EFFECT OF DRYING CONDITIONS ON STORAGE STABILITY OF TOMATO POWDER USING PACKAGING MATERIALS

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2024

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A dissertation submitted to the Department of Food Technology, Central Campus of Technology, Tribhuvan University, in partial fulfillment of the requirements for the degree of B. Tech in Food Technology.

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January, 2024

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Approval letter

This *dissertation* entitled ***Effect of Drying Conditions on Storage Stability of Tomato Powder using Packaging Materials*** presented by **Akriti Kandel** has been accepted as the partial fulfillment of the requirements for the **B. Tech. degree in Food Technology.**

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January 2, 2024

Acknowledgements

I would like to extend my sincere gratitude to my supervisor, Mrs Mahalaxmi Pradhananga, for her kind assistance, direction, encouragement, and helpful advice regarding the conduct of this study.

I am also grateful to Asst. Prof. Navin Gautam, Head of Department, Department of Food Technology, and Assoc. Prof. Dr. Dil Kumar Limbu, Campus Chief, Central Campus of Technology, for providing the resources necessary to complete this dissertation work to the best of my ability.

I sincerely thank all of my friends who helped me with the task, both directly and indirectly. I would especially like to thank my friends and junior, Prashamsa Pandey, Alisha Sharma Banjade, Alisha Adhikari, Samikshya Poudel, Aarti Pandey, Dipendra Pandey, Milan Bolakhe and Ranjana Mishra for their assistance in getting this task finished. I thank everyone whose insights, observations and contributions have either directly or indirectly aided me.

All of the instructors, staff personnel, and librarians are sincerely appreciated for their assistance. I would like to thank Mr. Prajwal Bhandari, Head Laboratory Assistant, CCT, Hattisar, Dharan, Mr. Mahesh Shrestha, Mr. Suman Pulami, Mrs. Meera Shrestha, Mrs. Sharon Bhandari, Ms. Dikxhya Rai, Mr. Sachin Basnet for helping me to learn in a passionate and enthusiastic setting.

I want to convey my love and gratitude to my esteemed parents, whose encouragement and support helped me get to this point. I would not have been able to achieve this feat without their help.

Date of Submission: January 2, 2024

(Akriti kandel)

Abstract

The aim of this present research was to study the effect of two different drying conditions i.e., sun drying and cabinet drying on the quality and storage stability of tomato powder using different packaging materials. Tomatoes were sorted, cleaned, and sliced into 5 mm thickness. It was then dried in sun and in cabinet dryer until the weight of tomatoes were constant. The dried tomatoes were powdered and sieved through 40 mesh size to a fine consistency which was then packed in three different packaging materials i.e., glass jar, HDPE and LDPE package. The sensory evaluation of stored tomato powder was assessed as well.

The proximate composition of fresh tomato was found to be for moisture, protein, crude fiber, fat, ash and carbohydrate was 95.77 %, 18.40 %, 10.41 %, 4.71 %, 8.07 % and 58.41 % respectively on the dry basis except for moisture. The lycopene content (mg/100g), acidity (% as citric acid) and pH of tomato were found to be 15.50 %, 0.73 % and 4.23 % respectively. Both sun dried and cabinet dried samples were analyzed for the proximate components, lycopene content, acidity and pH. The result showed that retention of nutrients was better in cabinet dried tomato powder in terms of protein, fat, and fiber while retention of lycopene was better in sun dried tomato powder. There were no significant changes in acidity and pH. During storage, the chemical analysis i.e., moisture content, lycopene content and TPC at different interval showed that glass bottles gave greater protection against degradation of the chemical attributes of the dried tomato powder followed by HDPE and LDPE package. The findings of this study showed that cabinet dried tomato powder stored in glass was found superior in terms of sensory quality and storage stability.

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List of Abbreviations

Abbreviation	Full form
ANOVA	Analysis of Variance
AOAC	Association of Analytical Communities
CD	Degree of Caking
CFU	Colony Forming Unit
CPP	Cast Polypropylene
db	dry basis
FAO	Food and Agriculture Organization
HDPE	High Density Polyethylene
LDPE	Low Density Polyethylene
LSD	Least Significant Difference
NEB	Non-Enzymatic Browning
OPP	Oriented Polypropylene
PP	Polypropylene
PS	Polystyrene
PVC	Polyvinyl Chloride
TA	Titratable Acidity
TPC	Total Plate Count

Part I

Introduction

1.1 General Introduction

The tomato (*Lycopersicon esculentum*) is one of the world's most popular and commonly grown vegetable crops. It is a member of the Solanaceae family. Tomatoes help to maintain a healthy, well-balanced diet. They contain a lot of minerals, vitamins, vital amino acids, sugar and fiber. Tomatoes are high in vitamin B and C, as well as iron and phosphorus. Tomatoes are eaten raw in salads or cooked in sauces, soups, and meat or fish dishes. They can be made into puree, juice, or ketchup. Tomatoes, both canned and dried, are commercially significant processed items (Naika *et al.*, 2005).

Tomatoes have a limited shelf life at room temperature and are highly perishable. It produces a glut during the producing season and becomes scarce during the off season. Short shelf life, along with insufficient processing facilities, results in significant revenue loss in the country. As a result, tomato preservation and processing are economically important (Davoodi *et al.*, 2007). The most popular method of tomato preservation is drying. Various drying procedures can be used. The removal of moisture from the tomato must be done in a way that is least damaging to the product's quality. Because of their superior characteristics, dried tomato products (such as tomato halves, slices, and powders) are becoming more popular. Among these many dried tomato products, powder promises a distinct market position due to numerous advantages, including simplicity of packing, shipping, and no drum clinging losses. Tomato powder is becoming popular among dehydrated soup manufacturers, and it is also used as an ingredient in a variety of food products, most notably soups, sauces, and ketchups (Liu *et al.*, 2010).

Quality variations in dried tomato products are common during manufacturing and storage. Several authors have researched the influence of varied processing and storage conditions on the chemical and physical qualities of dried tomato products due to their widespread consumption and industrial application (Liu *et al.*, 2010). Several modifications have been recorded during the production and storage of dried tomato powder.

Because of its unique nutritional value, tomatoes are one of the most essential foods for protection. It is a great source of antioxidants such lycopene, carotenes, and phenolics as well as vitamin C (Srivastava and Kulshreshtha, 2013). Drying of tomato saves weight and volume, reduces packing and transportation expenses, and allows the product to be stored at room temperature for extended periods of time. The determination of suitable drying conditions, which is a low-cost technique, and the conversion of dried tomato into powder form will significantly help to the reduction of losses and the generation of additional money for the country.

1.2 Statement of the problem

Tomatoes are one of the most important commercial horticulture crops grown in Nepal (Ghimire *et al.*, 2001). It ranks third in both overall cultivated area and productivity (MoALD, 2020). Tomato growing in Nepal covers around 20,000 hectares with an average output scale of 0.3 million metric tons, i.e., 15 tons per ha in fiscal year 2013/14 (MoAD, 2014), and has expanded to 22,566 ha of planted land with a productivity of 18 tons per ha in fiscal year 2018/2019 (MoALD, 2020).

However, due to insufficient processing and transportation, over one-fourth of total tomato harvest weight that enters the value chain is lost before reaching customers, and one-fifth is traded at a lower price due to quality degradation (Gautam *et al.*, 2017). Tomatoes are scarce in the off season and expensive.

Tomato preservation and later processing are economically important. To avoid significant revenue loss, optimal tomato use requires the use of appropriate technology. Tomatoes can be processed into a variety of value-added products, reducing postharvest losses. Processing of tomato into powdered form is one of the methods that we can rely for its optimum utilization and supplementing agricultural economy.

1.3 Objectives

1.3.1 General objective

The general objective of this dissertation was to study effect of drying conditions on storage stability of tomato powder using packaging materials.

1.3.2 Specific objectives

The specific objectives of this dissertation work were:

1. To analyze the physicochemical properties of raw tomato.
2. To prepare tomato powder by using different drying conditions.
3. To analyze the physicochemical properties of tomato powder.
4. To determine storage stability of tomato powder in different packaging materials.
5. To perform sensory analysis of stored tomato powder.

1.4 Significance of the study

Tomato is one of the most important protective foods because of its special nutritive value. It is an excellent source of vitamin C and antioxidants such as lycopene, carotenes and phenolics (Srivastava and Kulshreshtha, 2013). Tomato is highly perishable fruit and changes continuously after harvesting (Haile and Safawo, 2018). When there is an abundance of tomatoes during season, producers can dry them and preserve them for long-term use. Tomato drying reduces product weight and volume significantly, reduces packaging and shipping expenses, and enables long-term storage of the product at room temperature.

Dry tomato powder is a viable option to replace artificial flavoring and coloring. It can be used both in commercial and domestic food preparations. It can be used in masala powder, seasonings, tastemakers, sauces, ketchup, instant food, chips, snacks, instant soup mix, ready meals, beverages, cookies, confectionery and so on. It can be manufactured without any chemicals and stored in its natural form. It is easy to use and blends perfectly with the other ingredients. Using the natural tomato flavor powder also helps in cost maintenance for commercial eateries.

It can be manufactured without any chemicals and stored in its natural form The dried tomato powder has a longer shelf-life due to the absence of any moisture. The dry tomato powder lasts almost a year compared to other processed tomatoes that expire within months of purchase (Raman, 2022). The selection of the most advantageous drying conditions, which is a low-cost technique, and the conversion of dried tomato into powder form will significantly reduce losses and increase revenue for the nation.

1.5 Limitations of the study

The limitations of this work were:

1. Only two types of drying method were employed.
2. Storage stability of tomato powder was checked only up to 3 months due to time constraint.

Part II

Literature review

2.1 Historical background

Despite the fact that the tomato was transported to Europe centuries ago, the origin of its domestication remains unknown, and two possibilities are still being debated: the Peruvian and Mexican hypotheses. Tomatoes were apparently employed for human consumption fairly soon following their introduction to Europe, as cookbooks attested to their usage in gazpacho by the early 17th century. Nonetheless, because of its resemblance to deadly Solanum species like as mandrake and belladonna, the tomato was long cultivated primarily as a decorative. Thus, in Italy, the fruit was exclusively used for ornamentation and was not adopted into local cuisine until the late 17th or early 18th century. By the mid-18th century, tomato consumption was widespread in England. Tomatoes were "exported" from England to the Middle East/Asia by John Baker, the British consul in Aleppo. Tomatoes then traveled to North America as a result of English colonialism. The tomato's true domestication as an edible vegetable began in the nineteenth century (Bergougnoux, 2014).

Since the end of the nineteenth century, the different varieties available have been grown by open pollination under the surveillance of farms or small collectives. New cultivars were created through spontaneous mutation, natural outcrossing, or recombination of pre-existing genetic variety (Bauchet and Causse, 2012). The best example of tomato breeding is undoubtedly that of Alexander Livingston, who sought to produce tomato fruits that were smooth in shape, uniform in size, and flavorful. He selected tomatoes with various qualities in his farm for this reason. He stored the seeds, cultivated them in fields, and selected them repeatedly over the course of five years until he achieved a fleshier and larger fruit (Livingston and Smith, 1998). From an evolutionary point of view, domestication and breeding programs induced drastic physiological and morphological changes, but this artificial selection reduced the genetic diversity of cultivated tomato.

2.2 Botany of tomato

The tomato belongs to the Solanaceae family, which includes about 1500 tropical and subtropical species that most likely originated in Central and South (Davies *et al.*, 1981).

Several classical and modern botanists supported the categorization of tomatoes as the genus Lycopersicon (Symon, 1981). Plant breeders have consistently referred to the species as Lycopersicon (Taylor, 1986). However, this treatment has not been widespread. (Linnaeus, 1799) included these species in the genus Solanum in his original treatment, and many subsequent taxonomists have also recognized the tomatoes as belonging to Solanum rather than the segregated Lycopersicon (Fosberg, 1987).

2.3 Anatomy and morphology of tomato

The tomato is classified as a vegetable based on its use and culture. Botanically, it is a fruit, and among fruits, it is a berry, because it is indehiscent (non-shedding), pulpy, and contains one or more non-stone seeds. The 86 main commercial tomato cultivars are globular or oblate in shape, but certain unusual kinds are elongated or pear-shaped. The weight of the fruit can range from a fraction of an ounce in cherry tomatoes to 4.5 to 6 or 7 ounces in table and market cultivars and 9 to 12 ounces in canning varieties. The fruit has 2 to 25 locules in transection (Salunkhe *et al.*, 1974).

MacGillivray and Ford (1928) classified tomatoes into five parts: outer and inner walt, inner locule tissue, gelatinous pulp, peel, and seed. The fruit is made up of pericarp, placental tissue, and seeds. Groth (1910) demonstrated that the epidermis of tomato pericarp is composed of an epidermal layer followed by three or four distinct layers of collenchymatous tissue. Rosenbaum and Sando (1920) reported a total absence of stomata in the epidermis of tomato fruit and a thickening of the cuticular layer during the ageing process. The pericarp is mostly made up of big thin-walled cells with extensive intercellular gaps, and it thickens up to 60 hours following pollination (Smith and Cochran, 1935). Cells grow greatly during development. Some of the cells in the inner and middle sections of the carpels may partially dissolve as the fruit matures.

During ovule development, the parenchymatous cells of the placenta that surround their bases expand outward. The parenchyma forms a homogenous tissue of twin-walled cells that completely encloses the developing seeds. The cells do not fuse with the carpellary walls, but rather press against them and the seed surfaces. The tissue is initially stiff and compact, but as the fruit matures, the walls thin and the cells partially collapse. The gelatinous contents contain a large number of spherical starch granules. The mature seeds are oval in shape, flattened laterally, and vary greatly in size. The surface is coated with gray hairs and scales, which are the remains of the lateral walls of the integument's outermost cell layer. The integument is divided into four zones, the innermost layer or epidermis of which is highly pigmented and contributes color to the mature seed (Salunkhe *et al.*, 1974)

2.4 Varieties and yield of tomato

There are various tomato cultivars, the majority of which produce red berries, as well as some that produce yellow, orange, pink, purple, green, and white berries (Ghimire *et al.*, 2017).

In 2014, the globe dedicated 5.02 million hectares to tomato agriculture, and total production was approximately 188.2 million tons, with a global average farm yield of 37.46 tons/ha (FAOSTAT, 2016). The Netherlands had the most prolific tomato farms in 2012, with a nationwide average of 476 tons/ha, followed by Belgium (463 tons/ha) and Iceland (429 tons/ha). Tomato output was valued at 58 billion dollars in 2012, making tomatoes the eighth most valuable agricultural crop in the world. Around 7,500 tomato varieties are grown for a variety of applications (FAOSTAT, 2012). Heirloom tomatoes are gaining popularity, especially among home gardeners and organic farmers, because they provide more unique and delectable fruits at the expense of disease resistance and productivity (Gentilcore, 2010).

2.5 Chemical composition

Tomatoes are widely consumed as fresh vegetables around the world due to their high level of critical nutrients and antioxidant-rich phytochemicals. Tomatoes are high in minerals, vitamins, proteins, essential amino acids (leucine, threonine, valine, histidine, lysine, arginine), monounsaturated fats (linoleic and linolenic acids), carotenoids (lycopene and -carotenoids), and phytosterols (β-sitosterol, campesterol, and stigmasterol) (Davies *et al.*, 1981) . The tomato's composition is strongly influenced by the species, stage of ripeness, year of growth, climatic conditions, light, temperature, soil, fertilization, irrigation, and other cultivation conditions (Petro-Turza, 1986).

2.5.1 Sugar

Sugars, which make for around 50 % of the dry matter in tomato fruits, are one of the key ingredients responsible for its quality. The free sugars in commercial tomato fruit are almost reducing sugars, comprising primarily of glucose and fructose in about equal proportions except in the fruit of some Lycopersicon species, where it is the major sugar. Sucrose is present on occasion but seldom surpasses 0.1 % of the fresh weights. There have also been reports of trace levels of a ketoheptose. In general, the total sugar content increases significantly during ripening from the mature green stage to red-ripe, while cases of a decrease have been documented once the fruit has begun to color. The tomato is one of the few climacteric fruits in which sucrose is almost non-existent (Winsor, 1979).

2.5.2 Acids

Organic acids, primarily citric and malic acids, account up more than 10 % of the dry weight of tomatoes. In addition to the two primary acid components, the presence of a variety of additional acids was discovered at significantly lower proportions. The acid content of tomatoes changes as they ripen. The acid concentration of the berry increases during growth and ripening, up to the breaker stage, and then decreases. Initially, malic acid predominates; in the mature green stage, the malic acid: citric acid ratio is greater than one; following this, citric acid overcomes malic acid and in the ripe red tomato, the ratio is 0.5 or less (Petro-Turza, 1986). Citric acid accounts for 45-66 % of total acidity in fully ripe fruit in English cultivars, 40-90 % in American cultivars, and 60-85 % in Hungarian cultivars. The quality and quantity of organic acids are vital not only for flavor but also for technology, because butyric, thermophilic, and putrefactive anaerobic microbes cannot grow below pH 4.3 (Salunkhe *et al.*, 1974).

2.5.3 Vitamin C

Tomato contains significant amount of Vitamin C. Vitamin C is an antioxidant that lowers the risk of arteriosclerosis, cardiovascular disease, and several types of cancer (Harris, 2013). Tomatoes have an average vitamin C value of about 23 mg/100 g. However, because of preharvest factors such as climatic conditions, soil type, and variety, the actual concentration found in fruit samples may vary (Sablani *et al.*, 2006). Vitamin C is particularly vulnerable to deterioration when subjected to harsh handling and storage circumstances, and it is used to predict the stability of other nutrients. It is also light and oxygen sensitive, and it may degrade under typical transit and storage settings, reducing the nutritious content of the food (Arias *et al.*, 2000).

2.5.4 Pigments

The fruit color we see in tomatoes is a combination of various pigments accumulating in the epidermis, the sub-epidermal layer, and the fruit pericarp (flesh). Whereas in the pericarp of young fruits, the green color is predominant, and due to the presence of chlorophylls, the photosynthetic apparatus is present and functional. A significant increase in the content of certain carotenoids occurs during ripening, while the thylakoid membranes in the chloroplasts break down and the plastids are converted into chromoplasts. As a result, as different carotenoids and flavonoids are synthesized, the color of the fruit gradually changes from green to yellow, orange, and red, and lycopene, the major carotenoid in red ripe fruits, is finally accumulated. The color changes gradually between the mature green stage, when all of the plastids are still chloroplasts, and the fully ripe stage, when only matured chromoplasts are present (Egea *et al.*, 2010). Tomatoes are climacteric fruits, and significant quantities of ethylene are produced during the commencement of ripening. This hormone regulates many carotenoid biosynthesis genes (Alba *et al.*, 2005).

Lycopene is the pigment that is primarily responsible for the deep red color of ripe tomato fruits and tomato products. It has gained popularity due to its biological and physicochemical features, particularly its benefits as a natural antioxidant. Unwanted lycopene degradation impacts not only the sensory quality of the finished products, but also the health benefits of tomato-based foods for the human body. Lycopene is primarily found in all-trans configuration in fresh tomato fruits. Isomerization and oxidation are the primary mechanisms of tomato lycopene degradation during processing (Shi and Maguer, 2000).

2.5.5 Aroma and volatile constituents

Several research have been conducted to investigate the composition of tomato aroma volatiles. It is determined by cultivars, maturity stage, cultivation practice management and postharvest treatments. Despite the fact that over 400 chemicals have been discovered as volatile elements of tomato and tomato products (Petro-Turza, 1986) , only a small number are required for tomato flavor. The distinctive aroma of fresh tomatoes does not appear to be due to a single or small set of chemicals.

To assess the relative importance of volatiles to total odor, smell thresholds of components in water were measured and odor unit values were computed, i.e., the ratio of the component's concentration in food to its odor threshold in water (Buttery *et al.*, 1989). On this basis, 32 components were added in tomato computer improved flavor analysis (Stern *et al.*, 1990). The aroma was strongly influenced by ten of these chemicals ((Z)-3-hexenal, b-ionone, hexanal, 1-penten3-one, 3-methylbutanal, (E)-2-hexenal, 1-nitro-2-phenylethane, (E)-2-heptenal, 6-methyl-5-hepten-2-one, and 2-isobutylthiazole). Sniffing a tomato sample revealed that five aroma volatiles (hexanal, (E)-2-hexenal, 2-methyl-2-hepten-6-one, 2-isobutylthiazole, and Valero nitrile) were significant contributions to the fresh tomato scent (Dirinck *et al.*, 1977).

2.6 Nutritional value of tomato

Table 2.1 Nutritional value of tomato per 10 g

Phytochemicals	Value/100 g (unit)	Phytochemicals	Value/100 g (unit)
Energy	74kJ (18kcal)	Potassium	237 mg (5 %)
Carbohydrates	3.9 g	Lycopene	2573 µg
Sugar	2.6 g	Vitamin A equiv.	42 µg (5 %)
Dietary fiber	1.2 g	β-Carotene	449 µg (4 %)
Fat	0.2 g	Lutein/Zeaxanthin	123 µg
Protein	0.9 g	Thiamine	0.037 mg (3 %)
Water	94.5 g	Niacin	0.594 mg (4 %)
Magnesium	11 mg (3 %)	Vitamin B_6	0.08 mg (6 %)
Manganese	0.114 mg (5 %)	Vitamin C	14 mg (17 %)
Phosphorus	24 mg (3 %)	Vitamin E	0.54 mg (4 %)
		Vitamin K	7.9 µg (8 %)

Source: Butnariu and Butu (2015)

2.7 Tomato cultivation

Tomato is an annual plant that can grow to be over two meters tall. For maximum production and top quality, tomatoes require a rather chilly, dry climate. It is, however, adaptable to a wide range of climates, from moderate to hot and humid tropics. Most types prefer temperatures between 21℃ and 24 °C. Tomatoes grow well in most mineral soils that have enough water retention and aeration and are free of salt. It favors sandy loam soils that are deep and well-drained. The top layer must be porous. A good crop requires a soil depth of 15 to 20 cm. Deep ploughing improves root penetration in thick clay soils. Tomatoes are relatively tolerant of a wide range of pH (acidity levels), but grow best on soils with a pH of 5.5- 6.8 with enough fertilizer supply and availability. Organic matter addition is generally beneficial to growth. Because of their high-water retention capacity and nutritional inadequacies, soils with a high organic matter concentration, such as peat soils, are less appropriate. Tomatoes are typically transplanted since seedlings produced in a nursery produce far superior returns (Dam *et al.*, 2005).

2.8 Tomato harvesting and post-harvest handling

Tomatoes can be collected in three stages: matured green, slightly ripe, and ripe. Tomatoes, as climacteric fruits, can be harvested in their developed green stage, enabling ripening and senescence to proceed throughout the fruit's postharvest period. Producers aiming for faraway markets must harvest their tomatoes when they are matured and green (Moneruzzaman *et al.*, 2009) . Harvesting tomatoes in a ripened green stage not only allows producers more time to prepare the fruit for market, but it also reduces mechanical damage while harvesting (Arah *et al.*, 2015). Fully ripened tomatoes are more vulnerable to mechanical damage during harvesting, resulting in a shorter shelf life (Watkins, 2006).

To avoid these injuries, which may accelerate deterioration, care must be exercised when picking ripe tomatoes. To avoid bruising and puncturing of the fruits, harvesting and packing containers with sharp edges should be avoided. Fruit harvesting should be done early or late in the day to avoid excessive field heat generation. The inability of producers to follow these simple but critical harvesting procedures, combined with some inefficiencies (such as a lack of ready market and processing facilities) in the entire value chain, may explain why there are significant losses in tomatoes harvested at full ripeness in most developing countries. In most underdeveloped nations, access to a quick market is a significant difficulty when dealing with highly perishable crops such as tomatoes. This difficulty can be due to a variety of variables, the most significant of which is the production pattern that results in substantial gluts (Arah *et al.*, 2016).

Postharvest loss is a major hurdle to tomato production in most underdeveloped nations (Arah *et al.*, 2015). Tomatoes are a perishable crop with a short shelf life of roughly 48 hours under tropical circumstances due to their high moisture content (Muhammad *et al.*, 2011).To extend the shelf life of the crop after harvest, specialized postharvest handling practices and treatment technologies are required. Failure to follow these specialized handling techniques and treatment approaches will result in significant financial loss. In tropical countries, tomato losses of up to 50 % might be observed between the harvesting and consuming stages of the distribution chain (Nirupama *et al.*, 2010).

2.8.1 Precooling

Excessive field heat causes an unfavorable increase in metabolic activity, therefore fast cooling after harvest is critical (Akbudak *et al.*, 2012). Precooling reduces ripening rate, water loss, and degradation, conserving quality and prolonging shelf life of harvested tomatoes (Shahi *et al.*, 2012). It also reduces microbiological activity, metabolic activity, respiration rate, and ethylene generation (Ferreira *et al.*, 1994). Temperatures in the 13-20°C range are ideal for tomato handling and can be obtained early in the morning or late in the evening (Kader, 1984). Tomato growers in developing nations, particularly in Africa, arrange their gathered produce under tree shade to minimize field heat (Olayemi *et al.*, 2010). However, tree shade is not a dependable and effective method of lowering field heat in harvested crops. Arah *et al.* (2015) consequently proposed that the use of a basic on-farm structure, such as a tiny thatch hut, can be highly effective in precooling harvested tomatoes.

2.8.2 Cleaning or Disinfecting

Most tomato handlers in impoverished nations do not clean or disinfect their tomatoes after harvest. This behavior may be linked to a lack of portable water at the production sites or to a lack of knowledge about the practice. However, in areas where water is not a scarce resource, using disinfectants in water for washing or cooling can help prevent postharvest and food-borne illnesses in fruits and vegetables. The use of several disinfectants during tomato postharvest treatment is extensively documented. For example, before applying any postharvest treatment, tomato fruits were sterilized with sodium hypochlorite solution to minimize the incidence of fungal infection (Genanew, 2013). The microbial load on tomato fruits was lowered by dipping them in thiabendazole solution (Batu and Thompson, 1998).

2.8.3 Sorting and Grading

Sorting and grading are two of the most critical operations in the packing and marketing of fruits and vegetables (Arjenaki *et al.*, 2013). Sorting is the process of separating rotten, damaged, or infected fruits from healthy and clean ones. Damaged or sick fruits can create significant amounts of ethylene, which can impact the nearby fruits (Saltveit, 1999). Both methods are critical in preserving the postharvest shelf life and quality of harvested tomatoes. During tomato postharvest processing, sorting reduces the spread of infectious bacteria from poor fruits to other healthy fruits. Grading also assists handlers in categorizing fruits and vegetables in a given common parameter, allowing for easier handling (Arah *et al.*, 2016).

2.8.4 Packaging

Packaging as a postharvest handling procedure in tomato production is critical for dividing the produce into manageable portions. However, utilizing inappropriate packing can result in fruit damage and loss. Most poor countries employ wooden crates, cardboard boxes, woven palm baskets, plastic crates, nylon sacks, jute sacks, and polythene bags as packing materials (Idah *et al.*, 2007). The majority of the packing materials indicated above do not provide all of the protection required by the commodity. While the bulk of these packing materials, such as nylon sacks, do not allow for good aeration within the packaged item, resulting in heat buildup due to respiration, some, such as the woven basket, have rough surfaces and edges that cause mechanical injuries to the produce (Hurst, 2010).

2.8.5 Storage

Storage lengthens the processing season and aids in the continuity of product supply throughout the seasons. Tomato fruits can be stored at ambient temperatures for up to a week if there is enough ventilation to reduce heat accumulation from respiration (Žnidarčič and Požrl, 2006). Ripe tomatoes can be stored for extended periods of time at temperatures ranging from 10-15°C and relative humidity levels ranging from 85-95 % (de Castro *et al.*, 2005). Both ripening and chilling damage are reduced to a bare minimum at these temperatures. These conditions are particularly difficult to obtain in most tropical nations, resulting in significant losses of harvested tomatoes (Kader, 2004). This is consistent with the claim that when tomatoes are exposed to high temperatures and relative humidity, their quality suffers (Parker and Maalekuu, 2013). Low temperature storage is also harmful to the shelf life and quality of many tropical foods, such as tomatoes. For example, refrigerating a tomato reduces its flavor, which is largely governed by the total soluble solids (TSS) and pH of the fruit (Moretti *et al.*, 1998).

2.8.6 Transportation

Many tomato farmers' production areas in most poor countries are remote from marketing centers and also inaccessible by road. Transporting harvested tomatoes to the market on such a poor road network and in the absence of suitable transportation such as refrigerated vans becomes a significant difficulty for both producers and wholesalers (Adepoju, 2014). As a result, this problem generates unnecessary delays in delivering the produce to market. Meanwhile, any delay between tomato harvest and eating can result in losses (Kader, 1984). Producers suffer losses of up to 20 % as a result of shipping delays (Babatola *et al.*, 2008). However, the use of adequate transportation for tomatoes is an important issue to consider in the fruit's postharvest treatment. To avoid excessive movement or vibration during transit, the produce should be immobilized by adequate packaging and stacking. Vibration and impact during transportation as a result of road undulations are key sources of postharvest losses in most fruits and vegetables, particularly tomatoes (Idah *et al.*, 2007).

2.9 Bacteria and Yeast in tomato

Tomatoes and other fresh vegetables have a short shelf life due to the presence of spoilage microorganisms and high-water activity. The fermentation method was used to extend the shelf life of vegetables and ensure food safety (Piasecka-Jóźwiak *et al.*, 2013). The isolation and identification of bacteria linked with tomato rotting have received some research attention (Akinyele and Akinkunmi, 2012). Microbial infection of tomatoes can occur in most developing nations during harvesting, post harvesting, handling, storage, transit, storage and customer processing (Yeaboah, 2011). According to (Baiyewu *et al.*, 2007), another method of bacterial contamination is exposing them on benches and baskets in open markets for customers.

In several countries, studies on microorganisms related with tomatoes and tomato products have been conducted. Ajayi (2013) conducted a study in the United States and discovered that *Clostridium sp*., *Staphylococcus sp*., and *Bacillus sp*. were the most common bacteria recovered from canned and raw tomatoes. In India , in a study carried out in tomato puree *Klebsiella sp*., *Proteus mirabilis*, *Vibrio sp*., and *Pseudomonas sp*. were found (Garg *et al.*, 2013). *Bacillus subtils*, *Klebsiella aerogenes*, *Pseudomonas aeruginosa*, *Salmonella typhi*, *Proteus mirabilis*, and *Staphylococcus aureus* were recovered from spoiled tomatoes in Benin City by Wogu and Ofuase (Wogu and Ofuase, 2014). In Lagos State, Nigeria, a comparable study found significant levels of *Staphylococcus sp*. (22.5 %), *Bacillus sp*. (20 %), and *Escherichia coli* (15 %) (Ogundipe *et al.*, 2012).

Tomatoes and tomato-based products are regarded as nutritious (Mangels *et al.*, 1993). However, postharvest fungal infections cause significant losses. Though synthetic chemical fungicides can effectively control some diseases, issues such as fungicide toxicity, pathogen resistance, and potentially harmful effects on the environment and human health have prompted research into alternative disease control measures (Yao and Tian, 2005). The use of hostile microorganisms produced promising outcomes (Wisniewski and Wilson, 1992).

2.10 Tomato products

Tomatoes, as an agricultural produce, are a valuable commodity that is an important element of the human diet. They are one of the most versatile and commonly used fruits, being consumed raw and used to prepare a variety of items. Regular eating of tomatoes and tomato products has been linked to a lower risk of developing several cancers and cardiovascular problems. The antioxidants found in tomatoes are responsible for this beneficial effect (Borguini and Ferraz da Silva Torres, 2009).

2.10.1 Tomato paste and puree

Tomato paste is a product made by concentrating tomato pulp after removing the peels and seeds, and it includes 24 % or more natural tomato soluble solids (NTSS). Tomato paste, which is offered in small packs to consumers as a condiment, is also known as tomato puree. Tomato puree refers to tomato paste with a lower proportion of NTSS (8 % to less than 24 % NTSS). Unfortunately, tomato puree is also known as 'tomato pulp' in the United States. Color, consistency, and flavor are the primary quality characteristics for tomato paste, and there are other compositional guidelines such as total solid, salt content, ash content, copper content, Vitamin C and many more (Hayes *et al.*, 1998).

2.10.2 Tomato sauce/ ketchup

There is little to differentiate between sauce and ketchup. Sauces, on the other hand, are often thinner and contain more total solids than ketchups. Sauces are made from ingredients such as tomato, apple, papaya, walnut, soybean, and mushrooms. Sauces/ketchups are made with the same ingredients and method as chutney, except that the fruit or vegetable pulp or juice used is sieved before cooking to remove the skin, seeds, and stalks of fruits, vegetables, and spices and to give the final product a smooth consistency. Cooking time is increased due to the use of fine pulp or juice (Srivastava *et al.*, 2002).

2.10.3 Tomato pickle

Pickles are processed foods made from fruits, vegetables, fish, or meat that have been preserved with natural salt, vinegar, or oil. Pickles are an edible product that has been preserved and seasoned in a brine and edible acid solution, such as vinegar. In pickling, salt, vinegar, and spices are frequently used in combination (Bhuiyan, 2012). Homemade tomato pickles fermented with vinegar are increasingly popular due to their acidic flavor and improved piquancy (Barigela and Bhukya, 2021).

2.10.4 Tomato chutney

Chutney is produced from a combination of fruits, herbs, and spices. They are frequently made with fresh ingredients, therefore they must be consumed immediately or preserved in the refrigerator (Bhuiyan, 2012). Tomato chutney can be made with both green and ripe tomatoes, as well as onion, sugar, vinegar, and a variety of other ingredients, including spices (Siebert, 2017).

2.10.5 Tomato soup

Soup is a liquid made from vegetables, fish, or meat, together with water, juice, or stock and some thickening additives, and is classified as a heterogeneous food (Radha *et al.*, 2015). Heat improves lycopene bioavailability, which is better absorbed by the body when the tomato is cooked, making it perfect for consumption of tomato sauces and soups (Correia *et al.*, 2015).

2.10.6 Canned tomatoes

Food is preserved through canning when its components are prepared and sealed in an airtight container. As a result, canned goods that have been freeze-dried can remain edible for up to 30 years under certain circumstances (Potter and Hotchkiss, 2012). Processing tomatoes, which have a tougher outer peel and pectin layer, are used in commercial canneries. Tomatoes that have been industrially canned are a significant product that undergoes frequent market study and trade considerations. However, safety precautions must be followed because botulism poisoning can be brought on by inadequately canned tomatoes, whether they are made commercially or at home (Redlinger and Nelson, 1990).

2.10.7 Tomato juice

Tomato juice is created from whole crushed tomatoes that have been finely screened to remove the skin and seeds. The juice is made up of colloidal serum suspended particles larger than 150 m in diameter (Tanglertpaibul and Rao, 1987). Tomato juice viscosity is highly dependent on high molecular weight, water-soluble pectin and their degree of esterification (Fishman *et al.*, 1989). Tomato juice is a substantial source of antioxidants - carotenoids and vitamin E, as well as various minerals and trace elements, in terms of providing a man with micronutrients and minor biologically active chemicals (Ivanova *et al.*, 2018).

2.10.8 Tomato powder

Fruit and vegetable powders made by drying to a certain moisture level are an excellent addition to soups, sauces, marinades, infant meals, dips, extruded cereal products, fruit purees, and frozen toaster snack fillings (Francis and Phelps, 2003). Dehydrated tomato powder is a growing and potentially profitable industry for processing enterprises (Abinaya and Sridevi Sivakami, 2021).

Tomato powder is just pulverized dried tomatoes that have been stored and used for a long time. Tomato powder is in high demand since a large amount of it is utilized in convenience foods. Tomato powder is high in vitamins A and C, which not only preserve the immune system but also the health of the eyes and skin. It also contains a lot of nutrients like folate, potassium, magnesium, and iron, which help with a variety of metabolic processes in the body. It can be used as a spice, flavor, and garnish, as well as a base for liquid tomato preparations such as tomato paste and tomato sauce (Srivastava and Kulshrestha, 2013). The preparation of dehydrated tomato powder is also for the ease of transit, handling, and storage without extra care. If powdered tomato can be manufactured, it will help to reduce wastage, price, and enhance availability throughout the year (Jayathunge *et al.*, 2012). Dehydrated tomato powder can also be used as a raw tomato substitute in the development of fresh food recipes (Sarker *et al.*, 2014).

2.11 Preservation of tomato

Tomatoes are a perishable product. As a result, advantageous preservation methods are developed for farmers who produce a significant quantity of tomatoes. A large range of tomato products are manufactured utilizing concentrated juice or pulp, which necessitates expensive technology for high-quality results. As a result, the development of low-cost processing and packaging approaches to manufacture shelf-stable and convenience items is one of the most pressing needs in today's competitive market. As a result, drying is the best way for meeting the following conditions (Jayathunge *et al.*, 2012).

2.12 Drying

Drying is one of the oldest and most important physical ways of food preservation. It is used to reduce the moisture content of foods and is most commonly used on fruits, vegetables, spices, and other products with a high moisture content (>80 %) and are considered very perishable (Changrue *et al.*, 2006). Drying involves application of heat to a substance that causes moisture within the material to transfer to its surface and then water removal from the material to the atmosphere (Ekechukwu and Norton, 1999).

Drying is the most common technique of food preservation, increasing shelf-life and product quality. Aside from preservation, shrinking the volume and weight of dried materials lowers handling, packaging, and shipping expenses. Furthermore, drying is predicted to absorb 10 % to 15 % of the entire energy requirements of the developed world's food sectors (Keey, 2013). In a nutshell, drying is arguably the most long-standing, diverse, and conventional operation. Food drying is a vital technology for the food industry, providing opportunities for ingredient discovery and unique products for customers. There have been significant technological breakthroughs in recent years related to industrial drying of food, including pre-treatments, processes, equipment, and quality (Moses *et al.*, 2014).

2.13 Methods of drying

2.13.1 Sun drying

Sun drying is practiced in many parts of the world, particularly in tropical and subtropical countries. Solar energy is a significant alternative energy source that is favored above other energy sources because it is abundant, unlimited, and non-polluting. It is also renewable, inexpensive, and environmentally friendly (Basunia and Abe, 2001). The procedure is simple because it does not require any expensive equipment. The thing to be dried is laid out in the sun, and the moisture evaporates over time. Despite its simplicity, the procedure has drawbacks such as dust pollution, insect infestation, microbiological contamination, and deterioration due to rainfall. Product dried in this manner is unsanitary and, in certain cases, unsafe for human consumption (Garg and Prakash, 1997). Shrinkage, case hardening, loss of volatiles and nutritional components, and decreased water reabsorption following rehydration may occur as a result of sun drying. As a result, the quality of the sun-dried products degrades (Kulanthaisami *et al.*, 2010).

2.13.2 Solar drying

Solar driers can be utilized successfully in developing nations as an appealing drying technique that can assist minimize crop losses and improve dried product quality. Solar drying is used to improve product color, taste, and appearance. Solar drying reduces the possibility of microorganism growth while also preventing insect infection and contamination from foreign debris and toxins. The developed solar drier was capable of producing an average drying temperature ranging from 48°C to 54°C. The solar tunnel drier was compared to open air drying (Rajarajeswari *et al.*, 2016). As air travels through the collector, it is heated and then partially cooled as it picks up moisture from the produce. The product is heated by both hot air and the sun. An indirect type solar dryer is used as an alternative to traditional drying methods and to alleviate the problem of open sun drying (Lingayat *et al.*, 2017).

2.13.3 Cabinet drying

Cabinet driers are made out of an insulated cabinet with shallow mesh or perforated trays that each hold a small layer of food. The cabinet tray is filled with hot air. A duct and baffle system are utilized to direct air over and/or through each tray, promoting 12 consistent air distribution either horizontally between the food trays or vertically between the trays and food. Direct gas burners, steam coil exchangers, and electrical resistance heaters are all types of air heaters. Because the air is forced past the heater's, heated air is used for dying. It is generally inexpensive to create and maintain, has a flexible architecture, and provides inconsistent product quality due to weak control. It is used alone or in groups, primarily for small-scale (1-20 ton/day) production of dried fruits and vegetables (Fellows, 2022).

Cabinet dryers are the most used piece of farm equipment for drying fruit. These dryers have a basic structure, cheap installation costs, and may be used in nearly any location. Because non-uniformity in the moisture level of the end product is an inherent disadvantage of using the cabinet drier, companies are usually unwilling to use this drying (Amanlou and Zomorodian, 2010). When compared to sun drying, the drying rate in a cabinet drier with the same feed rate was faster since the temperature was higher and the conditions were monitored (Kaur *et al.*, 2006).

2.14 Drying of tomatoes

Drying procedures provide an alternate method of consuming tomatoes, and dehydration of tomatoes has been used for many years as a method of preservation. Dried tomato powder or slice aids in the development of innovative food components for ready-to-eat items. Natural sun / solar dried organic or bio grown tomato has recently gained popularity in international markets. Fresh tomatoes are dried in halves, quarters, slices, and powder form for use in a variety of goods (Kulanthaisami *et al.*, 2010). Traditionally, greater emphasis has been placed on thermal processing for tomato preservation and microbiological safety, with less emphasis placed on nutritional quality, but there has been a growing concern for tomato quality during thermal processing (Goula *et al.*, 2006). Alternative drying technologies such as freeze drying (FD), microwave drying, infrared drying, heat pump drying (HPD), and osmotic dehydration are used to limit these effects (Gaware *et al.*, 2010).

2.15 Nutritive Value of Tomato Powder

Table 2.2 Analyzed nutritive value of Tomato Powder

Nutrients	Spray dryer method	Foam dryer method	Cabinet dryer method	Solar dryer method
Energy (kcals)	268	321	328	338
Carbohydrates (g)	57	66	68	70
Sugar content (g)	35	42	40	41
Protein (g)	10	14	14	15
Fibre (g)	0.5	1.42	1.7	1.50
Lycopene (mg)	0.82	1.20	1.45	1.48
Betacarotene (µg)	180	285	300	305
Iron (mg)	216	430	501	498
Phosphorus (mg)	189	310	318	320
Magnesium (mg)	86	145	165	170
Folate (µg)	75	115	128	129
Vitamin C (mg)	65	112	117	120
Vitamin K (µg)	21	35	42	43
Potassium (mg)	102	1572	1850	1860
Calcium (mg)	72	166	167	171
Moisture (%)	3.4	11.5	10	12
pH	4.6	4.5	5	4.8

Source: Butnariu and Butu (2015)

2.16 Storage stability of tomato powder

Consumers are always demanding fresh and high-quality food products that retain their relevant sensory and nutritional attributes in the time between purchase and consumption.

Manufacturers use several approaches to anticipate and determine the end point of storage life under certain storage conditions. Criteria based on the amount of spoilage and harmful bacteria detected and their growth pattern can be defined very precisely. Non-microbiological criteria are more difficult to specify, however those based on well-defined chemical composition, such as pH, peroxide value, acid value, and vitamin content, can be addressed (Kilcast and Subramaniam, 2000).

It has been found that the moisture content, bulk density, and solubility of tomato powder, three of the most typically mentioned powder product specifications, were all dependent on the spray drying conditions, i.e., air inlet temperature, drying air flow rate, and compressed air flow rate (Goula and Adamopoulos, 2005).

Due to lycopene isomerization and oxidation, color fading and acceptability loss are prevalent in dried tomato products. Lycopene levels in dried tomato powder were altered by drying techniques, pre-drying treatments, and storage conditions, including packaging material. Dehydrated and powdered tomatoes have limited lycopene stability in general unless properly processed, quickly packed, and stored in appropriate storage conditions. Several investigations have shown that considerable oxidative damage can occur during dried tomato preservation. Dried tomatoes can experience significant lycopene degradation, according to shelf-life studies; degradation reactions are accelerated by high temperature, oxygen, and light exposure, as well as low moisture content and water activity. In tomato products, the oxidation of carotenoid pigments and the creation of dark compounds, in addition to the browning impact of the Maillard reaction, cause the product to darken to a reddish-brown color. These modifications are affected by storage temperature, oxygen availability, packing type, pH, and product activity (Yegrem and Ababele, 2022).

2.17 Packaging materials

Food packaging's primary functions are to protect food products from outside influences and damage, to keep food contained, and to provide consumers with ingredient and nutritional information (Coles *et al.*, 2003). Traceability, convenience, and tamper detection are all secondary tasks that are becoming increasingly important. Food packaging's purpose is to enclose food in a cost-effective fashion that meets industry needs and consumer expectations, maintains food safety, and has a low environmental impact.

The proper selection of packaging materials and technologies ensures that product quality and freshness are maintained during distribution and storage. Glass, metals (aluminum, foils and laminates, tinplate, and tin-free steel), paper and paperboards, and polymers have traditionally been used in food packaging. Furthermore, a broader range of stiff and flexible plastics have been introduced (Marsh and Bugusu, 2007).

Plastic packaging is prevalent in the food sector, serving a variety of roles, including a substantial part in food waste reduction (Barlow and Morgan, 2013). In the field of food packaging the most regularly utilized polyolefins are LDPE and HDPE. HDPE is stiff, durable, and strong, chemically resistant, permeable to gas and moisture, easy to process, and easy to form. HDPE is a more durable plastic with a higher melting point than LDPE. LDPE is flexible, easy to seal, resilient, strong, and moisture resistant. LDPE is a reasonably translucent plastic that is utilized in applications that need heat sealing (Sarkar and Aparna, 2020).

Glass has a long history in food packaging. Glass is rigid, provides high insulation, and can be manufactured in a variety of shapes. Glass's transparency allows customers to see the product. Despite efforts to employ thinner glass, the weight of the material adds to transportation expenses. Brittleness and susceptibility to fracture from internal pressure, impact, or heat stress are also issues (Marsh and Bugusu, 2007).

PP, PS and PVC were found to be unsuitable for storage of dehydrated tomato powder as the moisture content and water activity increased and rehydration ratio decreased during storage (Jayathunge *et al.*, 2012). Sagar and Maini (1997) have witnessed structural damage in items while stored in OPP/CPP, resulting in a drop in rehydration ratio and, as a result, impacting consumer preference after some time.

2.18 Changes during storage

All food products are fundamentally unstable, and how well they retain their quality depends on a variety of things, including how long they are stored and at what temperature. This is acknowledged in all work on new products, in updating or upgrading current products, and in changing processes (Desrosier and Desrosier, 1977).

Unless thoroughly prepared, quickly packed, and stored in the right conditions, dried and powdered tomatoes generally have low lycopene stability. Isomerization and oxidation are the primary factors in tomato lycopene degradation during processing and storage (Shi and Maguer, 2000).Tomatoes lose their characteristic red color during dehydration and subsequent storage, gradually turning brick-red and then brown. This event, often referred to as the NEB or Maillard reaction, results in the production of dark pigments and eliminates the natural color of items (Nguyen and Schwartz, 1998). Moisture content, total fungal load, total aerobic bacteria load, and sample lightness increased as storage time increased, while TA, pH, ascorbic acid, lycopene, redness, and yellowness declined. The rise in moisture content could be attributed to storage circumstances such as temperature and relative humidity, as well as the physiological activities of tomato powder (Obadina *et al.*, 2018).

Part III

Materials and methods

3.1 Materials

3.1.1 Tomato

Light red tomatoes var. Abhinash was bought from the local market of Dharan for the ease of cutting.

3.1.2 HDPE Packaging

HDPE plastic bag (8”×12”) was purchased from the local market of Dharan.

3.1.3 LDPE Packaging

LDPE plastic bag (4”×5”) was purchased from the local market of Dharan.

3.1.4 Glass jar

Glass jar of 125 ml was purchased from the local market of Dharan.

3.1.5 Equipment and chemicals used

The equipment and chemicals used were available in the lab of Central Campus of Technology which are given in Appendix B.1 and B.2.

3.2 Methods

3.2.1 Experimental procedure

3.2.1.1 Washing

Tomatoes were washed with clean tap water to remove adhered dust and dirt particles.

3.2.1.2 Cutting

The cleaned tomatoes were then sliced into the uniform slice of 5 mm for ease of drying.

Raw/Fresh Tomato

↓

Sorting

↓

Cleaning/ Washing

↓

Slicing (5mm)

↓

Drying of tomato slices in cabinet dryer at 60±5℃

↓

Cooling at room temperature

↓

Grinding (Sieving through 40 mesh size)

↓

Packaging in various packaging

(HDPE, LDPE and glass)

↓

Stored tomato powder at ambient temperature

Source: Sarker *et al.* (2014)

Fig 3.1 Flowchart for production and storage of tomato powder.

3.2.1.3 Drying

After cutting, 14,110 g of tomato slices were subjected to sun drying and 14,507 g of tomato slices were subjected to cabinet drying at 60℃ until the equilibrium moisture content was obtained.

3.2.1.4 Cooling and grinding

The dried slices were then cooled at room temperature and grinded in a grinder to make tomato powder. It was then sieved through 40 mesh size to a fine consistency.

3.2.1.5 Storage

The powdered samples were stored in glass jar, HDPE and LDPE with 15 g in each packaging material.

3.2.2 Analytical procedure

3.2.2.1 Chemical analysis of raw tomato and tomato powder

3.2.2.1.1 Moisture content

Moisture content of the sample determined by oven drying method at 100± 5°C as per (Ranganna, 1986) until constant weight was obtained.

3.2.2.1.2 Crude protein

Crude protein content of the sample was determined indirectly by measuring total nitrogen content by micro Kjeldahl method. Factor 6.25 will be used to convert the nitrogen content to crude protein as per (Ranganna, 1986).

3.2.2.1.3 Crude fat

Crude fat content of the sample was determined by solvent extraction method using Soxhlet apparatus as per (Ranganna, 1986).

3.2.2.1.4 Crude fiber

Crude fiber content of the sample was determined by the method as per (Ranganna, 1986).

3.2.2.1.5 Carbohydrate

The carbohydrate content of the sample was determined by difference method as per (Ranganna, 1986).

3.2.2.1.6 Total ash

Ash content was determined by method described by (Ranganna, 1986) by using muffle furnace.

3.2.2.1.7 Titratable acidity

Titratable acidity was determined by titrating with 0.1 N NaOH using phenolphthalein as indicator as per (Ranganna, 1986).

3.2.2.1.8 Lycopene content

0.5 g of sample was accurately weighed into a 125 ml Erlenmeyer flask and 50 ml of mixed solvent was added into it. Mixed solvent consists of hexane: ethanol: acetone in the ratio 2:1:1. The flask was sealed and after about 10 minutes of extraction, 7.5 ml of water was added to separate the phases. The upper phase was separated and its absorbance was determined at 503 nm on spectrophotometer.

The lycopene concentration is given by:

Lycopene (mg/kg fresh wt.) = $\frac{A \times 171.7}{W}$

where A_{503} is the absorbance and W is the exact weight of tomato added, in grams.

3.2.2.2 Storage study

Sun dried and cabinet dried tomato powder samples were filled in HDPE pouches, LDPE pouches and glass jars and were subjected to room temperature. The samples were drawn at the interval of 7 days and evaluated for properties like moisture content, lycopene content and microbiological qualities (TPC).

3.2.2.3 Microbiological examination

Total Plate Count (TPC) was determined by pour plate technique on Plate Count Agar (PCA) medium (incubated at 30°C for 48 h) (AOAC, 2005).

3.2.3 Sensory Evaluation

Sensory evaluation was carried out using 9-point hedonic scale described by (Ranganna, 1986). Sensory panelists were semi trained panelists which consists of teachers and students from Central Campus of Technology, Dharan. Sensory evaluation was carried out on the quality attributes viz., color, taste, flavor, mouthfeel and overall acceptability. The specimen of the evaluation of card is shown in Appendix A.

3.2.4 Statistical analysis

The experiment was conducted in triplicate. All calculations were performed in Microsoft Office Excel (2016). The data were subjected to statistical analysis and were analyzed by one-way and two-way analysis of variance (ANOVA), no blocking at 5 % level of significance using statistical software GenStat Release 12.1 (Copyright 2009 developed by VSN International Limited). The calculated mean value were compared using Fischer‘s unprotected LSD (Least Significant Difference) with LSD at 5 % level of significance to determine whether the samples were significantly different from each other and also to determine which one is superior between them.

Part IV

Results and discussions

The fresh tomatoes were cleaned and sliced into slices of uniform thickness (5mm). The slices were then subjected to two methods of drying; half of them were dried in cabinet dryer for 60±5°C and rest of them were sun dried until the constant weight was obtained. Then the dried tomato slices were powdered in a grinder, sieved through 40 mesh size to a fine consistency and packed in HDPE pouch, LDPE pouch and glass jars. The chemical analysis before and after storage were performed and sensory evaluation was carried out. The following results were obtained from the analysis.

4.1 Analysis of tomato

4.1.1 Yield of powder from tomato

The yield of tomato after drying process was found to be 4.75 % for sun dried tomato powder and 4.65 % for cabinet dried tomato powder.

4.1.2 Chemical composition of raw tomato

The chemical composition of the raw tomato collected from the local market of Dharan is presented in the Table 4.1.

The moisture, protein, fat, ash, crude fiber, carbohydrate, lycopene content, acidity and pH were found from the analysis as shown in above table. The moisture content of raw tomato (95.77 %) was comparable to the result obtained by Abdullahi *et al.* (2016) i.e. (93.8 %). The protein content of tomato is found to be 18.40 % which is lower as compared to data given by Schneider *et al.* (2003). The variations could be due to varietal influence, environmental conditions, or other agronomical procedures used during production (Agbemafle *et al.*, 2015).

The fat content of tomatoes were found to be 4.71 % which is similar to the data obtained by Del Valle *et al.* (2006) i.e. (5.85 %). The ash content of tomato was found to be 8.07 % which lies within the range given by Zaka (2011). The crude fiber content of tomato was found to be 10.41 % which is similar to that obtained by Ali *et al.* (2020). Brummell (2006) reported that the quantity of cellulose fluctuates during fruit ripening.

The carbohydrate content was found to be 58.41 %. Similar data was obtained by Abdullahi *et al.* (2016). According to Idah and Abdullahi (2010), the percentages of moisture and carbohydrate increase and decrease respectively as the storage period increases.

Table 4.1 Chemical composition of raw tomato

Parameters	Values
Moisture (% wet basis)	95.77±0.09
Protein (% dry basis)	18.40±1.51
Fat (% dry basis)	4.71±0.35
Ash (% dry basis)	8.07±2.33
Crude fiber (% dry basis)	10.41±0.77
Carbohydrate (% by difference method)	58.41±1.09
Lycopene (mg/100g dry basis)	15.50±0.14
Acidity (% as citric acid)	0.73±0.05
pH	4.23±0.02

* Values in the table are arithmetic mean of triplicate samples ± S.D.

The lycopene content of tomato was found to be 15.50 mg/100g which lies within the range as given by Davies *et al.* (1981) i.e. 6 to 16 mg/100g. Agricultural procedures (greenhouse, open field, varietals, water supply, fertilization), soil, climate conditions (temperature, moisture, solar radiation), fruit growth, harvesting date, degree of ripeness, and post-harvest handling all have an impact on lycopene concentration (Brandt *et al.*, 2003). The acidity of tomato was found to be 0.73 % as citric acid. Similar data was found by Aboagye-Nuamah *et al.* (2018). The pH of tomato was found to be 4.23 which is similar to data given by Moneruzzaman *et al.* (2008) i.e. 4.17.

4.1.3 Effect of drying methods on chemical composition of tomato powder

The chemical composition, including moisture, protein, fat, ash, fiber, carbohydrate, lycopene content, acidity and pH of tomato powder was assessed. All the parameters were measured in dry basis except moisture.

Table 4.2 Chemical composition of raw and dried tomato

Parameters	Fresh	Sun dried	Cabinet dried
Moisture content (% wet basis)	95.77±0.09^{a}	13.63±0.34^{b}	10.75±0.63^{c}
Protein (% dry basis)	18.40±1.51^{a}	11.70±0.14^{b}	13.17±0.33^{b}
Fat (% dry basis)	4.71±0.35^{a}	1.86±0.06^{b}	2.47±0.23^{c}
Ash (% dry basis)	8.07±2.33^{a}	11.23±0.24^{b}	10.67±0.11^{ab}
Fiber (% dry basis)	10.41±0.77^{a}	5.21±0.07^{b}	6.38±0.05^{c}
Carbohydrate (% dry basis)	58.41±1.09^{a}	85.21±0.16^{b}	78.98±0.06^{c}
Lycopene (mg/ 100g dry basis)	15.50±0.14^{a}	11.71±0.15^{b}	9.48±0.20^{c}
Acidity (% as citric acid)	0.73±0.05^{a}	0.83±0.04^{b}	0.81±0.02^{ab}
pH	4.23±0.02^{a}	4.1±0.4^{b}	4.06±0.05^{ab}

* The data presented are the mean values ± standard deviation obtained from triplicate measurements. Means with the same superscript letters within a column indicate no significant difference between them.

4.1.3.1 Moisture content

The fresh sample exhibited the highest moisture content of 95.78 % and lowest was observed in cabinet dried sample i.e., 10.75 %. Similar study was conducted by Abdullahi *et al.* (2016) where moisture content of fresh tomato was found to be 93.8 %. Also according to Ladi *et al.* (2017) the moisture content of cabinet dried tomato powder was found to be lower than that of sun dried tomato powder that aligns with this study. Results showed that tomatoes dried under a controlled environment i.e., cabinet dried gave a better result compared to the sun dried because of the controlled temperature and humidity. This will enhance the shelf life of oven dried sample with lower moisture content after drying to store longer than sun dried sample. All the samples are significantly different between each other.

4.1.3.2 Protein

The fresh sample has the highest protein content i.e., 18.41 % which was significantly different from other samples. The protein content of sun dried and cabinet dried tomato powder are not significantly different. The lower protein content could be related to the partial removal of protein from starch during drying as salt binds with protein. Changes in protein content may be connected to processes, such as non-enzymatic browning, which was discovered to be more prevalent in fresh tomato than dried powder. Similar findings were reported by Surendar *et al.* (2018).

4.1.3.3 Fat

The fresh sample revealed the highest fat content i.e., 4.71 % and the lowest fat content was shown by sun dried powder i.e., 1.86 %. According to the study conducted by Ladi *et al.* (2017) fat content of cabinet dried tomato powder was higher i.e. 0.82 % than that of sun dried tomato powder i.e. 0.53 % which is similar to this study. The high fat in oven dried tomato powder was attributed to its lower moisture content over sun dried tomato powder (Mozumder *et al.*, 2012). As seen in Table 4.2 all three samples are significantly different from each other.

4.1.3.4 Ash

The ash content was highest in fresh sample i.e., 8.07 % followed by sun dried sample i.e., 11.23 % and cabinet dried sample i.e., 10.67 %. The ash content of fresh sample is significantly different from other samples whereas there is no significant difference between sun dried and oven dried sample as seen in Table 4.2. The variance in ash content might be related to the drying method and degree of homogenization (Surendar *et al.*, 2018). Higher ash concentration indicates contamination by dust and other foreign elements (Owureku-Asare *et al.,* 2018). Since the tomatoes were dried in sun for longer period of time contamination by dust, dirt or debris maybe the reason for higher ash content in sun dried tomato powder although there is no significant difference in ash content between.

4.1.3.5 Fiber

The fiber content was highest in fresh sample i.e., 10.41 % and lowest in sun dried powder i.e., 5.21 %. As seen in Table 4.2 all three samples are significantly different from each other. The result showed that fiber content increases slightly with the decrease in moisture content. The result was similar to the findings of Opadotun *et al.* (2016) which also reported increase in fiber content with reduction in moisture. The faster rate of drying in the cabinet drier compared to solar drying reflected higher fiber content in cabinet dried tomatoes due to less breakdown of fibers (Ahmad *et al.*, 2020). The uncontrolled rate of drying along with exposure to sun for longer time period maybe the reason for higher breakdown of fiber and thus less fiber content in sun dried tomato powder. The research carried out by Siriwattananon and Maneerate (2016) also found that tomato dried in hot air oven showed higher fiber content than freeze dried and natural sun dried respectively.

4.1.3.6 Carbohydrate

The sun-dried sample displayed the highest carbohydrate content i.e., 85.21 % which is followed by cabinet dried sample i.e., 78.98 % and fresh sample i.e., 58.41 % as seen in Table 4.2. There was a significant increase in the carbohydrates content with reduction in moisture content considering the difference in the carbohydrates value for the fresh sample and the dried samples. Sun dried sample retained carbohydrate better than cabinet dried sample though. This results are in accordance with the results obtained by Opadotun *et al.* (2016).

4.1.3.7 Lycopene content

The highest lycopene content interpreted as mg/100 g was found in the fresh sample which had value of 15.50 mg/100g which was significantly higher than other samples. All three samples are significantly different from each other as seen in Table 4.2. Several studies found that lycopene was easily destroyed during heat processing (Choksi and Joshi, 2007). The lycopene content of sun dried tomato powder i.e. 11.71 mg/100 g which is slightly higher than that of cabinet dried tomato powder i.e. 9.48 mg/100 g which is in agreement with the findings of Mohseni and Ghavidel (2011) who found that lycopene content of tomato juice were 8.60-10.0 mg/100 g which was reduced in sun (9.368 mg/100 g) and tray drying (7.645 mg/100 g). Low oxygen content, low temperature, low moisture content during sun-drying of tomato prevent oxidation as well as lycopene degradation (Shi and Maguer, 2000).

4.1.3.8 Titratable acidity

The titratable acidity expressed as % citric acid was highest in sun dried tomato powder i.e., 0.83 % followed by cabinet dried tomato powder i.e., 0.81 % and fresh tomato i.e., 0.73 %. There is no significant difference in between the samples as shown in Table 4.2. During drying process, a rise in acidity is chiefly attributed to the high amount of moisture lost from the samples and decreasing of pH (Yusufe *et al.*, 2017). Although the dried fruits recorded higher TA values than the fresh fruits, they were not significantly different. This result suggests that dried fruits could be used in the same way as fresh fruits as far as the TA content is concerned since drying had no significant effect on the TA content (Aboagye-Nuamah *et al.*, 2018).

4.1.3.9 pH

The pH of fresh tomato sample was higher i.e., 4.23 as compared to dried tomato powder. There is no significant difference between the samples as shown in Table 4.10. pH of sun dried and cabinet dried tomato powder were 4.1 and 4.06 respectively. The pH of tomato decreased as temperature and duration of drying increased; this may be associated with the increase in titratable acidity. pH below 4.2 is an advantageous attribute, since it arrests the development of microorganisms in the finished product during industrial processing (Yusufe *et al.*, 2017).

4.2 Storage study

Prepared tomato powder (sun dried and cabinet dried) was stored for 85 days' time period at ambient temperature in 3 different packaging materials i.e., HDPE, LDPE and glass. Chemical analysis was carried out at 7 days of interval.

4.2.1 Changes in sun dried powder

4.2.1.1 Changes in moisture during storage

Effect of storage on moisture content of sun-dried powder is shown in fig 4.1. The moisture content increased gradually with the increase in storage time in all three packaging materials.

The graph shows that the increase in moisture content was higher in LDPE packaging material followed by HDPE and glass. The moisture content reached up to 16.22 % in LDPE, 15 % in HDPE and 13.74 % in glass from initial moisture content of 13.62 % during 84 days of storage time. The ingress of moisture through the packages, which have varying degrees of permeability to water vapor, may be the cause of the increase in moisture content of the powder during storage (Muzaffar and Kumar, 2016).

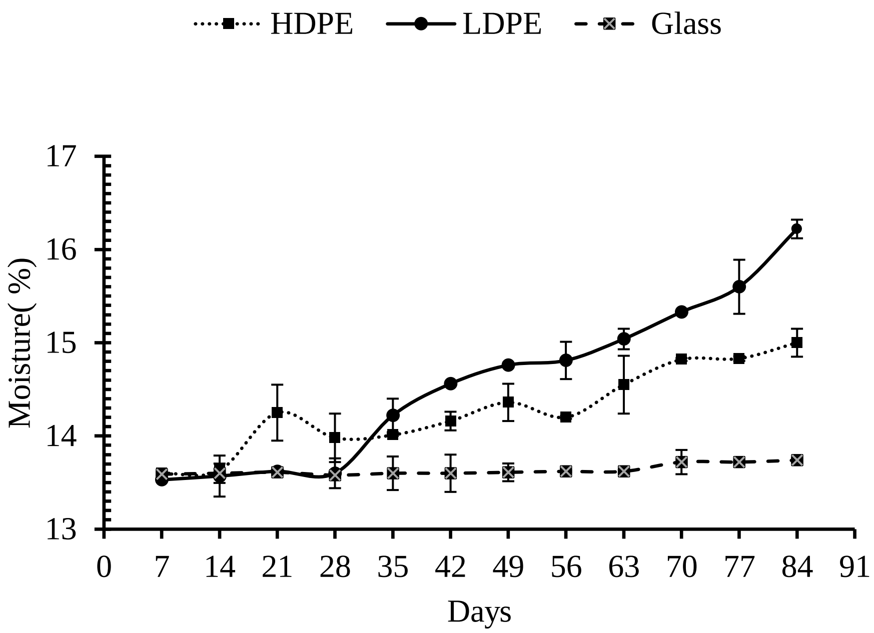

Fig 4.1 Effect of storage conditions on moisture content of sun dried tomato powder in three different packaging materials.

4.2.1.2 Changes in lycopene during storage

Effect of storage on lycopene content of sun-dried powder is shown in fig 4.2. The lycopene content decreased gradually with the increase in storage time in all three packaging materials.

The maximum degradation of lycopene was seen in LDPE packaging i.e., the lycopene content degraded from 11.71 mg/100 g to 0 mg/100g during 84 days of storage time. The minimum change in lycopene content was observed in glass jar i.e., the lycopene content degraded from 11.71 mg/100 g to 2.99 mg/100 g. As tomatoes are exposed to UV radiation for a longer amount of time while sun-drying , this could be one explanation for the increased lycopene degradation (And and Barrett, 2006). The lowest retention of lycopene was observed in low-density polyethylene bag packed sun dried tomato powder when stored for 6 months (Dufera *et al.*, 2023).

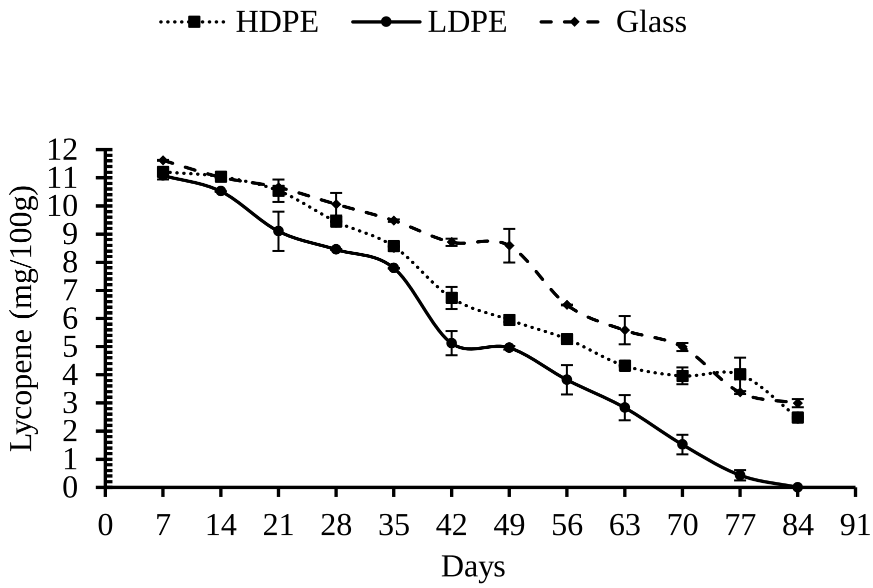

Fig 4.2 Effect of storage condition on lycopene content of sun dried tomato powder in three different packaging materials.

4.2.1.3 Total Plate Count (TPC)

In the sun-dried tomato powder, TPC was found to be increased from initial value of 2.46×10^5 cfu /g to 6.2×10^5 cfu /g in glass, 7.48×10^5 cfu /g in HDPE and 7.76×10^5 cfu /g in LDPE during 84 days of storge period. The maximum plate count was seen in LDPE package followed by HDPE package and glass. The total plate count lied within the limit ($< 10^6$) for dried products according to (FDA, 2013). This is shown in Fig 4.3.

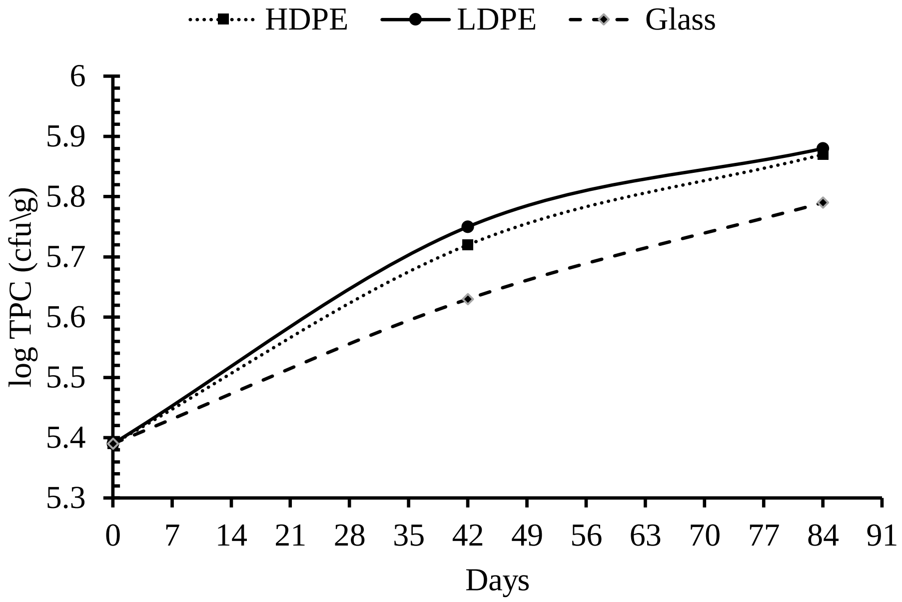

Fig 4.3 Effect of storage condition on TPC of sun dried tomato powder in three different packaging materials.

4.2.2 Changes in cabinet dried powder

4.2.2.1 Changes in moisture during storage

Effect of storage on moisture content of cabinet dried powder is shown in fig 4.4. The moisture content increased gradually with the increase in storage time in all three packaging materials.

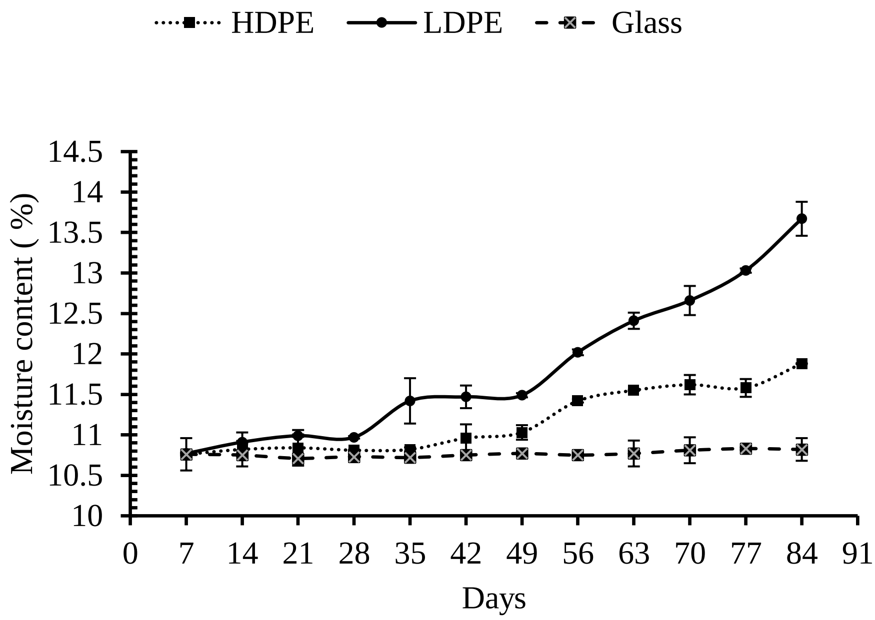

Fig 4.4 Effect of storage conditions on moisture content of cabinet dried tomato powder in three different packaging materials.

As seen in fig 4.4 maximum increase in moisture content was observed in cabinet dried tomato powder stored in LDPE package. The moisture content increased up to 13.67 % from initial moisture content of 10.75 % during 84 days of storage period. Moisture content increased only up to 10.82 % from initial moisture content of 10.75 % in glass jar during 84 days of storage period. Also, in HDPE package moisture content increased up to 11.88 % during same interval of time. Tamarind pulp powder packed in LDPE showed higher decrease in powder flowability due to considerable increase in moisture content and the powder became cohesive after a period of two months (Muzaffar and Kumar, 2016).

4.2.2.2 Changes in lycopene during storage

Effect of storage on lycopene content of cabinet dried powder is shown in fig 4.5. The lycopene content decreased gradually with the increase in storage time in all three packaging materials.

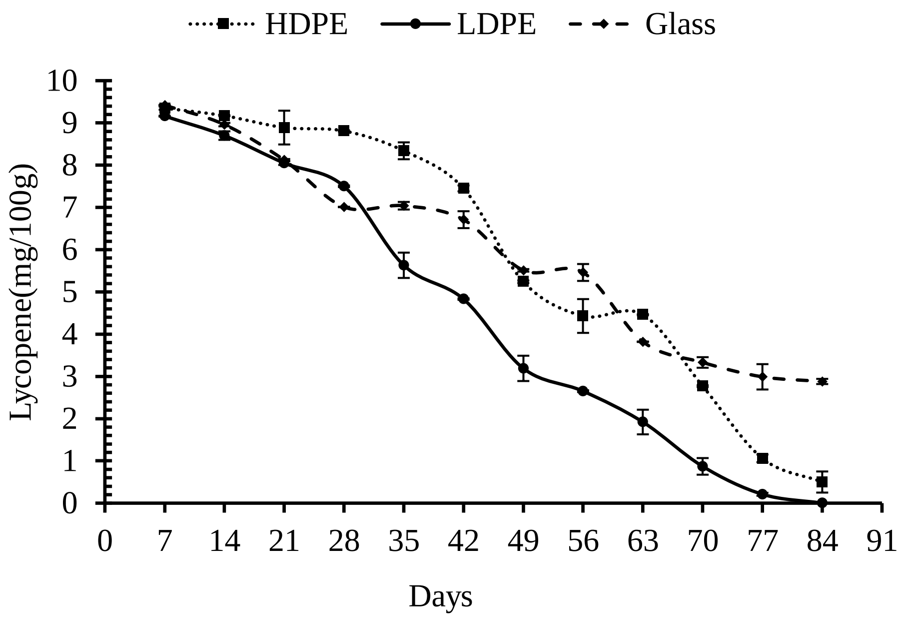

Fig 4.5 Effect of storage conditions on moisture content of cabinet dried tomato powder in three different packaging materials.

As seen in above fig 4.5, the maximum degradation of lycopene was observed in LDPE package followed by HDPE package and glass. Lycopene content decreased from initial value of 9.47 mg/100 g to 2.88 mg/100 g in glass jar, 0.5 mg/100g in HDPE package and 0 mg/100g in LDPE package. Lycopene loss was observed 10-20 % more, in tunnel dried tomato powders stored in low density polyethylene pouches (Ghavidel and Davoodi, 2009). The possibility of entrance of oxygen and water vapor in low-density polyethylene bag samples has resulted in higher increase in water activity of the tomato powder and lower retention of lycopene (Dufera *et al.*, 2023).

4.2.1.4 Total Plate Count (TPC)

In the cabinet dried tomato powder, TPC was found to be increased from initial value of 1.32×10^3 cfu /g to 4.97×10^3 cfu /g in glass, 5.23×10^3 cfu /g in HDPE and 5.72×10^3 cfu /g in LDPE during 84 days of storge period. The maximum plate count was seen in LDPE package followed by HDPE package and glass. The total plate count lied within the limit ($< 10^6$) for dried products according to FDA (2013). This is shown in Fig 4.6.

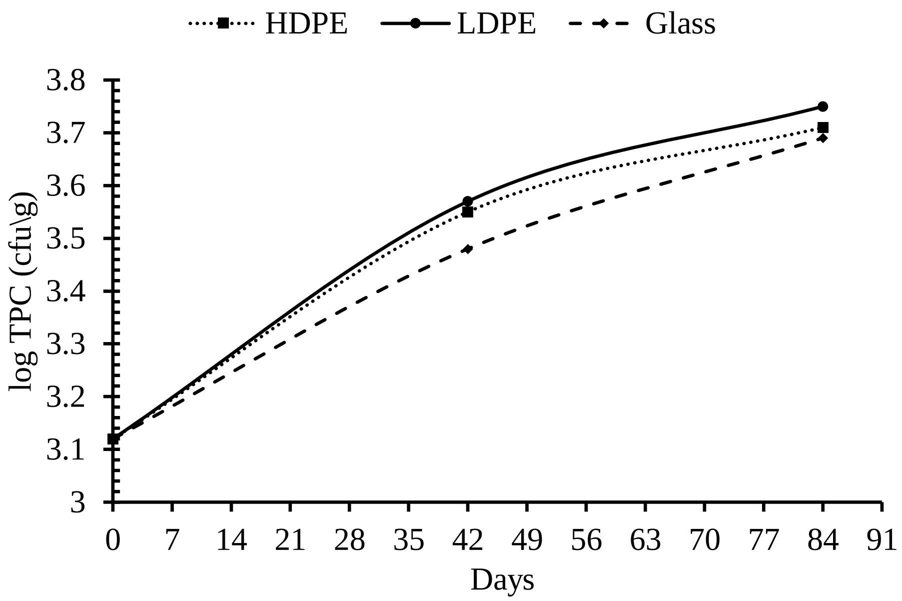

Fig 4.6 Effect of storage conditions on TPC of cabinet dried tomato powder in three different packaging materials.

The study revealed that the both sun-dried and cabinet dried tomato powder stored in glass was better than HDPE and LDPE pouch in terms of preventing the ingress of moisture, lycopene retention and microbiological point of view. The magnitude of the change in physicochemical properties of the powder measured during storage suggests that glass is best for long term storage of tamarind pulp powder (Muzaffar and Kumar, 2016).

Glass jar was found to be statistically better in maintaining the nutritive value of the dried samples because of it static chemical property and low permeability to absorbs moisture within the storage environment which ensures unimpaired taste, color and other vital nutrients followed by plastic container and polythene bag (Ahmad *et al.*, 2017).

LDPE packed powder was the least effective in moisture control, which led to increase of glass transition temperature (Tg) and degree of caking (CD) and loss of color and lycopene (Shishir *et al.*, 2017) which is also similar to the findings of our study. Lycopene loss was observed 10-20 % more, in tomato powders stored in low density polyethylene pouches (Ghavidel and Davoodi, 2010). HDPE gained less moisture due to low permeability to water vapor. Similarly, low density polypropylene is more permeable to moisture as a result there was absorption of moisture from environment and got affected by bacteria (Yadav *et al.*, 2010).

4.2.3 Comparison of sun dried and cabinet dried tomato powder in glass storage

4.2.3.1 Moisture content

The variations in moisture content of sun dried and cabinet dried tomato powder stored in glass over 84 days of time period is shown in figure 4.5.

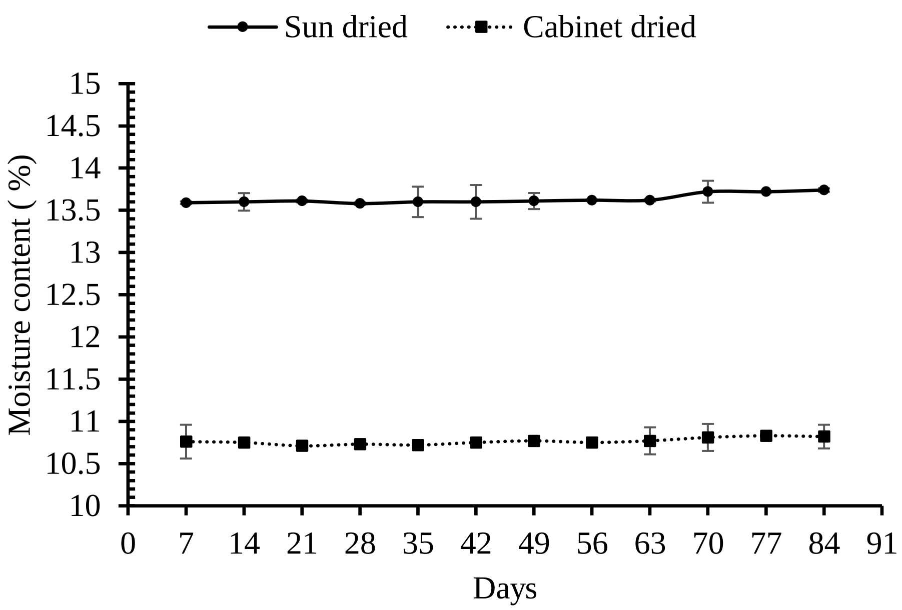

Fig 4.7 Changes in moisture content of sun dried and cabinet dried tomato powder in glass during storage

As seen in above fig 4.7, there is slight increase in moisture content of both sun dried and cabinet dried powder during storage. But the moisture content of cabinet dried powder is already low i.e., 10.75 % than sun dried powder i.e., 13.62 % during the initial phase of storage. Low initial moisture content enhances the keeping quality and increases the storage time (Ladi *et al.*, 2017). As, the cabinet dried product was dried at high temperature, high changes in moisture was not seen. The product was shelf stable and could be consumed for longer period of time.

4.2.3.2 Lycopene content

The variations in lycopene content of sun dried and cabinet dried tomato powder stored in glass over 84 days of time period is shown in figure 4.8.

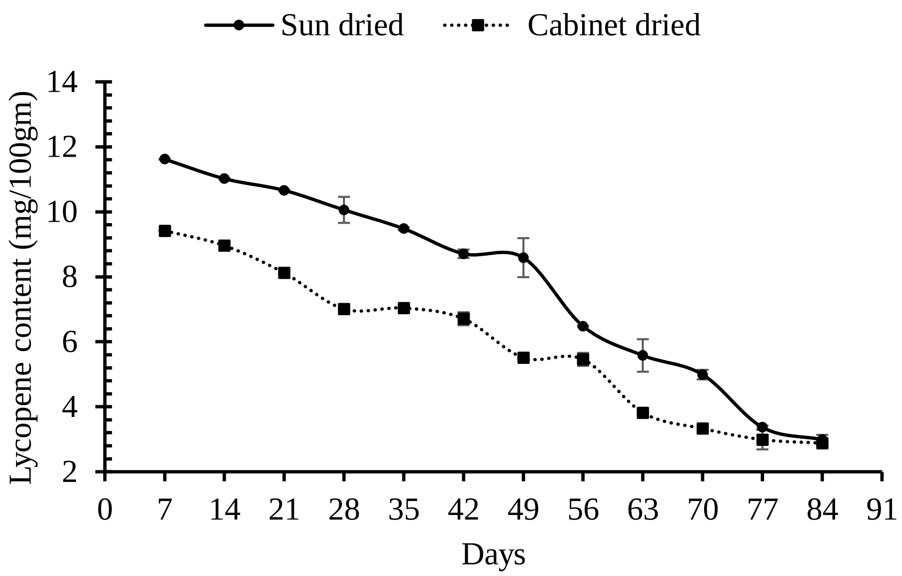

Fig 4.8 Changes in lycopene content of sun dried and cabinet dried tomato powder in glass during storage

As seen in above fig 4.8, there is gradual decrease in lycopene content in both sun dried and cabinet dried tomato powder during storage. The initial lycopene content is higher in sun dried powder i.e., 11.71 mg/100 g as compared to cabinet dried powder i.e., 9.48 mg/100 g. Irrespective of the higher initial lycopene content, the degradation of lycopene is also more in sun dried powder during storage. Sachna Shah (2022) explained that during sun drying the sample was exposed to air temperature for longer time which resulted in more degradation of lycopene during storage. Uncontrolled heat treatment disintegrated tomato tissue and increased exposure to oxygen and light, which resulted in the destruction of lycopene. Lycopene loss of dried tomato halves stored in the same storage environment, samples containing higher levels of moisture content degraded more lycopene than samples containing lower levels of moisture (Hossain and Gottschalk, 2009).

4.2.3.3 Total Plate Count (TPC)

The variations in total plate count of sun dried and cabinet dried tomato powder stored in glass over 84 days of time period is shown in figure 4.9.

As seen in fig 4.9, the total plate count increased sharply for sun dried powder than for cabinet dried powder. The initial plate count of cabinet dried powder is much less than that of sun-dried powder which could be accounted for due to less initial moisture content of cabinet dried powder. Low level of moisture and water activity are used as reference parameters for the commercialization of dried foods, since they inhibit the growth of most microorganisms (Lavelli and Vantaggi, 2009).

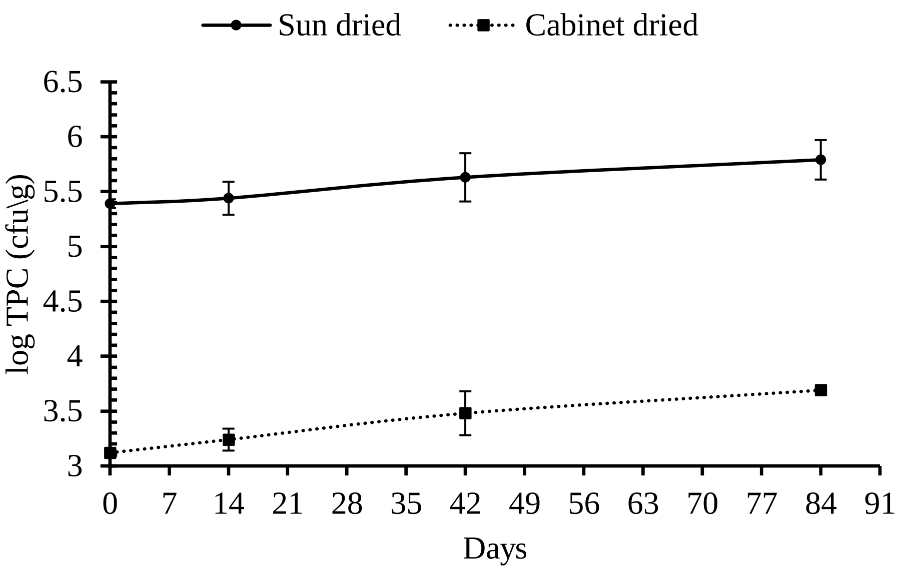

Fig 4.9 Changes in TPC of sun dried and oven dried tomato powder in glass during storage

4.2.4 Sensory analysis of tomato powder

Sensory evaluation of tomato powder stored in three different packaging materials were carried out by a group of 11 semi-trained panelist using 9-point hedonic scale after 3 month of storage period. Tomato soup was prepared from the reconstituted tomato powder. For the preparation of soup, 5 g of tomato powder was dissolved in 100 ml water, 0.5 g of salt and 0.3 g of pepper was added and then the whole mass was boiled for 3 minutes with continuous stirring to obtain a cup full of prepared soup. The parameters evaluated were appearance, taste, smell, mouthfeel and overall acceptance. The Analysis of Variance (ANOVA) was carried out using least significant difference (LSD) at 5 % level of significance. Here,

Sample A= Sun dried tomato powder stored in HDPE

Sample B= Cabinet dried tomato powder stored in HDPE

Sample C= Sun dried tomato powder stored in glass

Sample D= Cabinet dried tomato powder stored in glass

Sample E= Sun dried tomato powder stored in LDPE

Sample F= Cabinet dried tomato powder stored in LDPE

4.2.4.1 Color

Regarding color of soup prepared from tomato powder, the analysis showed that the mean score for sample A, B, C, D, E and F were found to be 7.4, 6.3, 6.7, 6.7, 6.5 and 5.4 respectively. Statistical analysis showed significant effect ($p<0.05$) in the color of tomato soup. LSD at 5 % level of significance indicated that sample B, C, D and E were not significantly different to each other but were significantly different from samples A and F which is shown graphically in Fig 4.10. However, the score of sample A was slightly higher than that of other samples from statistical analysis.

4.2.4.2 Flavor

Regarding flavor of soup prepared from tomato powder, the analysis showed that the mean score for sample A, B, C, D, E and F were found to be 5.6, 5.8, 5.8, 5.6, 5.5 and 5.1 respectively. Statistical analysis showed significant effect ($p<0.05$) in the flavor of tomato soup. LSD at 5 % level of significance indicated that sample A, B, C, D and E were not significantly different to each other but was significantly different to sample F. However, the mean sensory score of sample B and C were higher than that of other samples.

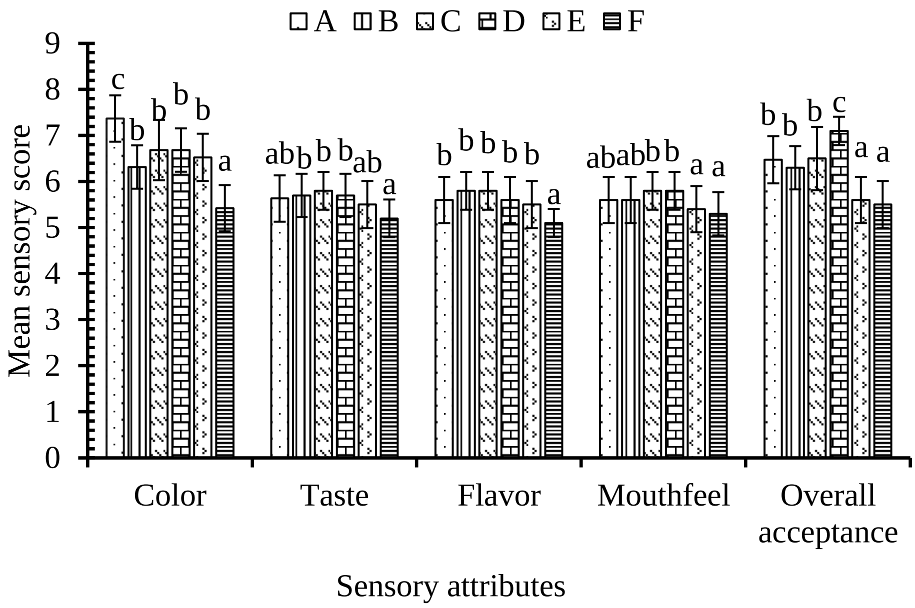

Fig 4.10 Mean sensory score of different sensory attributes of dried tomato powder soup

*Vertical error bars represent standard deviation of scores given by panelist.

4.2.4.3 Taste

The mean sensory score of taste for soup prepared from tomato powder was found to be 5.6, 5.7, 5.8, 5.7, 5.5 and 5.2 respectively. Statistical analysis showed no significant effect ($p>0.05$) in the taste of tomato soup. LSD at 5 % level of significance indicated that sample A, B, C, D, E and F were not significantly different to each other. However, sample C had the highest mean sensory score in terms of taste.

4.2.4.4 Mouthfeel

Regarding the mouthfeel of soup prepared from tomato powder, the analysis showed that the mean score for sample A, B, C, D, E and F were found to be 5.6, 5.6, 5.8, 5.8, 5.4 and 5.3 respectively. Statistical analysis showed significant effect ($p<0.05$) in the mouthfeel of tomato soup. LSD at 5 % level of significance indicated that sample A, B, C, D, E and F were not significantly different from each other. However, the mean sensory score of sample C and sample D were higher than that of other samples.

4.2.4.5 Overall acceptability

Mean sensory score for overall acceptability of soup prepared from tomato powder were found to be 6.5, 6.3, 6.5, 7.1, 5.6 and 5.5 respectively. The overall acceptability of sample was significantly different ($p<0.05$) for all samples. LSD at 5 % level of significance indicated that sample A, B and C were not significantly different to each other but were significantly different from sample D, E and F whereas sample E and F were not significantly different to each other. However, sample D had the highest mean sensory score in terms of overall acceptability.

Part V

Conclusions and recommendations

5.1 Conclusions

The primary result of this study can be summed up as follows based on its findings:

1) Retention of nutrients was better in cabinet dried tomato powder than sun dried tomato powder in terms of protein, fat, and fiber.
2) The retention of lycopene was more in sun dried powder than in cabinet dried powder.
3) The storage stability of both sun and cabinet dried tomato powder was better in glass jar than HDPE and LDPE packaging as shown by moisture, lycopene and TPC analysis.
4) The storage stability of cabinet dried tomato powder stored in glass jar was better than sun dried tomato powder stored in glass jar as shown by moisture, lycopene and TPC analysis.
5) From sensory analysis of the product conducted on the attributes like color, flavor, taste, mouthfeel and overall acceptability, the cabinet dried tomato powder stored in glass jar was rated as best in terms of overall acceptability.
6) From sensory analysis of the product, it can be concluded that when reconstituted, tomato powder had a coarse appearance and texture and was highly viscous with extreme tomato aroma.

5.2 Recommendations

1) Drying of tomatoes can be done at different temperatures to study the changes.
2) Study can be done on the pretreatment of tomatoes before drying in order to study the changes.
3) Further study can be done to investigate the potential application of dried tomato powder by using different methods in various food products.
4) Tomato powder soup mix can be prepared and its storage stability can be studied in different packaging materials.

Part VI

Summary

Tomato is one of the most popular and widely grown vegetable crops in Nepal. It is a great source of antioxidants such as lycopene, carotenes, and phenolics as well as vitamin C. Tomatoes have a limited shelf life at room temperature and are highly perishable. During the growing season, there is a glut, and during the off-season, there is a shortage. Short shelf lives combined with insufficient processing facilities cause a huge loss of revenue for the nation.

This work is mainly focused on the proper utilization of the perishable tomatoes by drying and processing it into powdered form. Study was carried out to know the effect of two different drying methods i.e., sun drying and cabinet drying on quality characteristics of tomatoes. The drying process was continued until the samples reached equilibrium moisture content. Cabinet drying was carried out at 60℃. Proximate analysis (% db) along with lycopene content (mg/100g) was assessed for both the fresh and dried tomato powder. The dried tomato powder was then packed into three different packaging materials i.e., glass jar, HDPE and LDPE package and stored in room temperature. The storage stability of sun and cabinet dried tomato powder packed in different packaging materials was studied. Moisture and lycopene content were analyzed on weekly interval for 84 days.

The findings revealed that drying of tomatoes by both sun drying and cabinet drying method resulted in a loss of nutrients to some extent. However, cabinet dried tomato powder resulted in higher retention of nutrients while greater retention of lycopene was observed in sun dried tomato powder when both were compared. The study on storage stability indicated that glass is the best packaging material for storage of both sun dried and cabinet dried tomato powder than HDPE and LDPE package as there was no such increase in moisture content, greater retention of lycopene and only few growths of colonies were seen. Further, sensory analysis was performed of all the six samples.

According to the sensory evaluation, it was concluded that cabinet dried samples stored at glass was mostly preferred by the panelists. From overall analysis, it is clear that cabinet drying of tomatoes at 60±5℃ and storing in glass jar was considered to be optimum in terms of moisture content, lycopene content, microbial count and sensory properties evaluated.

References

Abdullahi, I. I., Abdullahi, N., Abdu, A. M. and Ibrahim, A. S. (2016). Proximate, mineral and vitamin analysis of fresh and canned tomato. *Biosci. Biotechnol. Res. Asia*. **13** (2), 1163-1169. [doi:10.13005/bbra/2147].

Abinaya, C. and Sridevi Sivakami, P. (2021). Formulation and Incorporation of Tomato Powder in Selected Recipes. *Indian J. Nutr. Diet.* **3**, 149. [doi:10.21048/IJND.2021.58.S3.28440].

Aboagye-Nuamah, F., Hussein, Y. and Ackun, A. (2018). Biochemical properties of six varieties of tomato from Brong Ahafo region of Ghana as influenced by the ripening condition and drying. *African J. Food, Agric. Nutr. Dev*. **18** (1). [doi: 10.18697/ajfand.81.16975].

Adepoju, A. O. (2014). Post-harvest losses and welfare of tomato farmers in Ogbomosho, Osun state, Nigeria. *J. Stored Prod. Postharvest Res.* **5** (2), 8-13.

Agbemafle, R., Owusu-Sekyere, J. and Bart-Plange, A. (2015). Effect of deficit irrigation and storage on the nutritional composition of tomato (Lycopersicon esculentum Mill. cv. Pectomech). *Croat. J. Food Technol. Biotechnol. Nutr.* **10** (1-2), 59-65.

Ahmad, A., Gungula, D. and Tame, V. (2020). Effects of different drying methods on physicochemical and sensory quality of tomato powder. *J. Agric. Food Secur.* **7** (1), 94-100.

Ahmad, A., Gungula, D., Tame, V., Kapsiya, J., Kirawa, D. and Ilesanmi, J. (2017). Effects of Different Drying Methods and Packaging Materials on Quality of Tomato Powder. *Lapai J. Appl. Nat. Sci.* **5** (1), 126-133.

Ajayi, A. (2013). Nature of tomatoes microflora under storage. *Am. J. Exp. Agric.* **3** (1), 89.

Akbudak, B., Akbudak, N., Seniz, V. and Eris, A. (2012). Effect of pre-harvest harpin and modified atmosphere packaging on quality of cherry tomato cultivars “Alona” and “Cluster”. *Br. Food J.* **114** (2), 180-196. [doi:10.1108/00070701211202377].

Akinyele, B. and Akinkunmi, C. (2012). Fungi associated with the spoilage of berry and their reaction to electromagnetic field. *J. Yeast Fungal Res.* **3** (4), 49-57. [doi:10.5897/JYFR12.014].

Alba, R., Payton, P., Fei, Z., McQuinn, R., Debbie, P., Martin, G. B., Tanksley, S. D. and Giovannoni, J. J. (2005). Transcriptome and selected metabolite analyses reveal multiple points of ethylene control during tomato fruit development. *Plant Cell*. **17** (11), 2954-2965. [doi10.1105/tpc.105.036053].

Ali, M. Y., Sina, A. A. I., Khandker, S. S., Neesa, L., Tanvir, E., Kabir, A., Khalil, M. I. and Gan, S. H. (2020). Nutritional composition and bioactive compounds in tomatoes and their impact on human health and disease: A review. *Review. Foods*. **10** (1), 45. [doi:10.3390/foods10010045].

Amanlou, Y. and Zomorodian, A. (2010). Applying CFD for designing a new fruit cabinet dryer. *J. Food Eng.* **101** (1), 8-15. [doi:10.1016/j.jfoodeng.2010.06.001].

And, G. L. and Barrett, D. M. (2006). Influence of Pre-drying treatments on Quality and Safety of Sun-dried Tomatoes. Part II. Effects of Storage on Nutritional and Sensory Quality of Sun-dried Tomatoes Pretreated with Sulfur, Sodium Metbisulfite, or Salt. *J. Food Sci.* **71** (1), S32-S37. [doi:10.1111/j.1365-2621.2006.tb12402.x].

AOAC. (2005). "Official Methods of Analysis" (18th ed.). Vol. 222. Association of Official Analytical Chemists Washington, DC. USA. [ISBN 0935584676].

Arah, I. K., Ahorbo, G. K., Anku, E. K., Kumah, E. K. and Amaglo, H. J. A. i. A. (2016). Postharvest handling practices and treatment methods for tomato handlers in developing countries: A mini review. **2016**.

Arah, I. K., Kumah, E., Anku, E. and Amaglo, H. (2015). An overview of post-harvest losses in tomato production in Africa: causes and possible prevention strategies. *J. Biol. Agric. Healthc.* **5** (16), 78-88.

Arias, R., Lee, T. C., Specca, D. and Janes, H. (2000). Quality comparison of hydroponic tomatoes (Lycopersicon esculentum) ripened on and off vine. *J. Food Sci.* **65** (3), 545-548. [doi:10.1111/j.1365-2621.2000.tb16045.x].

Arjenaki, O. O., Moghaddam, P. A. and Motlagh, A. M. (2013). Online tomato sorting based on shape, maturity, size, and surface defects using machine vision. *Turk. J. Agric. For.* **37** (1), 62-68. [doi:10.3906/tar-1201-10].

Babatola, L., Ojo, D. and Lawal, O. (2008). Effect of storage conditions on tomato (Lycopersicon esculentum Mill.) quality and shelf life. *J. Biol. Sci.* **8** (2), 490-493.

Baiyewu, R., Amusa, N., Ayoola, O. and Babalola, O. (2007). Survey of the postharvest diseases and aflatoxin contamination of marketed Pawpaw fruit (Carica papaya L.) in South Western Nigeria. *Afr. J. Agric. Res.* **2** (4), 178-181.

Barigela, A. and Bhukya, B. (2021). Probiotic Pediococcus acidilactici strain from tomato pickle displays anti-cancer activity and alleviates gut inflammation in-vitro. *3 Biotech*. **11**, 1-11. [doi:10.1007/s13205-020-02570-1].

Barlow, C. and Morgan, D. (2013). Polymer film packaging for food: An environmental assessment. *Resour. Conserv. Recycl.* . **78**, 74-80. [doi:10.1016/j.resconrec.2013.07.003].

Basunia, M. and Abe, T. (2001). Thin-layer solar drying characteristics of rough rice under natural convection. *J. Food Eng.* **47** (4), 295-301. [doi:10.1016/S0260-8774(00)00133-3].

Batu, A. and Thompson, A. K. (1998). Effects of modified atmosphere packaging on post harvest qualities of pink tomatoes. *Turk. J. Agric. For.* **22** (4), 365-372.

Bauchet, G. and Causse, M. (2012). Genetic Diversity in Tomato (Solanum lycopersicum) and Its Wild Relatives, Genetic Diversity in Plants, Prof. Mahmut Caliskan (Ed.), ISBN: 978-953-51-0185-7, InTech.

Bergougnoux, V. (2014). The history of tomato: from domestication to biopharming. *Biotechnol. Adv.* **32** (1), 170-189. [doi:10.1016/j.biotechadv.2013.11.003].

Bhuiyan, M. (2012). Pickle and chutney development from fresh Hog Plum (Spondias dulcis). *J. Environ. Sci. Nat. Resour.* **5** (2), 67-72.

Borguini, R. G. and Ferraz da Silva Torres, E. A. (2009). Tomatoes and tomato products as dietary sources of antioxidants. *Food Rev. Int.* **25** (4), 313-325. [doi:10.1080/87559120903155859].

Brandt, S., Lugasi, A., Barna, É., Hóvári, J., Pék, Z. and Helyes, L. (2003). Effects of the growing methods and conditions on the lycopene content of tomato fruits. *Acta Aliment.* **32** (3), 269-278.

Brummell, D. A. (2006). Cell wall disassembly in ripening fruit. *Funct. Plant Biol.* **33** (2), 103-119. [doi:10.1071/FP05234].

Butnariu, M. and Butu, A. (2015). Chemical composition of vegetables and their products. *In:* "Handbook of Food Chemistry".). pp. 627-692.

Buttery, R., Teranishi, R., Flath, R. and Ling, L. (1989). "Flavour Chemistry: Trends and Developments. ACS Symposium Series 338". American Chemical Society. [ISBN 978-0841215702].

Changrue, V., Raghavan, V., Orsat, V. and Vijaya Raghavan, G. (2006). Microwave drying of fruits and vegetables. *Stewart postharvest Rev.* **2** (6), 1-7.

Choksi, P. M. and Joshi, V. Y. (2007). A review on lycopene—extraction, purification, stability and applications. *Int. J. Food Prop.* **10** (2), 289-298. [doi:10.1080/10942910601052699].

Coles, R., McDowell, D. and J. Kirwan, M. (2003). "Food packaging technology". Blackwell Publishing LLC. USA. [ISBN 1–84127–221–3].

Correia, A., Loro, A. C., Zanatta, S., Spoto, M. H. F. and Vieira, T. M. F. d. S. (2015). Effect of temperature, time, and material thickness on the dehydration process of tomato. *Int. J. Food Sci.* **2015**. [doi:10.1155/2015/970724].

Dam, B. v., Goffau, M. d., Lidth de Jeude, J. v. and Naika, S. (2005). "Cultivation of tomato: production, processing and marketing" (2005 ed.). Digigrafi, Wageningen. Netherlands. [ISBN 90-8573-039-2].

Davies, J. N., Hobson, G. E. and McGlasson, W. (1981). The constituents of tomato fruit—the influence of environment, nutrition, and genotype. *Crit. Rev. Food Sci. Nutr.* **15** (3), 205-280. [doi:10.1080/10408398109527317].

Davoodi, M. G., Vijayanand, P., Kulkarni, S. and Ramana, K. (2007). Effect of different pre-treatments and dehydration methods on quality characteristics and storage stability of tomato powder. *J. LWT Food. Sci. Technol.* **40** (10), 1832-1840.

de Castro, L. R., Vigneault, C. and Charles, M. T. (2005). Effect of cooling delay and cold-chain breakage on'Santa Clara'tomato. *J. Food Agric. Environ.*

Del Valle, M., Cámara, M. and Torija, M. E. (2006). Chemical characterization of tomato pomace. *J. Sci. Food Agric.* **86** (8), 1232-1236. [doi:10.1002/jsfa.2474].

Desrosier, N. W. and Desrosier, J. N. (1977). "The technology of food preservation" (Fourth ed.). AVI Publishing Company, Inc. Westport, Connecticut. [ISBN 978-0-870-55232-8].

Dirinck, P., Schreyen, L. and Schamp, N. (1977). Aroma quality evaluation of tomatoes, apples, and strawberries. *J. Agric. Food Chem.* **25** (4), 759-763. [doi:10.1021/jf60212a039].

Dufera, L. T., Hofacker, W., Esper, A. and Hensel, O. (2023). Effect of packaging materials on lycopene vitamin C and water activity of dried tomato (Lycopersicon esculentum Mill.) powder during storage. *Food Sci. Nutr.* [doi:10.1002/fsn3.3562].

Egea, I., Barsan, C., Bian, W., Purgatto, E., Latché, A., Chervin, C., Bouzayen, M. and Pech, J.-C. (2010). Chromoplast differentiation: current status and perspectives. *Plant Cell Physiol.* . **51** (10), 1601-1611. [doi:10.1093/pcp/pcq136].

Ekechukwu, O. V. and Norton, B. (1999). Review of solar-energy drying systems II: an overview of solar drying technology. *Energy. Conv. Manag.* **40** (6), 615-655. [doi10.1016/S0196-8904(98)00093-4].

FAOSTAT, F. J. P. F., Rome, Italy. (2012). FAOSTAT statistical database. (Food and Agriculture Organization of the United Nations).

FAOSTAT, F. J. P. F., Rome, Italy. (2016). FAOSTAT statistical database.

FDA. (2013). Revised Guidelines for the Assessment of Microbiological Quality of Processed Foods [Circular No. 2013-010]. p. 24. Retrieved from https://members.wto.org/crnattachments/2021/TBT/PHL/21_3930_00_e.pdf. [Accessed 31 July, 2023].

Fellows, P. J. (2022). "Food processing technology: principles and practice". Woodhead publishing. [0323984312].

Ferreira, M., Brecht, J., Sargent, S. and Aracena, J. (1994). Physiological responses of strawberry to film wrapping and precooling methods. *Proc. Fla. State Hort. Soc.* **107**, 265-268. [Accessed 5 August, 2023].

Fishman, M. L., Gross, K. C., Gillespie, D. T. and Sondey, S. M. (1989). Macromolecular components of tomato fruit pectin. *Arch. Biochem. Biophys.* **274** (1), 179-191. [doi:10.1016/0003-9861(89)90429-3].

Fosberg, F. J. P. (1987). New nomenclatural combinations for Galapagos plant species.

Francis, D. and Phelps, S. K. (2003). Fruit and vegetable juice powders add value to cereal products. *Cereal Food World*. **48** (5), 244.

Garg, H. and Prakash, J. (1997). Solar Photovoltaics. *In:* "Solar Energy: Fundamentals and Applications" (1st ed.).). pp. 116-389. McGraw Hill Education. [ISBN 978-0074636312].

Garg, R., Batav, N., Silawat, N. and Singh, R. (2013). Isolation and identification of pathogenic microbes from tomato puree and their delineation of distinctness by molecular techniques. *J. Appl. Biol. Biotechnol.* **1** (4), 024-031.

Gautam, S., Acedo Jr, A. L., Schreinemachers, P. and Subedi, B. P. (2017). Volume and value of postharvest losses: The case of tomatoes in Nepal. *Br. Food J.* **119** (12), 2547-2558. [doi:10.1108/BFJ-12-2016-0632].

Gaware, T., Sutar, N. and Thorat, B. (2010). Drying of tomato using different methods: comparison of dehydration and rehydration kinetics. *Dry. Technol.* **28** (5), 651-658. [doi:10.1080/07373931003788759].

Genanew, T. (2013). Effect of post harvest treatments on storage behavior and quality of tomato fruits. *World J. Agric. Sci.* **9** (1), 29-37. [doi:10.5829/idosi.wjas.2013.9.1.1719].

Gentilcore, D. (2010). "Pomodoro!: A History of the Tomato in Italy;[arts and Traditions of the Table, Perspectives on Culinary History]". Columbia University Press. [023115206X].

Ghavidel, R. A. and Davoodi, M. G. (2009). Effect of chemical pretreatments and dehydration methods on quality characteristics of tomato powder and its storage stability. *World Acad. Sci. Eng. Technol.* **3**, 6-27.

Ghavidel, R. A. and Davoodi, M. G. (2010). Studies on physiochemical properties of tomato powder as affected by different dehydration methods and pretreatments. *World Acad. Sci. Eng. Technol.* **69**, 596-605.

Ghimire, N., Kandel, M., Aryal, M. and Bhattarai, D. (2017). Assessment of tomato consumption and demand in Nepal. *J. Agric .Environ.* **18**, 83.

Ghimire, S. R., Subedi, P. P. and Green, S. K. (2001). Status of tomato yellow leaf curl virus in tomato in the western hills of Nepal. *J. Nepal Agric. Res.*, 1-4.

Goula, A. M. and Adamopoulos, K. G. (2005). Spray drying of tomato pulp in dehumidified air: II. The effect on powder properties. *J. Food Eng.* **66** (1), 35-42. [doi:10.1016/j.jfoodeng.2004.02.031].

Goula, A. M., Adamopoulos, K. G., Chatzitakis, P. C. and Nikas, V. A. (2006). Prediction of lycopene degradation during a drying process of tomato pulp. *J. Food Eng.* **74** (1), 37-46. [doi10.1016/j.jfoodeng.2005.02.023].

Groth, B. H. A. (1910). "Structure of tomato skins". Vol. 228. New Jersey Agricultural Experiment Stations.

Haile, A. and Safawo, T. (2018). Shelf life and quality of tomato (Lycopersicon esculentum Mill.) fruits as affected by different Packaging Materials. *Afr. J. Food Sci.* **12** (2), 21-27. [doi:10.5897/AJFS2017.1568].

Harris, J. R. (2013). "Subcellular Biochemistry: Ascorbic Acid: Biochemistry and Biomedical Cell Biology". Vol. 25. Springer Science & Business Media. [1461303257].

Hayes, W., Smith, P. and Morris, A. (1998). The production and quality of tomato concentrates. *Critical Rev. in Food Sci. and Nutr.* **38** (7), 537-564.

Hossain, M. A. and Gottschalk, K. (2009). Effect of moisture content, storage temperature and storage period on colour, ascorbic acid, lycopene and total flavonoids of dried tomato halves. *Int. J. Food Sci. Technol.* **44** (6), 1245-1253. [doi:10.1111/j.1365-2621.2009.01954.x].

Hurst, W. (2010). Harvest, handling and sanitation. *In:* "Commercial Tomato Production Handbook" (Vol. 1312).). University of Georgia. CAES publications.

Idah, M. and Abdullahi, M. (2010). Effects of storage period on some nutritional properties of orange and tomato. *Au. J. T.*

Idah, P., Ajisegiri, E. and Yisa, M. (2007). Fruits and vegetables handling and transportation in Nigeria.

Ivanova, N., Khomich, L. and Beketova, N. (2018). Tomato juice nutritional profile. *Vopr. Pitan.* **87** (2), 53-64. [doi:10.24411/0042-8833-2018-10019].

Jayathunge, K., Kapilarathne, R., Thilakarathne, B., Fernando, M., Palipane, K. and Prasanna, P. (2012). Development of a methodology for production of dehydrated tomato powder and study the acceptability of the product. *J. Agric. Technol.* **8** (2), 765-773.

Kader, A. (1984). Effects of postharvest handling procedures on tomato quality. *Symp. Tomato Prod. Arid Land 190*. 209-222. [Accessed 5 August, 2023].

Kader, A. A. (2004). Increasing food availability by reducing postharvest losses of fresh produce. *V Int. Postharvest Symp. 682*. 2169-2176.

Kaur, D., Wani, A. A., Sogi, D. and Shivhare, U. (2006). Sorption isotherms and drying characteristics of tomato peel isolated from tomato pomace. *Dry. Technol.* **24** (11), 1515-1520. [doi10.1080/07373930600961371].

Keey, R. B. (2013). "Drying: principles and practice" (Revised ed.). Vol. 13. Elsevier. [ISBN 978-1-483-14633-1].

Kilcast, D. and Subramaniam, P. (2000). "The stability and shelf-life of food". Woodhead Publishing Limited. Cambridge, England.

Kulanthaisami, S., Rajkumar, P., Venkatachalam, P., Subramanian, P., Raghavan, G., Gariepy, Y. and Orsat, V. (2010). Drying kinetics of tomato slices in solar cabinet dryer compared with open sun drying. *Madras Agric. J.* **97** (7-9), 287-295.

Ladi, O. J., Awod, Y. P., Obogeh, K. A. and Alfa, I. N. (2017). Effect of drying methods and storage conditions on nutritional value and sensory properties of dehydrated tomato powder (Lycopersicon esculentum). *Int. J. Biochem. Res. Rev.* **19** (1), 1-7. [doi: 10.9734/IJBCRR/2017/33103].

Lavelli, V. and Vantaggi, C. (2009). Rate of antioxidant degradation and color variations in dehydrated apples as related to water activity. *J. Agric. Food Chem.* **57** (11), 4733-4738. [doi:10.1021/jf900176v].

Lingayat, A., Chandramohan, V. and Raju, V. (2017). Design, development and performance of indirect type solar dryer for banana drying. *Energy Procedia*. **109**, 409-416. [doi:10.1016/j.egypro.2017.03.041].

Linnaeus, C. (1799). "Species plantarum". Vol. 3. Impensis GC Nauk.

Liu, F., Cao, X., Wang, H. and Liao, X. (2010). Changes of tomato powder qualities during storage. *Powder Technol.* **204** (1), 159-166. [doi:10.1016/j.powtec.2010.08.002].

Livingston, A. W. and Smith, A. F. (1998). "Livingston and the Tomato". The Ohio State University Press. [0814208096].

MacGillivray, J. H. and Ford, O. W. (1928). Tomato quality as influenced by the relative amount of outer and inner wall region.

Mangels, A. R., Holden, J. M., Beecher, G. R., Forman, M. R. and Lanza, E. (1993). Carotenoid content of fruits and vegetables: an evaluation of analytic data. *J. Am. Diet. Assoc.* **93** (3), 284-296. [doi:10.1016/0002-8223(93)91553-3].

Marsh, K. and Bugusu, B. (2007). Food packaging—roles, materials, and environmental issues. *J. Food Sci.* **72** (3), R39-R55.

MoAD. (2014). Statistical information on Nepalese agriculture 2013/ 2014. *Government of Nepal, Ministry of Agricultural Department (Agri-Business Promotion and Statistics Division).*

MoALD. (2020). Statistical information on Neplaese agriculture 2018/ 2019. *Ministry of agriculture and livestock development (Planning and Development Cooperation Coordination Division).* Retrieved from http://www.doanepal.gov.np/downloadfile/Statistical/04520information/04520on/04520Nepalese/04520agriculture_1601976502.pdf.

Mohseni, S. and Ghavidel, R. A. (2011). Effect of pre-drying treatments on quality characteristics of dehydrated tomato slices. *World Acad. Sci. Eng. Technol.* **59** (1), 2205-2215.

Moneruzzaman, K., Hossain, A., Sani, W. and Saifuddin, M. (2008). Effect of stages of maturity and ripening conditions on the biochemical characteristics of tomato. *Am. J. Biochem. Biotechnol.* **4** (4), 336-344.

Moneruzzaman, K., Hossain, A., Sani, W., Saifuddin, M. and Alenazi, M. (2009). Effect of harvesting and storage conditions on the post harvest quality of tomato (Lycopersicon esculentum Mill) cv. Roma VF. *Aust. J. Crop Sci.* **3** (2), 113.

Moretti, C. L., Sargent, S. A., Huber, D. J., Calbo, A. G. and Puschmann, R. (1998). Chemical composition and physical properties of pericarp, locule, and placental tissues of tomatoes with internal bruising. *J. Am. Soc. Hortic. Sci.* **123** (4), 656-660. [doi:10.21273/JASHS.123.4.656].

Moses, J., Norton, T., Alagusundaram, K. and Tiwari, B. (2014). Novel drying techniques for the food industry. *Food Eng. Rev.* **6**, 43-55. [doi:10.1007/s12393-014-9078-7].

Mozumder, N., Rahman, M., Kamal, M., Mustafa, A. and Rahman, M. (2012). Effects of pre-drying chemical treatments on quality of cabinet dried tomato powder. *J. Environ. Sci. Nat. Resour.* **5** (1), 253-265.

Muhammad, R., Bamisheyi, E. and Olayemi, E. (2011). The effect of stage of ripening on the shelf life of tomatoes (Lycopersi conesculentum) stored in the evaporative cooling system (ECS). *J. Dairy. Food Home Sci.* **30** (4), 299-301.

Muzaffar, K. and Kumar, P. (2016). Moisture sorption isotherms and storage study of spray dried tamarind pulp powder. *Powder Technol.* **291**, 322-327. [doi:10.1016/j.powtec.2015.12.046].

Naika, S., Jeude, v. L. d., de Goffau, M., Hilmi, M. and van Dam, B. (2005). Cultivation of Tomato. *J. Prod. Process. Mark.* .

Nguyen, M. L. and Schwartz, S. J. (1998). Lycopene stability during food processing. *Proc. Soc. Exp. Biol. Med.* **218**, 101-105. [Accessed 20 August,2023].

Nirupama, P., Gol, N. B. and Rao, T. R. (2010). Effect of post harvest treatments on physicochemical characteristics and shelf life of tomato (Lycopersicon esculentum Mill.) fruits during storage. *Am. Eurasian J. Agric. Environ. Sci.* **9** (5), 470-479.

Obadina, A., Ibrahim, J. and Adekoya, I. (2018). Influence of drying temperature and storage period on the quality of cherry and plum tomato powder. *Food Sci. Nutr.* **6** (4), 1146-1153. [doi:10.1002/fsn3.658].

Ogundipe, F., Bamidele, F., Adebayo-Oyetoro, A., Ogundipe, O. and Tajudeen, O. (2012). Incidence of bacteria with potential public health implications in raw Lycopersicon esculentum (tomato) sold in Lagos State, Nigeria. *Niger. Food J.* **30** (2), 106-113. [doi:10.1016/S0189-7241(15)30043-6].

Olayemi, F., Adegbola, J., Bamishaiye, E. and Daura, A. (2010). Assessment of post-harvest challenges of small scale farm holders of tomotoes, bell and hot pepper in some local government areas of Kano State, Nigeria. *Bayero J. Pure Appl. Sci.* **3** (2), 39-42.

Opadotun, O., Adekeye, S., Ojukwu, E. and Adewumi, A. (2016). Comparative analysis of nutritional values of tomatoes subjected to different drying conditions. *Int. J. Basic Appl. Sci.* **5** (1), 6-9.

Owureku-Asare, M., Oduro, I., Saalia, F. K., Tortoe, C. and Ambrose, R. K. (2018). Physicochemical and nutritional characteristics of solar and sun-dried tomato powder. *J. Food Res.* **7** (6), 1-15.

Parker, R. and Maalekuu, B. (2013). The effect of harvesting stage on fruit quality and shelf-life of four tomato cultivars (Lycopersicon esculentum Mill). *Agric. Biol. J. N. Am.* **4** (3), 252-259. [doi:10.5251/abjna.2013.4.3.252.259].

Petro-Turza, M. (1986). Flavor of tomato and tomato products. *Food Rev. Int.* **2** (3), 309-351. [doi:10.1080/87559128609540802].

Piasecka-Jóźwiak, K., Rozmierska, J., Chabłowska, B., Stecka, K. M., Skąpska, S., Kliszcz, M. and Szkudzińska-Rzeszowiak, E. (2013). Starter cultures for lactic acid fermentation of sweet pepper, pattypan squash and tomatoes. *Pol. J. Food Nutr. Sci.* **63** (2), 95-102. [doi:10.2478/v10222-012-0068-2].

Potter, N. N. and Hotchkiss, J. H. (2012). "Food science" (Fifth ed.). Springer Science & Business Media. [978-1-4613-7263-9].

Radha, C., Ogunsina, B. and Hebina Babu, K. (2015). Some quality and micro-structural characteristics of soup enriched with debittered Moringa oleifera seeds flour. *Am. J. Food Sci. Technol.* **3** (6), 145-149. [doi:10.12691/ajfst-3-6-1].

Rajarajeswari, K., Sunooj, K. and Sreekumar, A. (2016). Thermal investigation and food quality analysis on a solar tunnel drier. *Curr. Sustainable Renewable Energy. Rep.* **3**, 108-112. [doi:10.1007/s40518-016-0051-3].

Raman, S. (2022). Tomato Powder: Uses, Benefits, Manufacturing Process. Mevive International. Retrieved from https://www.meviveinternational.com/blog/tomato-powder-uses-benefits-manufacturing-process. [Accessed 3 January, 2024].

Ranganna, S. (1986). "Handbook of analysis and quality control for fruit and vegetable products" (Revised ed.). Tata McGraw-Hill Education. New Delhi. [ISBN 978-0-074-51851-9].

Redlinger, P. and Nelson, D. (1990). "Canning and freezing tomatoes". Cooperative Extension Service, Iowa State University.

Rosenbaum, J. and Sando, C. E. (1920). Correlation between size of the fruit and the resistance of the tomato skin to puncture and its relation to infection with Macrosporium tomato Cooke. *Am. J. Bot.*, 78-82. [doi:10.2307/2435042].

Sablani, S., Opara, L. and Al-Balushi, K. (2006). Influence of bruising and storage temperature on vitamin C content of tomato fruit. *J. Food Agric. Environ.* **4** (1), 54.

Sachna Shah, R. S., H.G. Prakash. (2022). Nutritional evaluation of tomato powder. *J. Food Sci. Nutr.* **5** (3), 112.

Sagar, V. and Maini, S. (1997). Studies on packaging and storage of onion powder. *Indian J. Hortic.* **54** (1), 75-79.

Saltveit, M. E. (1999). Effect of ethylene on quality of fresh fruits and vegetables. *Postharvest Biol. Technol.*

. **15** (3), 279-292.

Salunkhe, D., Jadhav, S. and Yu, M. (1974). Quality and nutritional composition of tomato fruit as influenced by certain biochemical and physiological changes. *Plant Food Hum. Nutr.* **24**, 85-113. [doi:10.1007/BF01092727].

Sarkar, S. and Aparna, K. (2020). Food packaging and storage. *Res. Trends Home Sci. Ext.* **3**, 27-51.

Sarker, M., Hannan, M., Quamruzzaman, M. and Khatun, H. (2014). Storage of tomato powder in different packaging materials. *J. Agric. Technol.* **10** (3), 595-605.

Schneider, S. M., Rosskopf, E. N., Leesch, J. G., Chellemi, D. O., Bull, C. T. and Mazzola, M. (2003). United States Department of Agriculture—Agricultural Research Service research on alternatives to methyl bromide: pre-plant and post-harvest. *Pest Manag. Sci.* **59** (6-7), 814-826. [doi:10.1002/ps.728].

Shahi, N., Lohani, U., Chand, K. and Singh, A. (2012). Effect of pre-cooling treatments on shelf life of tomato in ambient condition. *Int. J. Food Agric. Vet. Sci.* **2** (3), 50-56.

Shi, J. and Maguer, M. L. (2000). Lycopene in tomatoes: chemical and physical properties affected by food processing. *Crit. Rev. Food Sci. Nutr.* **40** (1), 1-42. [doi:10.1080/10408690091189275].

Shishir, M. R. I., Taip, F. S., Saifullah, M., Aziz, N. A. and Talib, R. A. (2017). Effect of packaging materials and storage temperature on the retention of physicochemical properties of vacuum packed pink guava powder. *Food Packag. Shelf Life*. **12**, 83-90. [doi:10.1016/j.fpsl.2017.04.003].

Siebert, T. (2017). Agro-processing of field crops-peppers and tomatoes: Farmlink Africa. *FarmBiz*. **3** (1), 38-39.

Siriwattananon, L. and Maneerate, J. (2016). Effect of drying methods on dietary fiber content in dried fruit and vegetable from non-toxic agricultural field. *GEOMATE J.* **11** (28), 2896-2900. [doi:10.21660/2016.28.1372].

Smith, O. and Cochran, H. L. (1935). Effect of temperature on pollen germination and tube growth in the tomato.

Srivastava, R., Sanjeev, K. and Kumar, S. (2002). "Fruit and vegetable preservation". Global Media. [8185860742].

Srivastava, S. and Kulshreshtha, K. (2013). Nutritional content and significance of tomato powder. *Ann. of Arid Zone*. **52** (2), 121-124.

Srivastava, S. and Kulshrestha, K. (2013). Nutritional content and significance of tomato powder. **52** (2), 121-124.

Stern, D. J., Buttery, R., TERANISHI, R., LING, L., SCOTT, K. and CANTWELL, M. (1990). Computer enhanced flavor analysis in tomatoes. *J. Food Qual.* **13** (5), 309-316.

Surendar, J., Shere, D. and Shere, P. (2018). Effect of drying on quality characteristics of dried tomato powder. *J. Pharmacogn. Phytochem.* **7** (2), 2690-2694.

Symon, D. J. J. o. t. A. B. G. (1981). THE SOLANACEOUS GENERA, BROWALLIA, CAPSICUM, CESTRUM, CYPHOMANDRA, HYOSCYAMUS, LYCOPERSICON, NIEREMBERGIA, PHYSALIS, PETUNIA, SALPICHROA AND WITHANIA, NATURALISED IN AUSTRALIA. *J. Adelaide Bot. Gard.*, 133-166.

Tanglertpaibul, T. and Rao, M. (1987). Rheological properties of tomato concentrates as affected by particle size and methods of concentration. *J. Food Sci.* **52** (1), 141-145. [doi:10.1111/j.1365-2621.1987.tb13991.x].

Taylor, I. (1986). Biosystematics of the tomato. *In:* "The tomato crop: a scientific basis for improvement".). pp. 1-34. Springer.

Watkins, C. B. (2006). The use of 1-methylcyclopropene (1-MCP) on fruits and vegetables. *Biotechnol. Adv.* . **24** (4), 389-409. [doi:10.1016/j.biotechadv.2006.01.005].

Winsor, G. (1979). Some factors affecting the quality and composition of tomatoes. *Symp. Qual. Veg.* 335-346.

Wisniewski, M. E. and Wilson, C. L. (1992). Biological control of postharvest diseases of fruits and vegetables: recent advances. *Hort. Sci.* **27** (2), 94-98.

Wogu, M. and Ofuase, O. (2014). Microorganisms responsible for the spoilage of tomato fruits, Lycopersicum esculentum, sold in markets in Benin City, Southern Nigeria. *Sch. Acad. J. Biosci.* **2** (7), 459-466.

Yadav, G., Soni, S. and Sawant, B. (2010). Study of effect of packaging and storage on the quality of onion powder prepared by osmotic dehydration. *Int. J. Agric. Eng.* **3** (1), 31-34.

Yao, H. and Tian, S. (2005). Effects of a biocontrol agent and methyl jasmonate on postharvest diseases of peach fruit and the possible mechanisms involved. *J. Appl. Microbiol.* **98** (4), 941-950. [doi:10.1111/j.1365-2672.2004.02531.x].

Yeaboah, A. K. (2011). A survey on postharvest handling, preservation and processing methods of tomato (Solanum lycopersicum) in the Dormaa and Tano South Districts of the Brong Ahafo Region of Ghana. Thesis. Kwame Nkrumah Univ. of Science and Technology, Ghana.

Yegrem, L. and Ababele, L. (2022). Pretreatments, dehydration methods and packaging materials: effects on the nutritional quality of tomato powder. *Austin J. Nutr. Food Sci.* **102**, 1167.

Yusufe, M., Mohammed, A. and Satheesh, N. (2017). Effect of Duration and Drying Temperature on Characteristics of Dried Tomato (L.) Cochoro Variety. *Acta Univ. Cibiniensis, Ser. E: Food Technol.* . **21** (1), 41-50. [doi: 10.1515/aucft-2017-0005].

Zaka, K. (2011). Household processing and dissemination of tomato paste technology. *J. Food Environ.* **152**, 157-162.

Žnidarčič, D. and Požrl, T. (2006). Comparative study of quality changes in tomato cv.'Malike'(Lycopersicon esculentum Mill.) whilst stored at different temperatures. *Acta Agric. Slov.* **87** (2), 235-243.

Appendices

Appendix A

Sensory Analysis Score Card

Name of the Panelist: ………….………   Date: ……………

Product name: Tomato powder soup

Dear panelist, you are given 6 coded samples of tomato powder soup. Please taste the following samples and check how much you prefer each sample. Give points for your degree of preference on the following parameter using the table given;

Sample code	Color	Taste	Flavor	Mouth feel	Overall acceptance
A					
B					
C					
D					
E					
F					

Judge the characteristics on the 1-9 scale as below:

Like extremely – 9   Like slightly – 6   Dislike moderately – 3

Like very much – 8   Neither like nor dislike – 5   Dislike very much – 2

Like moderately – 7   Dislike slightly – 4   Dislike extremely – 1

Any comments:

Signature: ……………………….

Appendix B

Table B.1 List of equipment used

Physical Apparatus	
Heating arrangement	Hot air oven
Electric balance	Muffle furnace
Daily routine glassware	Rotary shaker
Incubator	Spectrophotometer
Kjeldahl digestion and distillation set	Desiccators
Soxhlet apparatus	Grinder

Table B.2 List of chemicals used

Chemicals	
Boric acid	Acetone
Catalyst mixture (Potassium sulphate and Copper sulphate pentahydrate)	Hexane
	Sodium hydroxide
Hydrochloric acid	Ethanol
Methyl red	Petroleum ether
Bromocresol green	Plate count agar
Phenolphthalein	Oxalic acid

Appendix C

Table C.1 One way ANOVA (no blocking) of moisture content of sun and cabinet dried tomato powder

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Powder type	2	13986.4318	6993.2159	40017.13	<.001
Residual	6	1.0485	0.1748		
Total	8	13987.4803			

Table C.2 One way ANOVA (no blocking) of protein content of sun and cabinet dried tomato powder

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Powder type	2	74.6426	37.3213	46.04	<.001
Residual	6	4.8642	0.8107		
Total	8	9.5068			

Table C.3 One way ANOVA (no blocking) of fat content of sun and cabinet dried tomato powder

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Powder type	2	13.46747	6.73373	109.51	<.001
Residual	6	0.36893	0.06149		
Total	8	13.83640			

Table C.4 One way ANOVA (no blocking) of ash content of sun and cabinet dried tomato powder

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Powder type	2	17.070	8.535	4.66	0.060
Residual	6	11.001	1.834		
Total	8	28.072			

Table C.5 One way ANOVA (no blocking) of fiber content of sun and cabinet dried tomato powder

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Powder type	2	44.5883	22.2941	111.22	<.001
Residual	6	1.2027	0.2005		
Total	8	45.7910			

Table C.6 One way ANOVA (no blocking) of carbohydrate content of sun and cabinet dried tomato powder

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Powder type	2	1180.1778	590.0889	1453.78	<.001
Residual	6	2.4354	0.4059		
Total	8	1182.6132			

Table C.7 One way ANOVA (no blocking) of lycopene content of sun and cabinet dried tomato powder

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Powder type	2	55.68094	27.84047	422.35	<.001
Residual	6	0.39551	0.06592		
Total	8	56.07645			

Table C.8 One way ANOVA (no blocking) of titratable acidity of sun and cabinet dried tomato powder

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Powder type	2	0.018022	0.009011	4.22	0.072
Residual	6	0.012800	0.002133		
Total	8	0.030822			

Table C.9 One way ANOVA (no blocking) of pH of sun and cabinet dried tomato powder

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Powder type	2	0.04740	0.02370	0.28	0.764
Residual	6	0.50500	0.08417		
Total	8	0.55240			

Appendix D

ANOVA results of sensory analysis

Table D.1 Two way ANOVA (no interaction) for color of dried tomato powder soup

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Sample	5	21.4000	4.2800	18.17	<.001
Panelist	9	5.0000	0.5556	2.36	0.028
Residual	45	10.6000	0.2356		
Total	59	37.0000			

Table D.2 Two way ANOVA (no interaction) for smell of dried tomato powder soup

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Sample	5	3.3333	0.6667	4.09	0.004
Panelist	9	4.0667	0.4519	2.77	0.011
Residual	45	7.3333	0.1630		
Total	59	14.7333			

Table D.3 Two way ANOVA (no interaction) for taste of dried tomato powder soup

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Sample	5	2.2833	0.4567	2.31	0.059
Panelist	9	3.4167	0.3796	1.92	0.073
Residual	45	8.8833	0.1974		
Total	59	14.5833			

Table D.4 Two way ANOVA (no interaction) for mouthfeel of dried tomato powder soup

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Sample	5	2.0833	0.4167	3.08	0.018
Panelist	9	6.4167	0.7130	5.27	<.001
Residual	45	6.0833	0.1352		
Total	59	14.5833			

Table D.5 Two way ANOVA (no interaction) for overall acceptability of dried tomato powder soup

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Sample	5	18.3500	3.6700	17.41	<.001
Panelist	9	5.4167	0.6019	2.86	0.009
Residual	45	9.4833	0.2107		
Total	59	33.2500			

Color Plates

P1: Sun drying of tomato

P2: Preparation for oven drying of tomato

P3: Determination of absorbance

P4: Sensory evaluation