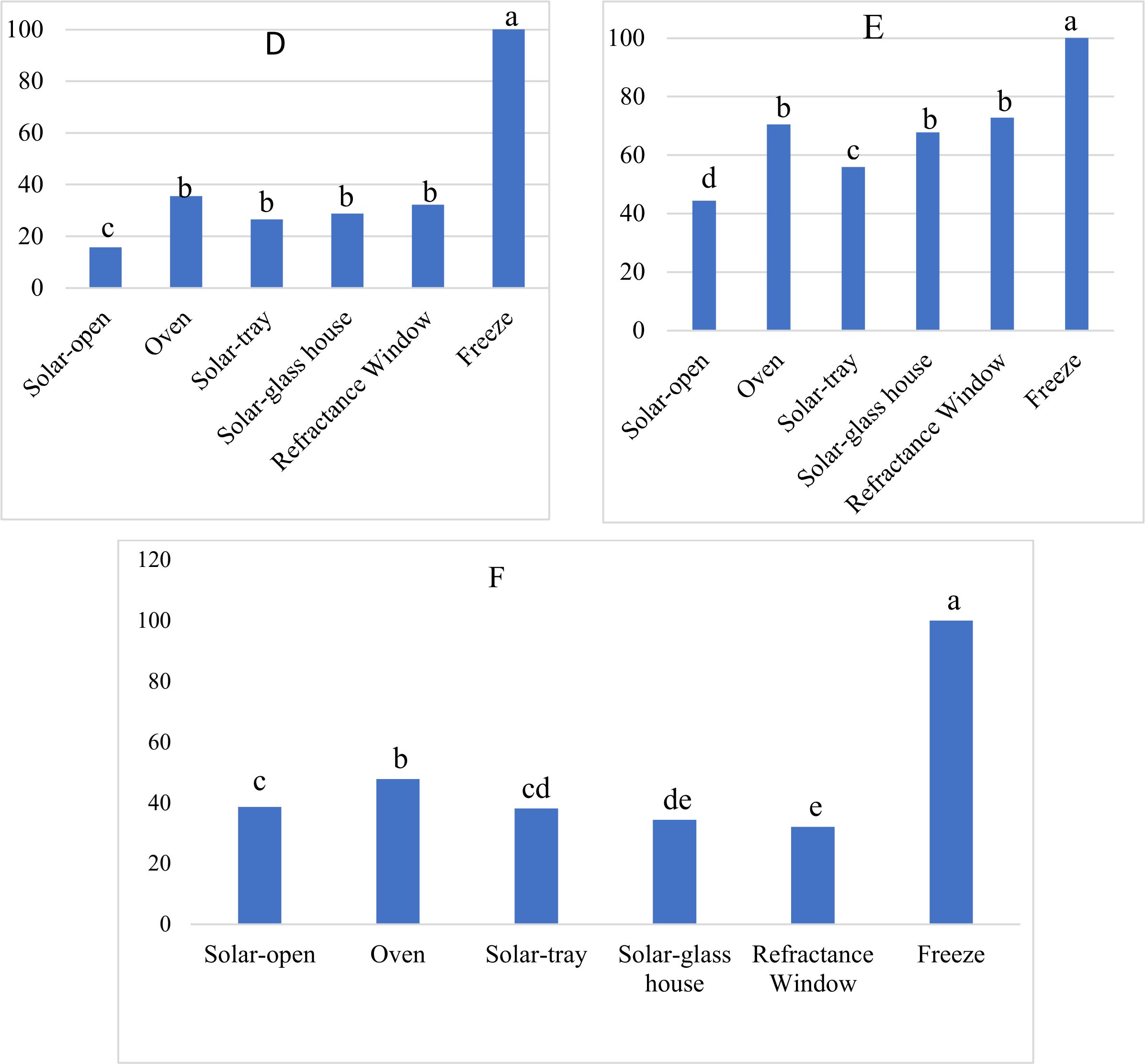


Figure 18; Retention (%) of phenolic (D), flavonoid (E), and Vitamin C (F) relative to freeze-dried

Substantial differences (P< 0.05) of total phenolic, flavonoid, and vitamin C percentage retentions relative to freeze drier in between driers were observed (Figure 18). For total phenolic and vitamin C nutrients of dried papaya, percent retentions relative to freeze dryer was below 50 %, for all driers being oven dryer was higher, that revealed 35.5 %, and 47.86 % of retentions respectively. Whereas in total flavonoid contents up to 72 % of retentions achieved, reflectance window dryer was being the highest following with oven and followed by a solar-glass house. Oven-dried papaya had maximum retention of vitamin C than other driers which would be the reasons that oxygen-deficient environment would have prevented the aerobic degradation of vitamin C (vacuum employed prevented the contact of the ascorbic acid from the sample with the free oxygen, thus preventing its oxidation) in the oven as compared to the other drying processes and results of the present findings agreed with the reported results of the previous works(Hawlader *et al.,* 2006; Vegagálvez *et al.,* 2019).

In this research report in both total flavonoid and phenolic content percentage retentions relative to freeze drier, solar-open dried product was inferior to other dried products but exceptionally Vitamin C percentage retentions were higher than a solar-glass house, and refractance window driers. 71 - 77 % retention loss of vitamin C for solar dried papaya was observed (Abrol *et al.,* 2014) which showed a similar trend to the current findings, but; the current research output percentage loss is lower than the report. In solar drying unstable temperatures (30 - 50 °C) might be observed (Sehrawat *et al.,* 2018), as a result, it possibly might not be effective enough to inactivate the enzymes responsible for vitamin C degradation (slow degradation).

In total phenolic content, the current research output is corroborate with the findings of (Chong *et al.,* 2013). The author evaluates the effect of different papaya dehydration methods and found losses varied from 7% to 69% (phenolic content), and the dried product had contents from 84.78 to 250 mg GAE/100g. For total flavonoid content, the findings of this research report are in line with the author (Kamiloglu *et al.,* 2014; Loizzo *et al.,* 2013), who found that up to 83 % of total flavonoid could be lost when the fruit is subjected to dehydrate. Furthermore, Vegagálvez *et al.,*(2019) reported that papaya dried with a different drier (freeze-drying, vacuum drying, solar drying, convective drying, and infrared drying) found 42– 65% loss, with final content of 1.17–1.93 mg g−1QE, which is harmonized with the present findings found from 44.36 (solar-open) – 72.75 % retentions (Refractance window), with a final value of 0.84 -1.89 mg/g QE. The nutrient losses may be attributed to the heat and light sensitivity of the nutrients.

Refractance window drying belongs to the fourth-generation driers and has improved features over previous generations (Bernaert *et al.,* 2019). Drying of the food material happens evenly over a thin infrared transparent material resting over the surface of water that is heated. Thermal energy carried by circulating water transmits heat through the film to the food material by conduction and radiation (Singh *et al.,* 2018). The nutrient retention of foods dried with a refractance window is higher than other more common drying systems (spray-drying) and is much more energy-efficient (Moses *et al.* 2014). The energy efficiency of the refractance window drying is three times higher than spray drying and forty-fold higher than freeze-drying (Bernaert *et al.,* 2019).

4.6 Effect of treatment on the nutrient retentions of dried papaya

The study also conducted, just treating the papaya slices with ascorbic acid formerly drying to see the pre-treatment effect on the nutrient retention, with different dryers, and results are described as a percentage of retentions relative to freeze dryer. Appropriate pre-treatment is one of the methods that can reduce the loss of nutrients during the drying of fruit and vegetable (Sablani, 2006). Table 8 presents pre-treated and untreated dried papaya percentage values of carotenoids and polyphenol retention relative to freeze-drying. Ascorbic acid pre-treatment significantly increased the retention of total carotenoids, B-carotenes, total phenolic, total flavonoids, and lycopene content ($P< 0.05$). The pre-treatment in refractance window dryer allowed more than 90% of the total carotenoids, beta-carotene, and lycopene, 86 % of total phenolic, and 71 % of total flavonoids to be retained. Better retentions of total carotenoids, beta-carotene, and lycopene content were observed in the refractance window dryer than others. Except for the total flavonoid content of refractance window and solar-glass house all the listed parameters existing in Table 8 significantly different ($p< 0.05$) retention than the untreated one. In the case of solar – glass house more than 80 % of total phenolic and lycopene content was retained, whereas other nutrients of total carotenoid, ß-carotenes, and total flavonoid contents obtained higher than 70 % of retention. And also, in a similar manner with refractance window drier all treated parameters are substantially different at $p < 0.05$ from untreated, except total flavonoid content.

Table 8; Effect of ascorbic acid pre-treatment on the retention of polyphenols and carotenoids

Drying	Ascorbic acid treatment		P-value
	Untreated (%)	Treated (%)	
Total carotenoids			
Refractance window	81.50 ± 0.96	89.60 ± 2.04	0.003
Solar glass-house	69.00 ± 1.54	76.77 ± 2.18	0.007
Solar tray	48.20 ± 1.40	58.50 ± 0.78	<0.001
Solar-open	43.43 ± 1.70	49.63 ± 0.80	0.005
Oven	50.57 ± 2.75	61.37 ± 2.27	<0.001
Freeze	100		
ß-carotenes			
Refractance window	66.99± 0.01	91.70± 0.15	<0.001
Solar glass-house	44.62± 0.55	78.74 ± 4.16	<0.001
Solar tray	24.47± 1.02	46.66± 1.57	<0.001
Solar-open	15.31 ± 2.38	23.42 ± 1.84	0.008
Oven	19.00± 0.49	37.79± 4.85	0.001
Freeze	100		
Total phenolic (TPC)			
Refractance window	32.23 ± 4.47	86.55 ± 2.51	<0.001
Solar glass-house	28.74 ± 1.53	86.55 ± 2.35	<0.001
Solar tray	26.58 ± 2.52	74.09 ± 6.23	<0.001
Solar-open	15.78 ± 0.29	22.59 ± 1.52	0.002
Oven	35.56 ± 3.00	89.70 ± 2.29	<0.001
Freeze	100		
Total Flavonoid (TFC)			
Refractance window	72.97 ± 0.81	71.73 ± 0.31	0.073
Solar glass-house	67.84 ± 1.91	73.85 ± 3.98	0.077
Solar tray	56.01 ± 2.14	86.04 ± 3.01	<0.001
Solar-open	44.52 ± 1.91	59.72 ± 4.90	0.007
Oven	70.67 ± 3.24	89.93 ± 5.23	<0.001
Freeze	99.99		
Lycopene			
Refractance window	78.89 ± 4.31	90.54 ± 2.55	0.016
Solar glass-house	42.91 ± 2.55	82.43 ± 1.78	0.000
Solar-tray	40.04 ± 3.96	67.57 ± 4.43	0.003
Solar-open	24.66 ± 1.78	37.50 ± 2.32	0.00
Oven	50.68 ± 3.08	64.70 ± 3.05	0.002
Freeze	100		

P-values are from a comparison of means between untreated and treated using an independent t-test

In solar-tray, the highest retention of total flavonoid content was achieved, next to oven drying while other very interesting nutrients, beta-carotene content with unexpectedly lower than 50 % retention. Oven drying, exceptionally more than 90 % of total phenolic and flavonoid content was reserved, but other lycopene, beta-carotene, and total carotenoids were lower retentions. The result of the current research's treated papaya being more retained nutrient than untreated is in concordance with previous studies showing higher retention in ascorbic acid-treated mango (Guiamba *et al.,* 2016). Indeed, the ascorbic acid treatment can slow oxidation reactions and prevent browning (Osae *et al.,* 2020).

4.7 Contribution of Dried Papaya to Vitamin A Nutrient Intake

Table 9 presents the contribution of the dried papaya to the vitamin A requirements if added to complementary foods (Lutter & Dewey, 2003). Just 25 g of dried papaya which is dried with a refractance window drier can significantly contribute to vitamin A requirements than other dryers: The highest contribution of retinol was for refractance window drying (38%), followed by solar glasshouse (25%), whereas the least (9%) was for solar-open. For pregnant and lactating women, about 100 g of dried papaya will be required to cover 20-25% of the daily requirements (Supplement table S 1). However, the benefits of carotenoids are far beyond the contribution to vitamin A intake and relate to their anti-oxidative properties that confer various health advantages (Eggersdorfer et al., 2018).

Table 9; Contribution of dried papaya to vitamin A requirements from complementary foods.

Drying	Vitamin A (µg RE/100)	% Contribution of requirements (in RE)		
		Children 6-23 months	Pregnant women	Lactating women
		25 grams	50 grams	
Refractance window	375.8±0.2	38	51	42
Solar- glass house	250.3±3.2	25	34	28
Solar tray	137.3±5.7	14	19	15
Oven	106.7±2.7	11	14	12
Solar- open	86.0±13.3	9	12	10
Freeze-drying	561.0±2.8	56	76	62

❖ RE, retinol equivalent; CF, complimentary food; Requirements from complementary foods for children 6-23 months (250 RE) as estimated by (Lutter & Dewey, 2003); for pregnant and lactating women the estimated daily requirement is 370 and 450 µg RE, respectively (WHO, 2004).

4.8 Color of Dried Papaya

Physical appearance including color change is a very important property of dehydrated fruit for marketing/consumption purposes because consumers are first visually assessed to check the food quality. Unexpected/ unappealing color or significant change in physical appearance will cause the product to be rejected by the consumer (Lopez *et al.,*1997b). Surely, undesirable chemical or biochemical reactions might arise during fruit drying that brings to changes in color, texture, odor, or other properties for the dried solid products (Ong *et al.,* 2010) due to the Maillard reaction, pigment degradation, enzymatic browning, and ascorbic acid oxidation (Manzocco *et al.,* 2000). Maillard's reaction during drying might have happened when the reducing sugars reacted with amino compounds because fruit contains high amounts of reducing sugar (glucose, sucrose, fructose, and carbohydrates) (Cornwell & Wrolstad, 1981). It has been reported that the Maillard reaction occurred after exposure to air drying at high temperatures and long drying duration (Chou *et al.,* 2000). Also, the enzymatic reaction changed the dehydrated fruit color to brown or darker color due to the oxidation of phenols to oquines (brown pigment or melanin's) (Beveridge & Harrison, 1984). On the other hand, the solid matrix of the foodstuff is unable to support its weight after drying, leading to drastic changes in physical structure (Ratti, 2001).

Table10; Colour values (L*, a*, b*) of dried papaya (treated and untreated)

Dryer	CIE Colour					
	L*		a*		b*	
	Untreated	Treated	Untreated	Treated	Untreated	Treated
Solar-open	$54.68^{A\text{-}Ca}\pm0.3$	$45.54^{Bb}\pm0.98$	$17.45^{Ca}\pm0.5$	$17.76^{Ba}\pm0.02$	$61.80^{Aa}\pm0.6$	$60.03^{Aa}\pm2.88$
Oven	$56.77^{ABa}\pm2.2$	$45.89^{Bb}\pm0.86$	$18.58^{BCa}\pm0.2$	$18.62^{Aa}\pm0.29$	$62.41^{Aa}\pm0.4$	$59.11^{Ab}\pm0.38$
Solar-tray	$57.66^{Aa}\pm0.42$	$44.37^{Bb}\pm0.39$	$16.92^{Cb}\pm0.1$	$18.96^{Aa}\pm0.26$	$60.72^{Aa}\pm0.2$	$60.08^{Aa}\pm3.6$
Solar-Glass house	$54.06^{BCa}\pm1.4$	$54.08^{Aa}\pm0.8$	$18.86^{A\text{-}Ca}\pm0.38$	$16.7^{Bb}\pm0.22$	$62.72^{Aa}\pm2.3$	$60.12^{Aa}\pm0.58$
Refractance Window	$53.178^{Ca}\pm0.9$	$53.08^{Aa}\pm0.26$	$19.645^{Aa}\pm0.4$	$16.64^{Bb}\pm0.21$	$60.25^{Aa}\pm0.5$	$58.71^{Ab}\pm0.42$
Freeze (control)	$57.73^{A}\pm0.09$	-	$17.13^{C}\pm0.02$	-	$57.27^{B}\pm0.9$	-

- Data are expressed as mean± SD (n=3). The different lowercase letters in the same row and different capital letters in the same column denote a significant difference ($P < 0.05$).

The chromatic attributes of color (L*, a*, b*) for all the six drier dried papaya products were analyzed, and results are existing in Table 10. The color parameters used were CIE L* (lightness/whiteness), a* (redness/greenness), and b*(yellowness/blueness) of three-dimensional uniform color space. The lightness L* value in between drier showed a statistically significant difference ($P <0.05$), indicate that browning reaction might take place. In between pre-treated and untreated dried product L*-value also displayed significant differences ($P <0.05$). The L*-value significance differences between treated and untreated might arise from a concentration of the carotenoids since in treated dried papaya more carotenoid was retained than untreated. As indicated in Table 10 solar-open, oven, and solar-tray had not a significant difference with the freeze drier (control).

The L* (lightness/whiteness) values of dried papaya of the five dryers dried products were lower than the freeze-dried product (control). Supporting with the current research (Canizares *et al.,* 2015; Reis, *et al.,* 2018) reported that L* value decreased for the dehydrated papaya via convective drying (60˚C and 70˚C) and displayed more yellowish/ reddish-brown coloration. Similarly, chromatic (a* & b*) was also evaluated, and a* value showed a significant difference ($p < 0.05$) from the freeze (control)in both treated and untreated dried products as visible in Table 10. However, b* value for all dryers dried papaya excluding freeze (control) had not shown a significant difference ($p < 0.05$) in between driers but in the oven and refractance window dried papaya considerable variations were observed in between treated and untreated papaya being treated is lower b* value than untreated. This could be due to the more concentrations of treated carotenoids than untreated. All the dried papaya showed a more intense and more reddish color than the freeze-dried (control), being higher values of a* and b* except a* value of solar-tray (untreated) and solar-glass house and refractance window (treated). This result may be related to the concentrations of carotenoids after drying, particularly lycopene, responsible for the red color of the fruit (Rodriguez., 2010). Accordingly, Mishra *et al.,*(2015) report also observed that an increase in the values of a* for the dehydrated papaya through a combination of osmotic dehydration and infrared drying. The higher b* value of the dried papaya relative to the freeze drier(control) of the present finding also in concordance with the research reports of (Chong *et al.,* 2013), which might be due to the enzymatic reaction of polyphenol compounds. These reactions increase the value of b* till 62.71.

Table 11 presents the color change and browning index of both the treated and untreated dried papaya. The total color change (ΔE) of both pre-treated and untreated as compared to the freeze-dried papaya was found to a maximum of 14.05 and 6.88. Statistical differences ($p < 0.05$) were also observed in between each drier dried product as well in between pre-treated and untreated dried products. However; for solar-glass house and refractance window drier there were no significant differences between pre-treated and untreated dried products. For supporting with the present investigation, Reis *et al.,(*2018) reported that the total color change (ΔE) of papaya drying under oven-dried at 60 ºC treated with sugar found 12 compared with fresh papaya, and Chong *et al.,* (2013) found 10.36 for dried papaya using hot-cold air technology. According to these authors, the use of high drying temperatures (70˚C) despite promoting the inactivation of the polyphenol oxidase enzyme, favors the oxidation of papain enzyme, releasing free amino acids that react with the reducing sugars of the papaya, triggering the Maillard reaction.

Table 11; Total color change and browning index

Dryer	Browning index		(ΔE)	
	Untreated	Treated	untreated	Treated
Solar-open	$0.66^{Ba}\pm0.07$	$1.00^{Ba}\pm0.07$	$5.49^{Ab}\pm0.73$	$12.69^{Aa}\pm1.8$
Oven	$0.96^{Cb}\pm0.07$	$1.44^{Bb}\pm0.16$	$5.73^{Ab}\pm0.62$	$12.09^{Aa}\pm0.70$
Solar-tray	$0.91^{Cb}\pm0.03$	$1.80^{Bc}\pm0.07$	$3.49^{Bb}\pm0.29$	$14.05^{Aa}\pm1.46$
Solar-Glass house	$0.91^{Cb}\pm0.07$	$1.57^{Bbc}\pm0.16$	$6.88^{Aa}\pm2.26$	$4.75^{Ba}\pm0.3$
Refractance Window	$1.58^{Dc}\pm0.049$	$1.72^{Bc}\pm0.04$	$6.04^{ABa}\pm0.71$	$4.91^{Ba}\pm0.04$
Freeze (control)	$0.29^{A}\pm0.01$			

- Data are expressed as mean± SD (n=3). The different lowercase letters in the same row and different capital letters in the same column denote a significant difference ($P < 0.05$).

Browning is a key quality measuring factor for fruit products during drying processing and storage, as it is directly affected the sensory and nutritional attributes (Udomkun *et al.,*2016). Browning may occur in both enzymatic and non-enzymatic but non-enzymatic browning is only avoiding at a water activity of below 0.3 (Corzo *et al.,* 2012) but the drying process usually elevates the non-enzymatic browning reactions (Chou *et al.,* 2001). During drying of fruit and vegetable, usually, a color change is observed, due to different reactions to the chlorophyll, in which degree of browning is being used as indicators of color change. Factors such as temperature, carbonyl compounds, and organic acids have been reported to be responsible for causing non-enzymatic browning in heated foods (Hemlata *et al.,* 2014). The degree of browning value for this study varied from 0.29 (freeze-dried) to –1.8 (pre-treated) (Refractance window) as shown in table 11. As continually reported, in the above color value, substantial differences were found between pre-treated and untreated dried papaya, being pre-treated value is higher for all dried papaya products.

In the present finding, the more browning product was observed for refractance window dryer and oven than did another dryer but the freeze-dried product is being the least. In the refractance window and oven drier, to be higher browning is might be the influence of high heat induced to the product, since heat is one of the factors that brought browning in dried fruit and vegetable products. In Oven, solar-tray, and solar-glass house driers of dried papaya had not shown a significant difference ($P < 0.05$) for the untreated dried product. Dried products that dried with the lowest temperature showed the lowest value of non-enzymatic browning irrespective of commodity, but non-enzymatic browning increased with the related increase in drying temperature, and outcomes of the current research were in concordance with the studies of (Kaur *et al.,* 2020).

4.9 Sensorial Evaluations of Dried Papaya Products

Physical appearance and total color change are important physical properties of dehydrated fruit, and also the major challenges for dried fruit and vegetable because they are more sensitive to be more acceptable like fresh products. It is important to visually assess the dehydrated fruit because the first judgment made by consumers on food quality is by physical appearance and color. Abnormal color or significant change in physical appearance will cause the product to be rejected by the consumer (Lopez *et al.,*1997a). Sensorial analysis is a method of analysis unlike instrument, accurate measurement of human responses to foods with minor biasing effects (Ong *et al.,* 2010). Sensory attributes of food are mostly allied with its physical and chemical properties (Omolola *et al.,* 2017). After drying of fruits, nutrients are concentrated and sensorial acceptability is preferable to fresh but the aroma and flavor may be changed due to loss of volatiles during drying and storage of the dried fruits, leading to lower product acceptance (Sagar & Kumar, 2010).

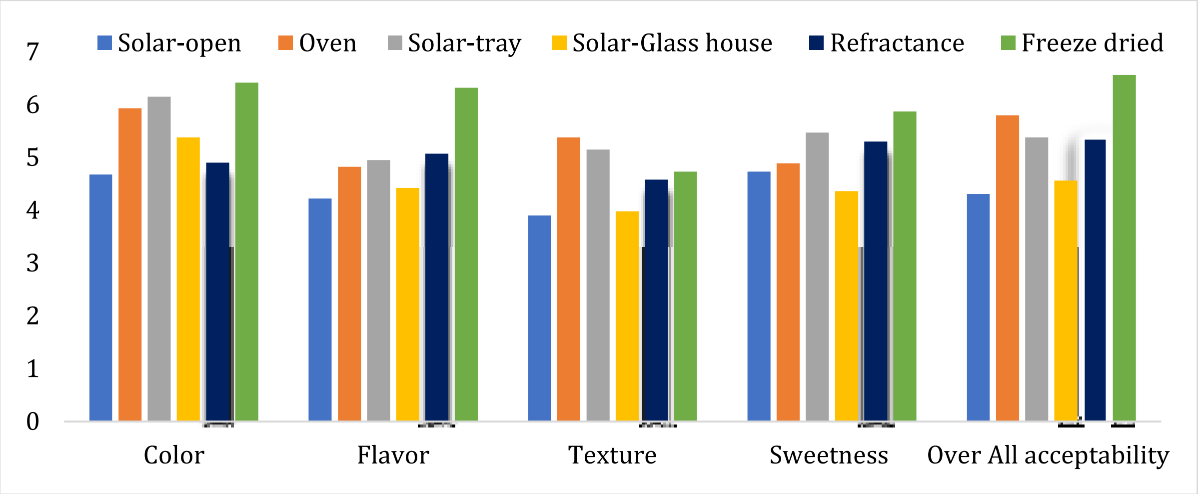


Figure 19; Sensory evaluation of dried papaya chips

1= Dislike Extremely, 2= Dislike very much, 3= Dislike, 4= Neither like nor a dislike, 5= Like, 6= Like very much , 7= Like extremely

In this research report, the 7-point hedonic scale "Acceptance rating scale "using 13 semi-trained panellists and triplicate sample sensorial analysis were performed, and results for untreated papaya are presented in Figure 19. In flavor and texture sensorial attributes of dried papaya products statistical differences ($p<0.05$) were not observed among driers. But for colour, sweetness, and overall acceptability sensorial attributes of dried papaya showed considerable differences ($p<0.05$) in within driers which is freeze-dried being the uppermost while solar-open (colour & overall acceptability), and solar-glass house (sweetness) is the lowest. In overall acceptability, freeze-dried is being most preferable (control) followed by oven-dried papaya and solar-tray

4.10 Shelf stability of dried papaya

Shelf life refers to the end of consumer acceptability and is the time at which the majority of consumers are displeased with the product for the different change (Labuza & Schmidl, 1985). The dried papaya products shelf-life was evaluated, by storing at room temperature (25 ºC, RH, 60 %) for 6-month. The optimum relative humidity for storage of dried products is 55– 70% depending on the moisture content of the products, ranging from 2 to 20% (Kader *et al.,* 2014). The stored dried papaya products were subjected to evaluate their moisture, water activity, total carotenoid, beta-carotene, total flavonoid, and total phenolic contents for every month, exceptionally for the first month. Drying conditions, storage period, and hygroscopic nature of the dried product meaningfully affected the quality of the end product (Kaur *et al.,* 2020). When a food product is exposed to an environment above or below this equilibrium point, the protective packages and its barrier level will determine how much the food will be impacted (Esse *et al.,* 2004).

4.10.1 Moisture & Water activity of Dried Papaya

The moisture content of all dried papaya products of solar-open, oven, solar-tray, solar-glass house, and refractance window drier for six-month storage were evaluated and results found from 12.34 - 16.16, 9.86–16.17,13.02 –16.89, 12.90 -16.23, and 10.13 -16.00 measured as g/ 100g, respectively offered in figure 20. The moisture content of all dried papaya products increases in the storage month (figure 20). Even though the fact that moisture content was evaluated for six months, and values were varied, but except for the third month, for all months there was no significant difference ($p < 0.05$) among the drier for each month. In the storge period, for each drier dried papaya product moisture content were showed statical differences ($p < 0.05$). In solar- open, moisture content of dried papaya for 1st, 2nd, 3rd storage period, were not displayed statistical differences at $p < 0.05$ but substantial differences were observed starting from 4th-month storage with a final value of 16.16 %. Oven, in b/n 1st and 2nd-month statistical differences, were not detected, but statistical differences were observed in progress from 3rd-month storage, ending value of 16.17 %. In solar- tray, moisture values statistically varied from 4th month and wind-up with 16.89 % value. Solar-glass house initial moisture value was 12.90, after 4th month the moisture content showed a statistically significant ($p < 0.05$) increment change, and end-up with 16.23%. Remarkably among other drier dried papaya moisture content, the refractance window dried papaya moisture, 1st month is showed a statistical difference with 2nd month, and finalized with 15.83 %. (**Annex 3 &4**; Disclosed the moisture and water activity of dried papaya within storage time).

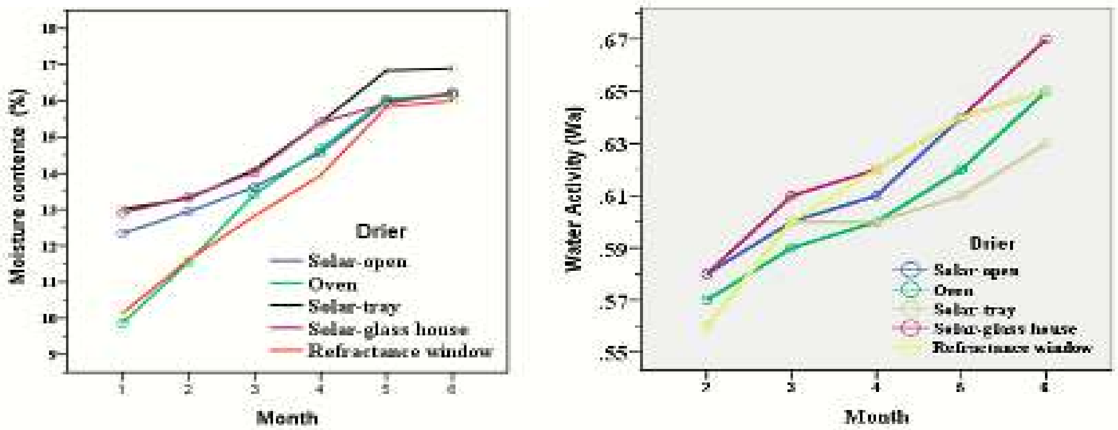


Figure 20; Moisture contents & water activity of dried papaya within storage month.

Water activity (A_w) of dried papaya products within the storage period increase as shown in figure 20. Water activity values of different driers such as solar-open, oven, solar-tray, solar-glass house, and refractance window were found to be 0.58 – 0.65 0.57 – 0.65,0.56 – 0.63, 0.58 – 0. 67 ,0.56 – 0.64 respectively. Water activity is significantly increased ($p <0.05$) for each and individual drier dried papaya products in a storage month. Dried products having higher water activity values might have leads to shorter shelf life, due to the presence of high free water for biochemical degradation (Quek *et al.,* 2007). Results for water activity (A_w) of all dried papaya produces is consistent with findings carried out by (Wong & Lim, 2016), who stated that the spray-dried papaya powder water activity (A_w) increased (0.16- 0.28) with increasing storage time (7 weak storge months), stored with aluminum foil and polyethylene.

In general, the moisture content, and water activity through the storage period for all dried papaya was increased, and significant differences ($p < 0.05$) were observed. The increment of moisture content and water activity for the dried papaya products might be due to (1) the high rate of migration of water vapor from the storage environment into the packaging material (Pua *et al.,* 2008), and (2) the transfer of wet air/ moisture from the environment to the sample during sample analysis when it opens to weight. Besides (Borges and Calvidal (1994), reported that the kinetics of water sorption is governed by several factors such as the amount of water absorbed by the drying material, environmental conditions (temperature and humidity), and microstructure of the products

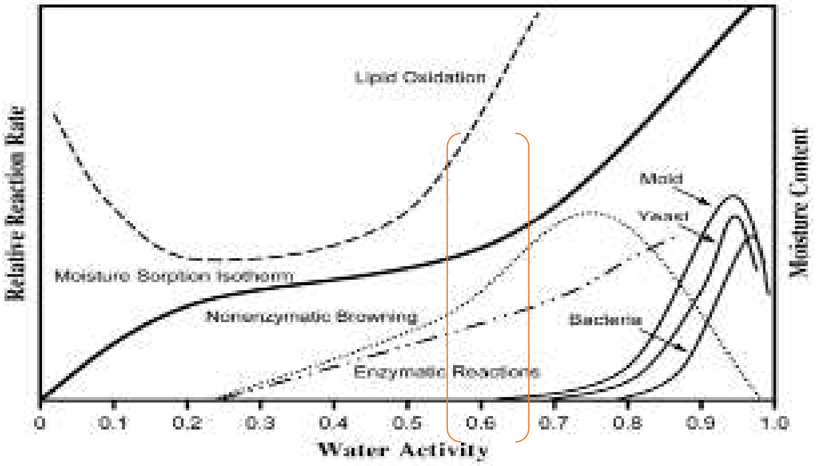


Figure 21; Food stability map as a function of water activity

Source; (Labuza & Rahman, 1999)

The water and moisture content increment within the storage period finding is with the support of (Megías *et al.,* 2014) who reported that the dry matter content ranged from 76.2% to 94.3% and the water activity values from 0.216 - 0.561. Moreover ; (Udomkun *et al.,* 2016) also found that dried papaya (convective at 70 °C) with 9 month storage periods, the moisture and water activity values varied from 13.28 – 17.04 % and 0.51 – 0.67 respectively, which agreed that through storage time, moisture and water activity increases. Figure 19 showed the range of the water activity of dried papaya that changes within six-month storage, and also what the possible chemical reactions take place.

4.10.2 Carotenoids

Carotenoids present in colored plant pigments, responsible for different colors in fruit and vegetable, and have health-promoting effects. As a result of being healthy human nutrition as they have pro-vitamin A activity, their availability in processed food is a critical issue (Regier *et al.,* 2005). The presence of main carotene compounds (Alpha-carotene, b-carotene, b-cryptoxanthin, lutein, and lycopene) contributes to the total carotenoids present in fruits and vegetables. Figure 22 reveals the total carotenoids and beta-carotene contents of dried papaya products' shelf-life stability. As clearly observed in the previous discussion initially, the total carotenoids showed a significant difference between driers, also showed a statistically significant difference ($p< 0.05$) along with the storage period. With corresponding driers of solar-open, oven, solar-tray, solar glass house, and refractance window of the total carotenoid values were decreased from 45.1 - 31.4, 52.5 - 42.2, 49.9 - 40.9, 71.6 - 57.44, and 84.6 - 73.7 as measure ug/g, in the storage period. In all dried papaya products carotenoid content was decreased, and a considerable difference ($p < 0.05$) was observed across a month and also with a drier for each month. In the case of beta-carotene also the same scenario has happened, it decreases within the storage month. Beta carotene was done for four driers of dried papaya, and its contents were being from 6.40 – 3.30, 8.24 – 3.46, 15.02 – 6.25, and 22.55 – 15. 35 with particular drier of oven, solar-tray, solar-glass house, and refractance window. Mean comparison for each drier across month was done, and significant differences ($P<0.05$) were observed up to six months. And also, dryers were compared for their beta-carotene mean value in each sequential storage month, and statistical differences were also observed.

Carotenoids are susceptible to heat, light, oxygen and undergo autoxidation due to the structures (contains a conjugated double bond system over the entire length of the polyene chain) (Britton, 1995). Carotenoid reduction through storage time is due to oxidation, the thermo labile and photosensitive nature; isomerization, and epoxide forming nature of carotene (Nath &Technology, 1993). Confidently, the oxidative process beginning during the drying process, and with the formation of free radicals, the reaction was triggered even in the absence of light. (**Annex 5 & 6**; Revealed the total carotenoid and beta-carotene contents of dried papaya within storage time).

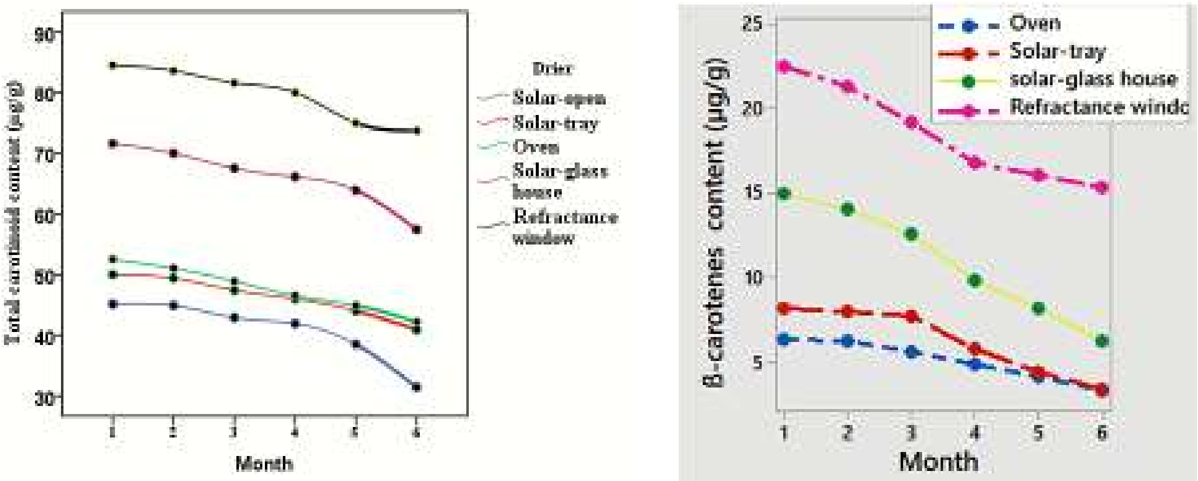


Figure 22; Total carotenoid and beta-carotene shelf-life stability

(Reis, *et al.,* 2006) described that as well oxidative process, heating of papaya during the dehydration process can encourage the redistribution of the cellular food constituents, with the release of acids. These situations goodwill the isomerization of the carotenoids (trans to cis), and these isomers may also undergo oxidation. Moreover, the isomerization and oxidation process results in loss of the pro-vitamin A activity of some carotenoids, such as β-carotene (Rodriguez, 1999). As revealed by (Kaur *et al.,* 2020) also, who reported that the reduction of carotenoids (tomato and sweet pepper) with six months of the storage period, maybe due to exposure to oxygen and light, which resulted in the oxidation of carotenoids. During storage, the stability of carotenoids was mainly dependent on the water activity of the product.

4.10.3 Changes in Bioactive Parameters

Bioactive compounds such as polyphenol, antioxidants, flavonoids, and vitamin C have antioxidant properties, which can lower the risk of carcinogenic and cardiovascular diseases (Harborne & Williams, 2000). In the current study, the stability of flavonoid and phenolic contents of the dried papaya products were evaluated (figure 23). The total phenolic contents of all dried papaya were decreased within a storge period, as presented below.

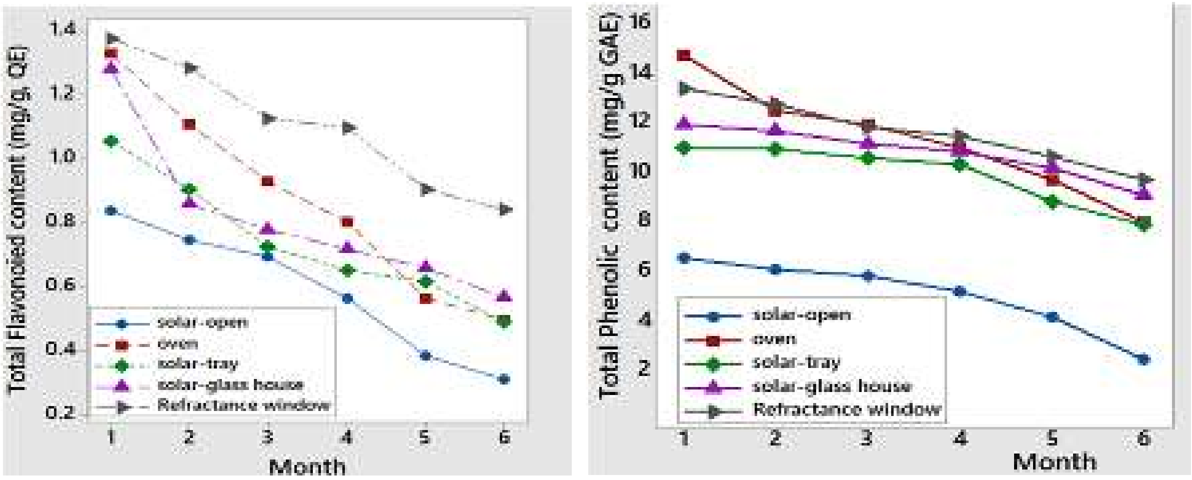


Figure 23; Total phenolic and flavonoids contents of dried papaya.

It is varied from 6.56 – 2.45, 14.78 – 8.01, 11.05 – 7.90, 11.95 – 9.14, and 13.4 – 9.74, with corresponding order of solar-open, oven, solar-tray, solar- glasshouse, and refractance window dryer. Whereas the total flavonoid contents of the dried papaya found to be 0.84 – 0.31, 1.33 – 0.50, 1.06 – 0.49,1.28 – 0.57, and 1.38 – 0.84 with a corresponding drier of solar-open, oven, solar- tray, solar glass house, and refractance window. Like the total phenolic content, a total flavonoid also decreases with storage time significantly ($p < 0.05$). Results of the present finding are consistent with the finding of (Kaur *et al.,* 2020; Sachin, 2013). The possible reason that could be phenolic compounds degradation due to oxidation, cleavage, or mediated by the enzyme polyphenol oxidase (Wani *et al.,* 2020), and also for flavonoid due to precipitation, oxidative degradation, or hydrolysis of the flavanols (Sonawane *et al.,* 2015). Polyphenol Oxidase activity is highly influenced by processing temperature and is high at a temperature of 55 °C and lasts up to a temperature of 75 °C. Phenol degradation starting during processing and storage. Drying provides more suitable conditions for degradation reactions like the availability of oxygen and suitable temperature.

4.10.4 Color Stability of Dried Papaya

Colour is a sensory parameter widely used to validate the consumer acceptance of dehydrated fruit. Color stability of dried papaya for six-month storage at ambient temperature and relative humidity was conducted starting the analysis from the second-month storage period, and values are found in the figure below 24. For all dried papaya products, color attributes of CIE (L*, a*, and b*) showed a significant decrease ($P < 0.05$) along the storage period. Lightness (L*) value of all dried papaya found to be in the array of 54.68 - 49.88, 56.78 - 49.50, 57.66 - 49.60, 54.06- 50.55, 53.18 - 48.76, the order of dryer of solar-open, oven, solar-tray, solar- glasshouse, and refractance window dryer. (**Annex 11;** Presented the color shelf-life stability of dried papaya).

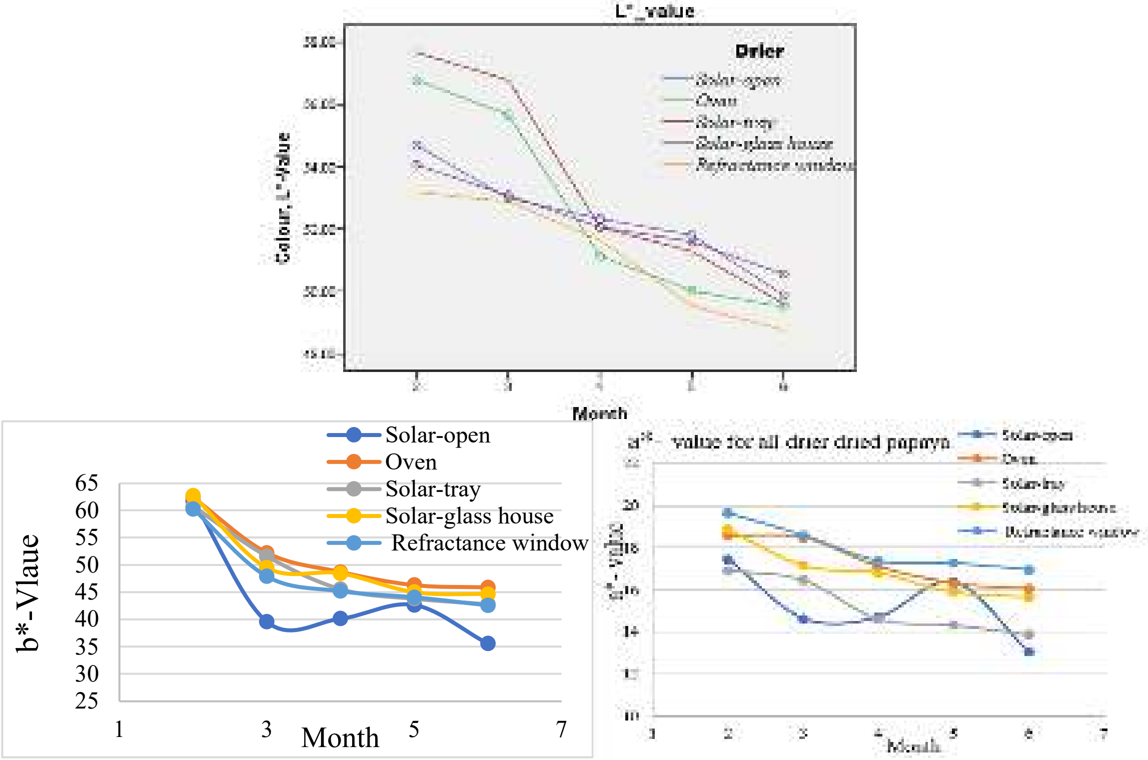


Figure 24; Dried papaya color (L*, a*, and b*) stability within storage month.

The L*, a*, and b* values of all dried papaya products decrease with a storage month, and substantial statistical differences ($p < 0.05$) were observed. The dried products progressively become darkened (fade the color); this is might be due to the Maillard reaction. The Maillard reaction, which polymerizes with compounds containing amine groups, under less acidic conditions (pH >5.0), giving rise to brown pigments called melanoidins (Reis *et al.,* 2018).

The results of the present study are in agreement with (Reis *et al.,* 2018), for three-month storage and (Udomkun *et al.,* 2015) for 9-month observations of browning of dried papaya.

An increasing, water activity (maximum b/n 0.6 – 0.7) of the dried product by itself also favors this reaction (Fennema *et al.,* 2010). The other possible reasons for the contribution of browning, stored dried papaya (1), dehydroascorbic acid oxidation which hydrolyses to form 2,3-diacetogulonic acid which undergoes polymerization reaction with amino acids for promoting the dark pigment formation (Chong *et al.,* 2013), (2) degradation of β-carotene can also result in the generation of compounds from the Maillard reaction, leading to the browning of the product (Hymavathi *et al.,* 2005). However, at intermediate water activity ranges of 0.4–0.65, nonenzymatic browning reactions take place during storage due to the high concentration of the reacting species and slow molecular mobility (Perera, 2005). On the other hand, carotenoid reduction may be one of the major contributions for the reductions of a* and b* color value across a tested month, since the papaya color is the result of β-carotene, α-carotene, cryptoxanthin, and lycopene (Reis *et al.,* 2018).

4.10.5 Microbial Load

Microbiological stability is the most critical factor in determining the stability of food products, it the issues of physical and chemical stability of the product. Dried papaya products were subjected to microbial load analysis of total bacterial & fungus (mold, yeast) count, and analysis was performed every month for six months, and the results exhibited in table 12 & 13. Microbial growth is depending upon the water activity values of the dried products and their moisture contents. In this research finding, microbial growth on the dried papaya products up to four (4) month storage was not observed with a dried papaya a water activity and moisture content values 0.59 – 0.62, and 13.94 - 15.40. This report is in line with the outcomes (Sagar & Kumar, 2010) who stated that no microbiological growth has been reported in dried fruit and vegetable at a water activity value lower than 0.62.

The microbial load such as total bacterial count and total fungus (mold and yeast) was observed starting from the 5th month. However, there was no considerable difference ($p<0.05$) between the 5th and 6th-month storage of total fungus, and bacterial count for all drier dried papaya products. But only for solar-open and refractance window driers dried papaya product, total bacterial count in between 5th and 6th-month storage was shown a significant difference ($p <0.05$). During this storage period water activity value of the dried papaya was varied from 0.61 – 0.67, as a result, it is expected to grow the microbial infections as supported with the report of (Rockland & Beuchat, 1987) who stated that fungal infection might occur during storage of products with water activity (aw) level of 0.65 or less. The best way to prevent fungal and bacterial growth on harvested products is to maintain the optimum range of temperature and relative humidity throughout the handling system (Perera, 2005).

Table 12; Total fungus count for dried papaya

Total Fungus (CFU/g)	Storage Month					
	1st	2nd	3rd	4th	5th	6th
Solar-open	ND	ND	ND	ND	0.16^{aA}±0.28	0.56^{aA}±0.07
Oven	ND	ND	ND	ND	0.10^{aA}±0.17	0.52^{aA} ±0.24
Solar-tray	ND	ND	ND	ND	0.36^{aA}±0.39	0.36^{aA} ±0.5
Solar-Glass house	ND	ND	ND	ND	0.52^{aA}±0.24	0.62^{aA} ±0.15
Refractance Window	ND	ND	ND	ND	0.10^{aA}±0.17	0.36^{aA} ±0.10

ND; not detected

- ❖ *Values are given as mean + SD (n=3). The different lowercase letters in the same column and the different uppercase letters in the same row denote a significant difference (P < 0.05); independent t-test.*

Moreover; Pathogenic bacteria, yeast, and mold do not grow in media with lower 0.85, 0.7, and 0.65 water activity values, respectively (Labuza & Rahman, 1999; Sagar & Kumar, 2010) but the present studies found that some bacterial, and fungus was grown in dried papaya with lower water activity value as mentioned in previous. Similar observations were also reported by (Wong & Lim, 2016) for the spray-dried papaya powder.

Table 13; Total bacteria count for dried papaya

Bacterial (CFU/g)	Storage month					
	1st	2nd	3rd	4th	5th	6th
Solar-open	ND	ND	ND	ND	1.96 ^{aA}±0.24	2.59^{aB}±0.11
Oven	ND	ND	ND	ND	1.8^{aA}±0.17	2.26 ^{aA}±0.24
Solar-tray	ND	ND	ND	ND	2.06^{aA}±0.10	2.10 ^{aA}±0.17
Solar-Glass house	ND	ND	ND	ND	2.03^{aA}±0.35	2.56 ^{aA}±0.24
Refractance Window	ND	ND	ND	ND	1.7 ^{aA}±0.00	2.10 ^{aB}±0.17

ND; not detected

Values are given as mean + SD (n=3). The different lowercase letters in the same column and the different uppercase letters in the same row denote a significant difference (P < 0.05); independent t-test.

The total bacterial count and fungus were found up 2.59 (4*102 CFU/mL), and 0.62 (4.33 CFU/mL) increments within a given storage period (Table 12 & 13) . However, the microbial load of total bacteria and fungi value for ready-to-eat dried fruit food should lower than 10^6 CFU/mL, 10^3 CFU/mL as established by the New South Wales (NSW) Food Authority guidelines (Authority, 2009; Ruta Svagzdiene, 2010). Therefore; the present study dried fruit microbial load is much below the recommended, as a result, it safe being consuming up to six-month storage.

5. Conclusions and Recommendations

Conclusions

In this research, most of the possible solar drying technology (solar-open, solar-tray, and solar-glass house), refractance window dryer, and freeze (control) were evaluated for their dried papaya products physical, chemical, microbial, nutrient retentions, and product shelf stability. Apparently, Slice load has an effect in refractance window, oven, and solar- tray on drying time as well nutrient retention. Dried papaya is more preferable to fresh papaya in terms of nutrient-dense, reduces transportation cost, easy transportation, reduces packaging materials, affordability, and increases shelf stability. Pre-treatment of papaya slices with ascorbic acid had better nutrient retention than untreated dried papaya products. Refractance window drying and solar glass-house lead to superior quality dried papaya products than those dried with oven-, solar open- and solar-tray drying. As per the shelf-life study, dried papaya can be shelf-stable for up to six months of storage. Eventhough the fact that the refractance window dryer has better nutrient retention than other dryers but solar- glass house would be better in terms of cost-benefit analysis, and availability of the drying materials. Promoting the drying of papaya with environmental-friendly drying methods like solar drying can extend the shelf-life, maintain nutritional and bioactive compounds, which in turn could increase the availability, accessibility, and affordability of fruits like papaya. Dried papaya can easily be integrated into diets and can significantly contribute to meeting vitamin A requirements. Refractance window and solar-glass house drying can constitute a promising food systems' intervention that can improve year-round availability, accessibility, and affordability of vitamin A-rich fruits like papaya.

Recommendations

- Appropriate ripened stage papaya should be used for drying because if it is not more ripen, the required nutrient might not be more available, and if more ripened, it might not be sliced rather juicy.
- Sliced papaya should not be dry for more than two days in solar drying technologies (solar-open, solar-tray & solar glass), because the fungus will grow on it.
- The researcher recommends using a solar-glass house dryer for drying papaya fruit unless it is used refractance window.
- Dried papaya fruit can contribute to the reduction of Vitamin A prevalence in the community.
- The researcher recommended eating dried papaya stored for up to six months because the amount of microbial load is much less than recommended.
- Consuming dried papaya is better than eating fresh papaya due to dense nutrients as a result of concentration.
- A farm that has a high potential area of papaya production, should adapt a solar glass house dryer in their area to dry papaya for reducing the post-harvest loss if there is no such good electric power supply.
- Further study is needed, for a possible packaging material of dried papaya.
- The study was conducted for only yellow flesh papaya with a moderate ripening stage (above 75% yellow skin cover). But there are two major papaya varieties, depending on flesh colors such as yellow (more beta-carotene) and red (more lycopene) pulp. Therefore; the researcher recommends further studies, for the rest papaya varieties to see the effect of drying on the nutrient retention of varieties.
- The researcher recommended also further studies of papaya drying, without being sliced, at the last stage of ripening (meaning drying with juicy papaya not sliced form).

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Annexs

Annex 1; Carotenoid Contents of (treated and untreated) dried papaya

	Total Carotenoid (µg/g)		Beta-carotenoids (µg/g)		Lycopene (µg/g)	
Dryer	Untreated	Treated	Untreated	Treated	Untreated	Treated
Solar- open	45.1^{Db}± 1.8	51.49^{Da}±0.81	5.16^{Da}±0.80	7.88^{Ca}±0.62	3.91^{Db}±0.28	5.94^{Ca}±0.37
Oven	52.46^{Cb}±2.81	63.67^{Ca}±2.3	6.40^{CDb}±0.23	13.37^{Ba}±1.68	8.03^{Bb}±0.49	10.25^{Ba}±0.48
Solar-tray	49.97^{CDb}± 1.45	60.68^{Ca}±0.83	8.24^{Cb}±0.48	15.71^{Ba}±0.75	6.34^{Cb}±0.63	10.70^{Ba}±1.0
Solar- glass house	71.62^{Bb}± 1.60	79.64^{Ba}±2.3	15.02^{Bb}±0.26	26.51^{Aa}±2.00	6.80^{BCb}±0.40	13.06^{Aa}±0.28
Refractance window	84.55^{Aa}± 1.00	92.95^{Ab}±2.14	22.55^{Ab}±0.01	30.87^{Aa}±0.7	12.50^{Ab}±0.68	14.34^{Aa}±0.40

- *Data are expressed as mean± SD (n=3). The different lowercase letters in the same row and different capital letters in the same column denote a significant difference (P < 0.05).*

Annex 2; Polyphenol (phenolic and flavonoid) and vitamin C content of dried papaya

Dryer	Total phenolic (mg/g GAE)		Total Flavonoid (mg/g QE)		Vitamin C (mg/100g)	
	Untreated	Treated	Untreated	Treated	Untreated	Treated
Solar- open	6.56^{Cb}± 0.12	9.39^{Ca}±0.63	0.84^{Cb}±0.03	1.13^{Ca}±0.10	17.22^{Bb}±0.92	57.47^{Da}±1.1
Oven	14.78^{Ab}± 1.25	37.29^{Aa}±0.95	1.33^{Ab}±0.06	1.70^{Aa}±0.1	21.35^{Ab}±0.73	64.12^{Ca}±0.69
Solar-tray	11.05^{Bb}± 1.04	30.80^{Ba}±2.5	1.06^{Bb}±0.05	1.62^{Aa}±0.06	17.00^{Bb}±0.32	78.45^{Aa}±0.7
Solar- glass house	12.01^{ABb}± 0.62	35.98^{Aa} ±0.98	1.28^{Ab}±0.03	1.39^{Bb}±0.08	15.33^{Cb}±0.43	59.55^{Da}±0.62
Refractance window	13.40^{ABb}± 1.86	35.98^{a}±1.0	1.38^{Ab}±0.02	1.36^{Bb}±0.01	14.33^{Cb}±0.33	72.25^{Ca}±0.86

- *Data are expressed as mean± SD (n=3). The different lowercase letters in the same row and different capital letters in the same column denote a significant difference (P < 0.05).*

Annex; Shelf-life Data

Shelf-life stability was done for untreated dried papaya sample

Annex 3; The moisture content of dried papaya with inn six-month storage.

Moisture %	Storage month					
Drier	1st	2nd	3rd	4th	5th	6th
Solar-open	12.34^{aB}±1.4	12.94^{abA}±0.2	13.62^{abAB}±0.3	14.56^{bcA}±1.1	15.99^{cA}±0.4	16.16^{cA}±0.6
Oven	9.86^{aA}±0.5	11.55^{aA}±1.3	13.43^{bAB}±0.5	14.67^{bcA}±0.6	16.05^{cA}±0.2	16.17^{cA}±0.2
Solar-tray	13.05^{aB}±1.0	13.30^{aA}±0.2	14.10^{abA}±0.5	15.40^{bcA}±0.9	16.83^{cA}±0.4	16.89^{cA}±0.3
Solar-Glass house	12.90^{aAB}±0.1	13.35^{aA}±0.5	14.02^{abA}±0.3	15.40^{bcA}±1.2	15.92^{cA}±0.6	16.23^{cA}±0.7
Refractance Window	10.13^{aAB}±0.5	11.61^{bA}±0.7	12.82^{bcB}±0.3	13.94^{cA}±0.6	15.83^{dA}±0.5	16.00^{dA}±0.2

- *Data are expressed as mean± SD (n=3). The different lowercase letters in the same row and different capital letters in the same column denote a significant difference (P < 0.05).*

Annex 4; Water activity of dried papaya

Water Activity	Storage Month				
Drier	2nd	3rd	4th	5th	6th
Solar-open	0.58^{aA}±0.01	0.6^{abAB}±0.00	0.61^{bA}±0.01	0.64^{cBC}±0.01	0.65^{cAB}±0.01
Oven	0.57^{aA}±0.01	0.59^{abA}±0.01	0.60^{bcA}±0.01	0.62^{cdAB}±0.00	0.65^{dAB}±±0.01
Solar-tray	0.56^{aA}±0.00	0.6^{bAB}±0.01	0.6^{bA}±0.01	0.61^{bcA}±0.01	0.63^{cA}±±0.00
Solar-Glass house	0.58^{aA}±0.01	0.61^{bB}±0.01	0.62^{bcA}±0.01	0.64^{cBC}±0.01	0.67^{dB}±0.01
Refractance Window	0.56^{aA}±0.01	0.6^{bAB}±0.00	0.62^{bcA}±0.01	0.64^{cC}±0.00	0.65^{cAB}±0.01

- *Data are expressed as mean± SD (n=3). The different lowercase letters in the same row and different capital letters in the same column denote a significant difference (P < 0.05).*

Annex 5; Total carotenoid content of dried papaya

Total Carotenoids(µg/g)	Storage Month					
Drier	1st	2nd	3rd	4th	5th	6th
Solar-open	45.07^{aD}±1.8	44.89^{aD}±1.6	42.93^{abD}±1.5	41.93^{abD}±2.5	38.53^{bD}±0.7	31.36^{cD}±1.5
Oven	52.46^{aC}±2.8	51.02^{abC}±0.2	48.93^{c-aC}±2.4	46.46^{c-bC}±0.7	44.87^{cdC}±0.3	42.17^{dC}±2.0
Solar-tray	49.97^{aCD}±1.4	49.43^{aC}±2.0	47.34^{abCD}±2.2	45.98^{abC}±1.5	43.97^{bcC}±0.4	40.85^{cC}±1.9
Solar-Glass house	71.616^{aB}±1.6	70.00^{abB}±1.0	67.54^{bcB}±0.9	66.10^{cdB}±0.6	63.93^{dB}±0.3	57.44^{eB}±0.8
Refractance Window	84.545^{aA}±1.0	83.58^{abA}±0.5	81.62^{bcA}±1.8	79.96^{cA}±0.8	75.01^{dA}±0.6	73.67^{dA}±0.8

- *Data are expressed as mean± SD (n=3). The different lowercase letters in the same row and different capital letters in the same column denote a significant difference (P < 0.05).*

Annex 6; Beta carotene content for four dried papaya

Dryer	ß-carotenes(µg/g)					
	Storage month					
	1	2	3	4	5	6
Oven	6.40^{aD}±0.16	6.30 ^{aC}±0.3	5.67^{bC}±0.30	4.93^{cC}±0.34	4.15^{dC}±0.9	3.30^{eB}±0.39
Solar-tray	8.24^{aC}±0.34	7.99^{aC}±0.67	7.75^{a}C±1.3	5.77^{bC}±0.87	4.45^{bcBC}±0.86	3.46^{cB}±0.35
solar-glass house	15.02^{aB}±0.19	14.12^{abB}±0.44	12.60^{bB}±0.51	9.89^{cB}±1.33	8.24^{cAB}±0.72	6.25^{dB}±1.22
Refractance window	22.55^{aA}±0.01	21.32^{aA}±0.64	19.19^{bA}±0.62	16.87^{cA}±0.25	16.13^{cA}±1.53	15.35^{cA}±1.67

- Data are expressed as mean± SD (n=3). The different lowercase letters in the same row and different capital letters in the same column denote a significant difference (P < 0.05).

Annex 7; Total phenolic contents for dried papaya

Total phenolic (mg/g GAE)	Month					
	1st	2nd	3rd	4th	5th	6th
Solar-open	$6.56^{aC}\pm0.1$	$6.10^{aC}\pm0.3$	$5.86^{abC}\pm0.3$	$5.22^{bC}\pm0.3$	$4.18^{cD}\pm0.4$	$2.45^{dC}\pm0.2$
Oven	$14.78^{aA}\pm1.3$	$12.52^{bAB}\pm0.4$	$11.98^{bAB}\pm0.7$	$11.04^{bcAB}\pm0.5$	$9.74^{cdBC}\pm0.2$	$8.01^{dB}\pm0.3$
Solar-tray	$11.05^{aB}\pm1.1$	$10.97^{aB}\pm1.2$	$10.63^{abB}\pm0.4$	$10.36^{abB}\pm0.3$	$8.84^{bcC}\pm0.4$	$7.90^{cB}\pm0.5$
Solar-Glass house	$11.95^{aAB}\pm0.6$	$11.71^{aAB}\pm0.4$	$11.17^{abAB}\pm0.5$	$10.90^{abAB}\pm0.1$	$10.19^{bcAB}\pm0.4$	$9.14^{cA}\pm0.2$
Refractance Window	$13.40^{aAB}\pm1.9$	$12.79^{abA}\pm0.6$	$11.84^{a\text{-}cA}\pm0.3$	$11.51^{a\text{-}cA}\pm0.3$	$10.68^{bcA}\pm0.4$	$9.74^{cA}\pm0.2$

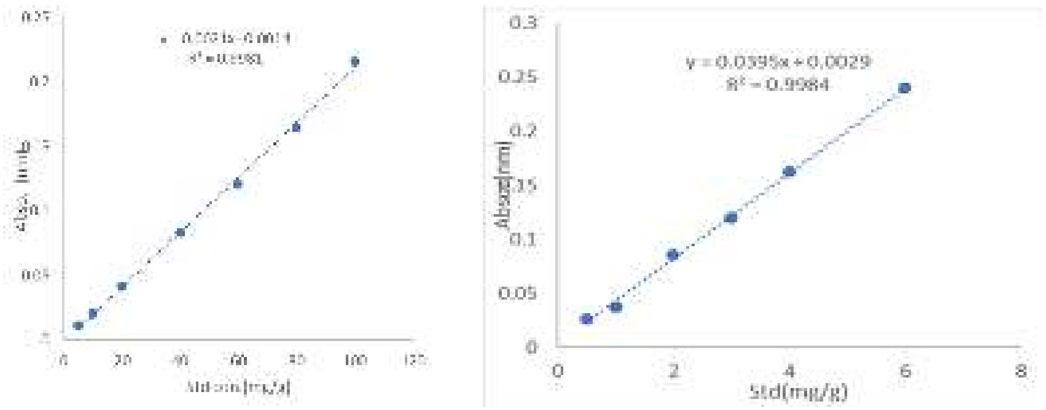
- *Data are expressed as mean± SD (n=3). The different lowercase letters in the same row and different capital letters in the same column denote a significant difference (P < 0.05).*

Annex 8; Total flavonoid contents of dried papaya

	Total Flavonoid (mg/g QE)					
	Storage Month					
	1st	2nd	3rd	4th	5th	6th
Solar-open	$0.84^{aC}\pm0.03$	$0.75^{bD}\pm0.03$	$0.69^{bC}\pm0.01$	$0.55^{cE}\pm0.02$	$0.39^{dD}\pm0.02$	$0.31^{eCB}\pm0.02$
Oven	$1.33^{aA}\pm0.06$	$1.11^{bB}\pm0.1$	$0.93^{cB}\pm0.03$	$0.81^{cB}\pm0.03$	$0.57^{dC}\pm0.03$	$0.50^{dB}\pm0.04$
Solar-tray	$1.06^{aB}\pm0.05$	$0.91^{bC}\pm0.03$	$0.73^{cC}\pm0.05$	$0.65^{cdD}\pm0.02$	$0.62^{dBC}\pm0.03$	$0.49^{eB}\pm0.02$
Solar-Glass house	$1.28^{aA}\pm0.03$	$0.86^{bCD}\pm0.03$	$0.78^{bcC}\pm0.07$	$0.72^{cdC}\pm0.01$	$0.66^{deB}\pm0.02$	$0.57^{eB}\pm0.02$
Refractance Window	$1.38^{aA}\pm0.01$	$1.29^{aA}\pm0.02$	$1.13^{bA}\pm0.02$	$1.10^{bA}\pm0.02$	$0.91^{cA}\pm0.05$	$0.84^{cA}\pm0.06$

- *Data are expressed as mean± SD (n=3). The different lowercase letters in the same row and different capital letters in the same column denote a significant difference (P < 0.05).*

Annex 9; Standard curves for total phenolic(left) and total flavonoid (right).



Annex 10; Sensory Evaluation Ballot for Dried papaya Sample.

Date;------------------------------------

Sex;- ----------------------------

Sensory Evaluation Ballot for Dried papaya Sample.

In this sensory evaluation of dried papaya fruit, you are given samples of papaya for your evaluation. You are kindly requested to taste the samples and indicate your response by putting the values given below (seven-point hedonic scale having values) in front of each attribute and don't forget to rinse your mouth after taste.

1= Dislike Extremely, 2= Dislike very much, 3= Dislike, 4= Neither like nor dislike, 5= Like, 6= Like very much, 7= Like extremely

sample code	Color	Flavor	Texture /Crispness	Sweetness	Overall Acceptability
543					
283					
423					

Comments;

Signature;

Thank you very much for your cooperation.

Annex 11; Color shelf-life stability of dried papaya

Colour	Month of storage														
Drier	2 st			3rd			4th			5th			6th		
	L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*
Solar-open	54.68^{aA-C}	17.45^{aC}	61.81^{aA}	52.99^{abB}	14.63^{bcC}	39.58^{cD}	52.33^{aA}	14.70^{bcB}	40.15^{cC}	51.81^{cA}	16.38^{bA}	42.64^{bC}	49.88^{cA}	13.07^{cD}	35.57^{dC}
Oven	56.78^{aAB}	18.58^{aBC}	62.41^{aA}	55.67^{aA}	18.48^{aA}	52.22^{bA}	51.65^{bA}	17.11^{bA}	48.70^{cA}	50.02^{bAB}	16.31^{bcA}	46.33^{dA}	49.50^{aA}	16.06^{cB}	45.87^{dA}
Solar-tray	57.66^{aA}	16.92^{aC}	60.72^{aA}	56.78^{aA}	16.46^{aB}	51.58^{bAB}	52.05^{bA}	14.62^{bB}	45.56^{cAB}	51.28^{bAB}	14.33^{bcB}	43.80^{dBC}	49.60^{cA}	13.87^{cC}	42.80^{eB}
Solar-Glass house	$54.0\ 6^{aBC}$	18.86^{aA-C}	62.72^{aA}	53.08^{abB}	17.15^{bB}	49.49^{bBC}	52.06^{a-cA}	16.80^{bA}	48.47^{bAB}	51.59^{bcA}	15.87^{cB}	45.02^{cAB}	50.55^{cA}	15.65^{cB}	44.64^{cA}
Refractance Window	53.18^{aC}	19.65^{aA}	60.25^{aA}	52.88^{aB}	18.61^{aA}	47.90^{bC}	51.65^{abA}	17.37^{bA}	45.19^{bcB}	49.54^{bcB}	17.26^{bA}	44.07^{cBC}	48.76^{cA}	16.95^{bA}	42.58^{cB}

- Data are expressed as mean (n=3). The different lowercase letters in the same row and different capital letters in the same column denote significant difference ($P < 0.05$), but comparison was made for only L* with L*, a* with a*, b* with b* for all dryer dried papaya products.