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# Pretreatments, Dehydration Methods and Packaging Materials: Effects on the Nutritional Quality of Tomato Powder- a review

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## Abstract

Pretreatments and drying are commonly used before drying tomatoes to inactivate enzymes, improve the drying process, and improve the quality of dried tomato powders. In this review, the effects of different pretreatments (osmotic solutions), dehydration methods and packaging materials on quality attributes of tomato powder were summarized. These include pretreatments and osmotic agent solution (potassium metabisulfite, calcium chloride, sodium metabisulphite, ascorbic acid, citric acid, sodium chloride and sodium benzoate), thermal blanching (steam blanching and hot water) and non-thermal processes like freezing, sulfuring, etc. and drying methods (oven, sun and indirect solar dryer). The tomato powders were dried to preserve, store, and transport them. Drying implies not only physical changes, which the consumer can easily detect through visual inspection, but also chemical modifications. These are responsible for alterations in color, flavor and nutritional value, which compromise the overall quality of the final tomato powder. Maximum lycopene, vitamin A and C contents were found in freeze dried and direct sundried than samples dried using other methods in low drying temperature. Freeze driers showed in keeping the nutritional quality of tomato powder with a combination of different pretreatments. Different pretreatments including osmotic agent solutions have their own merits and demerits for the final tomato powder. To overcome the drawbacks of nutritional quality, non-thermal pretreatment categories may be a better alternative to thermal blanching, and more fundamental research is required for better design and scale-up.

**Keywords:** Drying methods; pretreatments; nutritional quality and tomato powder

## Introduction

Tomato (*Lycopersicun esculentum L.*) is the family Solanaceae. After carrots, lettuce, and onions, tomatoes are the world 4th most popular fresh vegetable. The production of tomato is growing dramatically in the world as like its consumption. According to the data provided by [1] world has produced 182,301,395 tons tomatoes in 2017. To achieve this production, almost 5 million hectares were used. However, China, India and the USA are the top most countries dominating in the production of tomatoes. Tomato is considered as one of the most important vegetables produced in commercial agriculture because of income generated from export. Moreover, tomatoes contribute to a healthy, well-balanced diet and is rich in carotene, vitamins B, ascorbic acid (vitamins C) and other nutrients that are valuable for human growth and health.

Domestic production of tomato concentrate in Ethiopia offers attractive investment opportunities, with the existing producers unable to meet the ever-growing local demand. Urban population growth in Ethiopia is about 4% while GDP has been growing by more than 7% per annum for the last few years. Ethiopia's tomato processing sector represents untapped market potential for export to regional, European and Middle Eastern Markets. Regionally, tomato is one of the commodities with the most potential, especially as tomato concentrate is the most commonly-used ingredient in African cooking, Europe is facing change in the tomato industry with decoupling of subsidies in European countries, resulting in increased costs for domestic production of tomatoes. Europe's are number one importer of tomato concentrate, Italy, imports the majority from the USA, Spain and China. Ethiopia has advantage over the USA and China due to its geographic proximity, availability of land and low labor costs. UAE import $USD 41.6m worth of processed tomato, of which $USD17.9m is sourced from China alone. This is almost double the value of Ethiopia's export of raw tomatoes. There is potential for Ethiopia to capture some of this market share.

Tomato is highly perishable in its natural state after harvest due to its high moisture content and high rate of metabolic

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activities; hence, it is prone to high postharvest losses. Fresh tomatoes difficult to preserve due to their high moisture content leading to wastages and losses during harvesting and storage especially in sub-Saharan Africa. Losses in tomato productions are also accrued to poor postharvest handling practices. Therefore, the prevention of these losses and wastage is paramount especially in the developing countries like Ethiopia whose populace are all year-round heavy tomato consumers and there is subsequent imbalance in demand and supply at the harvesting off-seasons. The term drying usually refers to the operation by which the moisture present in a material evaporates because of heat and matter exchange between the product and the working medium. Drying is one of the most common preservation methods for extending the shelf life of tomatoes by reducing the water content to a level so as to prevent the growth and reproduction of microorganisms and to inactivate many of the moisture-mediated deteriorative reactions [2]. Tomatoes are usually subjected to physical or chemical pretreatment before drying to shorten the drying time, reduce the energy consumption and preserve the quality of products [3]. The drying rate and quality of products do largely relate to the pretreatments carried out before drying [4].

The most antique and traditional consists of placing the agricultural products on beaten earth, floor covering or floor exposed to the sun. Although sun energy-based methods present economic advantages, being for this reason largely used in tropical countries, the product quality parameters and food safety-related issues become often difficult to monitor and control. Osmotic, convective, fluidized bed, ohmic, microwave, vacuum or freeze-drying techniques have been applied for tomatoes dehydration. The foremost used drying techniques promote water vaporization from a food product by using heat through conduction, convection and radiation, being the formed vapor subsequently removed through forced air.

The demand for dried tomato is increasing rapidly both in domestic and international market with major portion being used for preparation of convenience food. And the reason of preparing dehydrated tomato powder also concerns the ease of transportation handling and storage without extra care. If powder can be prepared then it will help to reduce wastage, price and increase the availability of powdered tomato throughout the year [5]. The dehydrated tomato powder can also be used as substitute of raw tomato to develop new food recipe. Quality of dehydrated tomato powder was influenced by storage condition including packaging material during storage period, and subsequent storage of product in metalized poly-ester bags is suggested to protect product against light, oxygen, and humidity and retard the quality changes of tomato powder during storage period [6].

The drying process has also a crucial role in the chemical composition and nutritional value of final dried tomatoes. Chemical modifications subjacent to drying include Maillard reactions, vitamins degradation, lipids oxidation, color changes and flavor losses. To prevent or minimize these alterations and maintain as high as possible the nutritional similarities with the fresh product, the tomatoes are often submitted to treatments before the drying process. Tomatoes are commonly subjected to various chemical and/or physical pretreatments prior to thermal drying to shorten the drying time, reduce the energy consumption and preserve the quality of products. In this review paper the authors try to provides an overview of the effects of different pre-treatments, dehydration methods and storage materials and conditions on the physicochemical, sensory and storage stability of tomato powder.

## Tomato productions

The tomato is warm season crop. Temperatures of 20-25 °C are considered ideal for tomato cultivation, and tomatoes develop an excellent quality red color at temperatures of 21-24 °C. Due to intense heat (temperature above 43 °C), the plants get burnt, and flowers and small fruits also fall, whereas less than 13°C and greater than 35 °C decreases the fruits and the red color productionatio.The tomato plant is a vine that grows approximately 180 cm above the ground. The plant is a dicot that grows in the form of a series of branching stems. The terminal bud is responsible for the actual growth. The vines are covered with short, fine hairs that turn into roots on coming in contact with the ground. Most of the plants have compound leaves while some have simple ones. The fruit of the plant is classified as a berry and is the part that is consumed. The fruit bears hollow spaces that are laden with seeds and moisture.

Tomato has been consumed since the ancient times. The Aztecs of South America used the fruit in their dishes as per evidence. By about 500 BC, tomato was already being cultivated in southern Mexico and a few other areas. The tomato plant was probably first introduced to Europe by the Spanish conquistador Hernan Cortes. Soon, it became a popularly cultivated crop across Europe and was also introduced to other parts of the world by European explorers and colonists.

Tomato is grown practically in every country of the world in outdoor fields, greenhouses, and net houses. China, India, the United States, Turkey, Egypt, Iran, Italy, Spain, and Brazil are the world's leading tomato producers. China, the leading producer of tomatoes, accounted for 31% of the total production. In China, tomatoes are widely cultivated in open fields or plastic tunnels. In 2014, tomatoes accounted for 23% of total fresh vegetable output in the European Union. Of this, more than half was produced in Spain, Italy, and Poland. It covers approximately 4.73 million hectares and produces 163.96 million tons globally (FAO, 2016). After potatoes and onions, it is the world's third largest vegetable crop. Tomatoes are a vital vegetable crop in terms of both income and nutrition. In its fruit contain vitamins like A and C and antioxidant in abundance quantity. Tomato demand remains nearly constant throughout the year due to the unique properties contained in its fruit.

## Nutritional and health importance of tomato

Tomatoes contain numerous phytochemicals, the most well-known of which is lycopene. In addition, other carotenoids (e.g., β-carotene, phytoene, phytofluene), phenolics (e.g., coumaric and chlorogenic acids, quercetin, rutin and naringenin), moderate amounts of the antioxidant vitamins and trace elements selenium and zinc, some sulfur compounds and other individual substances are present (Table 1). Carotenoids are found in a wide variety of vegetables and fruits, but lycopene is more concentrated in tomatoes, guava, rosehip, watermelon, and pink grapefruit. Lycopene is a carotenoid pigment that is primarily responsible for the deep red color of ripe tomato fruits and tomato products. It is absorbed in the human body and is one of the most common circulating carotenoids. Other tomato carotenoids may also be bioavailable for our body. Many factors influence the bioavailability of lycopene and other carotenoids, including the nature of the food matrix, thermal processing, and the presence of fat. Of the phenolics, naringenin from tomatoes has been shown to be bioavailable, but data on other phenolics are lacking. Tomatoes are high in vitamins such as vitamin C and vitamin A equivalents (in the form of -carotene), as well as vitamin E, folic acid, potassium, and other trace elements.

***Table 1:*** *Major dietary components per 100 g red raw tomato.*

| Nutrient | USA | Other |
|---|---|---|
| Vitamin A | 31 μg RAE; 623 IU | 1000 IU |
| Vitamin B1 (μg) | 59 | 60 |
| Vitamin B2 (μg) | 48 | 40 |
| Folic Acid (μg) | 15 | 28 |
| Vitamin C (mg) | 19.1 | 22 |
| Vitamin E (mg) | 0.38 | 1.2 |
| Potassium (mg) | 222 | 290 |
| Calcium (mg) | 5 | 21 |
| Magnesium (mg) | 11 | 14 |

*Note: USDA National Nutrient Database for standard reference*

Globally, considerable research is being conducted into the health benefits of lycopene. It is a strong antioxidant; antioxidants neutralize free radicals, which can harm cell components (e.g., DNA, protein, lipids). It could also have a variety of other modes of action. The strongest scientific evidence is for a role of lycopene in reducing the incidence of prostate cancer. Lycopene may also aid in the prevention of other cancers and cardiovascular diseases, as well as play a role in eye health. There has been less study of the role of other tomato phytochemicals. β- Carotene is an important precursor of vitamin A and, like lycopene, may play a role in cancer prevention. Flavonoids also have anti-allergic, anti-inflammatory, antimicrobial, and anti-cancer properties. The yellow jelly surrounding tomato seeds may help prevent heart attacks, strokes, and blood vessel problems by preventing platelet aggregation.

## Osmotic dehydration of tomato

Concerns about the prevention or minimization of tomato quality degradation during the drying process have received increased attention in recent years. Tomatoes contain a diverse range of phytochemicals, including vitamins, minerals, antioxidants, pigments, and other bioactive compounds that are thought to protect against cardiovascular disease, cancer, and age-related degenerative changes. However, some nutrients are degraded by heat during drying, affecting the quality and acceptance of the final tomato powder product [7]. To improve the retention of these important antioxidant compounds, pretreatments such as osmotic dehydration prior to drying are desired.

Osmotic dehydration involves the immersion of material in hypertonic solution (mainly sugar or salt) for several hours. It has been used as a pre-treatment for tomato drying because it reduces drying time, resulting in cost savings and improved sensorial properties of the final product. During osmotic pretreatment, the plant's cellular structure acts as a semi-permeable membrane, allowing for countercurrent mass transfer: the solute flows into the products while moisture is transferred from the interior to the hypertonic solution [8]. The osmotic pressure difference between the food material and the hypertonic solution is the driving force of water removal from the food material to the osmotic solution [9]. Osmotic dehydration of foods is the partial removal of water caused by the pressure created when the product comes into contact with a hypertonic solution of solutes (sugar, salt, or both), resulting in a decrease in food water activity. (**Figure 1**). Osmotic dehydration removes 10%–70% of the water from fruits and vegetables at room temperature without causing phase changes, providing an alternative method for reducing drying time and mitigating the thermal effects of drying on bioactive compounds [8,10].

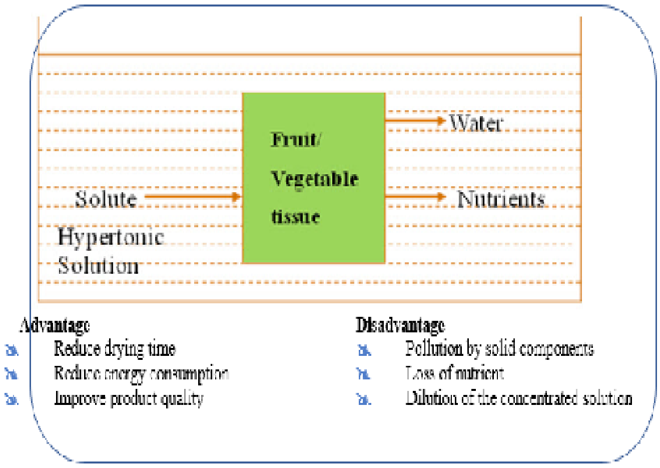


***Figure 1:*** *Mass transfer across a fruit tissue during osmotic dehydration.*

Variables such as variety, maturity, pretreatments, osmotic agent temperature and concentration, geometry of the material, agitation, food pieces to osmotic solution ratio, additives, physicochemical properties, and structure all influence mass transfer kinetics during osmotic dehydration [11].

The concentration of osmotic agent plays an important role in osmotic dehydration. Increased solution concentration resulted in the increase in the osmotic pressure gradients and higher water loss. The increase in solute concentrations during extended osmotic treatment causes an increase in water loss and solid gain rates [39]. The solution to sample ratio is another important parameter which affects osmosis. The change in ratio affects the mass transfer during osmosis up to a certain limit. Solution to sample ratio should be chosen wisely so that the driving force for the removal of the moisture exists till the end of the process. The driving force decreased to release of water when osmotic solutions become dilute. As dehydration progresses, the osmotic solution becomes increasingly dilute, acting as a driving force for further water drop release [36]. Because of the increase in cell permeability with respect to process temperature, temperature is the most important variable influencing the kinetics of mass transfer during osmotic dehydration [40]. The effect of temperature is more pronounced between 30 to 600C for fruits and vegetables on the kinetic rate of moisture loss without affecting solid gain.

Initially, the water loss and solid gain increases temperature increases up to 500C depending upon the fruit and variety and later on falls sharply becoming nearly constant at 600C which indicated negligible increase in the rate of sucrose diffusion above 600C. Since water loss is higher at higher temperature, the osmotic equilibrium is achieved by flow of water from the cell rather than by solid diffusion.

The duration of osmotic dehydration also affects the dehydration process of fruits and vegetable drying processes. Increased immersion time results in greater moisture loss during osmotic dehydration [41]. In general, weight loss increases with treatment duration, but the rate at which it occurs decreases. The treatment time can be selected in such a way that the amount of water removal is maximum with no appreciable uptake of solids. The sample weight to solution ratio is critical during the osmotic treatment of fruits and vegetables, and it influences mass transfer kinetics to some extent. Many researchers worked on the influence of different sample to solution ratio (1:1 to 1:5) on mass transfer kinetics. A higher ratio of 1:10 to 1:60 was used to avoid medium dilution caused by water gain and solute loss. As a result, the osmotic drying force decreases [38].

***Table 2:*** *Most common pretreatment (osmotic agents) and their main effects in osmotic dehydration process on tomato powder.*

| Osmotic agents | Remarks | Reference |
|---|---|---|
| Salt (NaCl) | It a capacity to hinders oxidative and non-enzymatic browning. It provides the driving force for mass transfer and hinders the surface shrinkage. It has limited use in fruit dehydration due to its salty taste. | [43] |
| Sucrose | Reduces browning by preventing oxygen entry, provides pigment stability, and aids in the retention of volatile compounds during the drying of osmotically treated materials. It proved to be best, based on convenience, effectiveness and flavor. It tends to crystallize upon drying. Sweetness hinders its application in vegetable processing. | [44] |
| Potassium Metabisulphite | Used to protect carotenoid pigments and color retention during dehydration, and its effect is more well-known during processing, but a clear explanation of the mechanism by which calcium serves to retard non-enzymatic browning in tomato dehydration cannot be provided. | [47] |
| Calcium chloride | Calcium may be acting in some way to block the amino group, preventing it from participating in the browning reaction. Calcium is also thought to be capable of forming chelating compounds with organic substances with an alpha amino carboxylic acid structure. Under these circumstances, it would be reasonable to expect that calcium treatment may be applicable to control non-enzymatic browning. | [14] |
| Sodium Metabisulphite | In the food industry, metabisulphite agents are widely used to inhibit non-enzymatic and enzymatic browning reactions during fruit preparation, drying, and subsequent storage of dehydrated fruit. | Ling et al., 2005; Kadam et al., 2008 |
| Week Acids | Citric acid can change tissue properties by influencing pectin gelation, hydrolysis, and depolymerization, which increases the rate of water removal and softens the material tissue, lowering the hardness of dried products. | [49] |
| Sodium Benzoate | When compared to calcium chloride and sodium metabisulphite, sodium benzoate retained more nutrients, maintained color, and reduced microbial load in tomato powder. | [58] |
| Sugar | Sugars are utilized in two ways as pre-drying agents. The first is characterized by low concentrations and quick treatment times. There is no substantial mass transfer between the tissue and the surrounding fluid in this mode. The second mechanism uses sugars at high concentrations, resulting in significant dewatering and impregnation of the tissue, as well as an induced osmotic pressure difference. | [16] |

Because the use of highly concentrated viscous sugar solutions causes major problems such as floating food pieces hindering contact between food material and the osmotic solution, causing a reduction in mass transfer rates, agitation or stirring can be used to enhance mass transfer during osmotic dehydration [39]. Different chemical treatments (Osmotic dehydration methods) have been applied before the drying process of tomato, in order to minimize nutrient losses and thus improve the nutritional quality of dried tomato powder (**Table 2**). The most popular/repeated pretreatment chemicals (osmotic solutions) used for tomato by different researches are: Potassium Metabisulphite (KMS), Calcium chloride (CaCl2), Sodium metabisulphite (SMS), Ascorbic Acid (C6H8O6), Citric Acid (C6H8O7), Sodium chloride (NaCl) and Sodium Benzoate, are individually or by mixing them in different ratio example ascorbic acid with citric acid, KMS with CaCl2 and with different concentrations etc.

## Effects of different pretreatments on tomato powder quality

To minimize adverse changes during drying and subsequent storage, tomatoes were pre-treated with chemicals before drying. Some quality attributes of tomato were affected by pretreatment, including total solids, lycopene, dehydration ratio, rehydration ratio, and color. Here below (**Table 3**) tried to show the effects of different chemical pretreatments on the quality of tomato powder.

***Table 3:*** *Effects of pretreatments on the quality of tomato powder (color, physical and nutritional composition).*

| Processing conditions | Pretreatments (osmotic agents) | Main conclusion | Reference |
|---|---|---|---|
| Dried in hot-air and freeze driers | 0.5% ascorbic acid + 0.5% citric acid | * Ascorbic acid, lycopene, and -carotene levels increased | [11] |
| | 1% sodium metabisulphite | *Total sugar, reducing sugar, rehydration ratio, TSS, and lightness (L*), redness (a*), and yellowness (b*) values were higher.<br>*Pretreatments with ascorbic acid, citric acid, and sodium metabisulphite, combined with freeze-drying, produced tomato powder with higher chemical constituent stability than non-pretreated and hot-air-dried methods. | |

| | | | |
|---|---|---|---|
| Oven drying, Solar drying and microwave | Dipped into 0.2% sodium meta bisulfite solution for 1 min | *The tomato slices dried by oven air had the highest phenolic content, -carotene, and total flavonoids. | [12] |
| | Dipped into 1% Calcium chloride solution for 1 min | *Showed lowest dehydration ratio as compared to sodium metabisulphite | |
| Approximately 1 hr of pretreatment and exposed to direct sunlight | steam blanching (100 °C) at atmospheric pressure for 20, 40, and 60 s | *Decreasing the final sulfur dioxide content in tomatoes from an average of 2444 ppm to 1829, 1675, and 1587 ppm, respectively.<br>Both the color and rehydration ratio were not improved. | [13] |
| | brine blanching, and sulfuring | * The salt content of the tomato has also increased. The use of high temperatures (greater than 60 °C) promotes salt uptake by modifying tissue characteristics. | |
| | Salt dipping (0%, 10%, 15%, 20%) | *Concentration of the dipping solution had a significant effect on yeast count and rehydration ratio.<br>*Had lower rehydration ratios and did not improve the color of tomato powder | |
| | Sodium metabisulfite dipping (DSM) (0%, 4%, 6%, 8%) | * The dipping solution concentration had a significant effect on sulfur dioxide content, color, rehydration ratio, and yeast count. The color value decreased as concentration increased.<br>*Generally (DSM) offer a safer, more convenient, and more controllable method for producing high-quality tomato powder. | |
| Solar and Continuous conveyor drier | Dipping in 1g/100g $CaCl_2$ | *Slightly better color was observed.<br>*Showed independent significant effect to prevent or reduce the rate of browning followed by KMS. | [14] |
| | Dipping in Potassium Metabisulphite (KMS) 0.2 g/100g | *Showed slightly more acidity as compared to the control.<br>*Had significant protective effect on lycopene degradation. | |
| | Dipping in 1 g/100g CaCl2 + 0.2 g/100g KMS | * A higher sugar content resulted in the best rehydration ratio properties and a higher value | |
| | Dipping in 7g/100g NaCl | *Showed slightly more acidity as compared to the control and slightly better color was observed and lowest dehydration ratio as compared to other treatments | |
| Solar and hot air oven dehydration | $CaCl_2$ (1g/100g), KMS (0.2g/100g), $CaCl_2$ + KMS) and NaCl (7g/100g) | *$CaCl_2$ + KMS of both dryers with NaCl of solar and $CaCl_2$ of tray dryer showed slightly more acidity.<br>*KMS had the least Vitamin C retention as compared with others pre-treatments.<br>* In general, KMS treated dryers were found to have a greater protective effect on the quality of dehydrated tomatoes during the dehydration process. | [15] |
| Cabinet dryer | Dipping in 0.2% KMS (1:1 w/w), 1% $CaCl_2$ (1:1 w/w) and 0.2% KMS+1% $CaCl_2$ (1:1w/w) | *$CaCl_2$ increased water removal rate than the other pretreatment.<br>*The combination of KMS and $CaCl_2$ achieved the highest yield of tomato powder and total sugar content.<br>* There was no significant difference in texture, flavor, or overall acceptability between control and treated samples, but there was a significant difference in color. | [44] |
| Oven dried | Sodium Meta-bisulfate (0.5% N.M) and 0.5% w/v ((0.5% C.C) calcium chloride | *Lycopene, total phenolic compounds and β carotene was best retained by drying at 0.5% N.M.<br>*The degree of darkening was least in the dried samples as follows: 0.5% N.M < 0.5% C.C < control | [17] |
| Hot oven dryer | Dipping of 0.5% SMS, 0.1%acetic acid + 0.1% citric acid and distilled water for 10 minutes. | * SMS recorded the least lycopene degradation, highest dehydration ratio and also facilitated the drying of tomato better than other treatments. All the pretreated tomato samples show good visual color and exhibited a desirable read color. | [17] |

| | | | |
|---|---|---|---|
| Twin layer solar tunnel dryer | 0.5% calcium chloride ($CaCl_2$), 0.5% ascorbic acid ($C_6H_8O_6$), 0.5% citric acid ($C_6H_8O_7$), and 0.5% sodium chloride (NaCl) | * It was discovered that dried tomato slices pretreated with 0.5 percent ascorbic acid retained the most vitamin C and total phenolic content while maintaining a high sugar/acid ratio.<br>*Pretreating dried tomato slices with 0.5 percent sodium chloride resulted in better lycopene retention and faster drying, while pretreating tomatoes with 0.5 percent citric acid resulted in better color values than the other treatments.<br>*All the pretreated tomato samples had a good overall color value than the control, and the degree of darkening was least in the pretreated samples as follows: citric acid < sodium chloride < ascorbic acid < calcium chloride < control. | [18] |
| Oven drying process for tomato quarters | Dipping in 250, 500, 1000 ppm ascorbic acid, 0.5, 2, 4% $CaCl_2$, freezing at –18ºC for 15 days, 500 ppm ascorbic acid solution for 10 min then freezing at –18ºC for 15 days and 2% $CaCl_2$ solution for 10 min then freezing at –18ºC for 15 days | *Pre-drying treatments with $CaCl_2$ and ascorbic acid produced the best results in terms of lycopene, total phenol contents, ascorbic acid retention, color parameters, and dried tomato rehydration ratio. | [19] |
| Hot air-drying vacuum drying, freeze drying and sun drying | dipping into 1% ascorbic acid + 1 % citric acid (EPSA) and 2 % sodium metabisulfite (EPSM) after 2% ethyl oleat + 4% potassium carbonate solution | *EPSA pretreatment increased the lycopene amount of dry tomato at the high temperature drying applications. In respect of color parameters, EPSM pretreatments the better results of L*, a* and b* values.<br>* In general, hot air-drying method after EPSA pretreatment and no difference in color parameters of tomato samples pretreated EPSA and EPSM in terms of a* values. | [48] |
| Oven drying | NaCl 5%, NaCl 10%, NaCl 5% + sucrose 10%, NaCl 10% + sucrose 5%, sucrose 5%, sucrose 10% (w/v) | * Except for the sucrose solutions, which did not change the pH of the tomatoes, there was an increase in soluble solids, titratable acidity, and a reduction in pH.<br>* Dehydration with 5% sucrose solution, followed by 10% sucrose and 5% NaCl solutions, resulted in higher lycopene retention in dried tomatoes. | [21] |
| Hot water blanching for 3-5 minutes and then dried by Sun dry | Dipping in 2% sodium benzoate, 2% calcium chloride and 0.25% sodium metabisulphite | *When compared to pretreatment with calcium chloride and sodium metabisulphite, 2% sodium benzoate improved the protein, ash, fiber, total soluble solids, lycopene, vitamin C, and color of tomato powder.<br>*The 0.25 percent sodium metabisulphite treated powder retained the most carbohydrate, but the fat content was highest in the untreated powder. | [24] |
| Mechanical dryer | Sugar syrup 40°Bx at 1 h Osmotic time, 40°Bx at 2 h osmotic time, 60ºBx at 1h osmotic time, 60°Bx at 2 h osmotic time | * When compared to samples pre-treated with 40 0Bx, those treated with 60 0Bx had higher nutritional contents and color.<br>* The nutritional content and color of samples treated for 2 hours osmotic time were superior to those treated for 1 hour.<br>*Drying of samples pre-treated with $60^0$Bx for 2 hrs at a drying temperature of $50^0$C gave the best color of dried tomato. | [45] |
| Sun drying | Sugar syrup first 30°Brix, 50°Brix and 60°Brix, second mixture of CaCl2 (500ppm) in sugar syrup 30°Brix, 50°Brix and 60°Brix. And thirdly 10% NaCl in sugar syrup 50°Brix for 6 and 8 hrs | * The results suggested that tomato slices could be dried by osmotic dehydration with (50 Brix sucrose with NaCl 10%) followed by sun drying. | [46] |

## Dehydration methods

Drying is the oldest method of food preservation. Throughout history, the sun, wind, and a smoldering fire have all been used to remove water from fruits and vegetables. Food dehydration is defined as the process of removing water from food by circulating hot air through it, preventing the growth of enzymes and bacteria. Although food preservation is the primary reason for dehydration, dehydrating fruits and vegetables reduces the cost of packaging, storing, and transporting the final product by reducing both its weight and volume. Given the improvement in dehydrated food quality, as well as the increased emphasis on instant and convenience foods, the potential of dehydrated fruits and vegetables is greater than ever. Dried fruits and vegetables are high in fiber and carbohydrates and low in fat, making them healthy food choices. Because dried fruit contains more carbohydrates than fresh fruit, serving sizes are typically smaller.

Dried or dehydrated fruits and vegetables can be produced by a variety of processes. These processes differ primarily by the type of drying method used, which depends on the type of food and the type of characteristics of the final product. In general, dried or dehydrated fruits and vegetables go through the following stages: pre-drying treatments like size selection, peeling, and color preservation; drying or dehydration using natural or artificial methods; and post-dehydration treatments like sweating, inspection, and packaging.

Several drying methods are commercially available and the selection of the optimal method is determined by quality requirements, raw material characteristics, and economic factors. There are three types of drying processes: sun and solar drying; atmospheric dehydration, which includes both stationary or batch processes (kiln, tower, and cabinet driers) and continuous processes (tunnel, continuous belt, belt-trough, fluidized-bed, explosion puffing, foam-mat, spray, drum, and microwave-heated driers); and sub atmospheric dehydration (vacuum shelf, vacuum belt, vacuum drum, and freeze driers).

Sun drying refers to foods that are dried under the direct sun. Sun drying is the traditional method of drying food because it makes use of direct solar radiation as well as the natural movement of air, ambient air temperature, and relative humidity. This process is slow and requires continuous care, the food must be protected from insects, covered at night and it cannot be used in rainy periods. As a result of the long drying time and the inability to control the process's conditions and parameters, the final product's quality is poor. However, because it is the cheapest drying method and requires no special equipment or energy consumption, it is appropriate for developing countries with suitable weather for the process. The disadvantages include total reliance on the elements and moisture levels no lower than 15 to 20%. Solar drying utilizes black-painted trays, solar trays, collectors, and mirrors to increase solar energy and accelerate drying.

Atmospheric forced-air driers artificially dry fruits and vegetables by passing heated air with controlled relative humidity over or through the food to be dried, and are the most widely used method of fruit and vegetable dehydration. Sub atmospheric (or vacuum) dehydration occurs at low air pressures and includes vacuum shelf, vacuum drum, vacuum belt, and freeze driers. The main purpose of vacuum drying in ambient conditions is to eliminate moisture at temperatures below the boiling point. Vacuum driers are used for drying raw materials that may deteriorate as a consequence of oxidation or may be chemically changed as a result of exposure to air at extreme temperatures due to their high installation and operating expenses. High taste retention, maximum nutritional value retention, minimal damage to product texture and structure, little change in product form and color, and a finished product with an open structure that permits fast and thorough rehydration are all advantages of freeze drying. High capital investment, high processing costs, and the requirement for special packaging to prevent oxidation and moisture gain in the completed product are all disadvantages.

***Table 4:*** *Effects of different drying methods on the quality of tomato powder.*

| Processing conditions | Drying methods | Main conclusion | Reference |
|---|---|---|---|
| Dipped into DMS, Calcium chloride solution and steamed under atmospheric pressure, then tomato slices were drained | Hot air drying (dried at 55°C for 8 hours), Solar drying (dried at 40°C) and Microwave /convection dryer | * Solar drying had a detrimental influence on all of the features of tomato slices, and the color was dark.<br>* Both drying procedures boosted total phenolic compounds, total flavonoids, and lycopene while dramatically lowering ascorbic acid, according to the findings. | [12] |
| pilot-plant tunnel air dryer | Drying at various temperatures in the range of 50–90$^0$C | * The drying process was carried out at a lower air temperature, so that the temperature inside the fruit did not exceed the permitted limit of 55°C. | [24] |
| Dipping in ascorbic acid + citric acid, and sodium metabisulphite, after pre-drying treatment of 10 min | freeze-drying (at −20$^0$C for 24 hrs and hot-air-drying (60$^0$C) for 1hr | *It was observed that freeze-drying showed significantly higher ash, total sugar, reducing sugar, ascorbic acid, lycopene, β- carotene, lightness (L*), redness (a*), and yellowness (b*) values than hot-air-dried samples.<br>*TSS, pH, total sugar, reducing sugar, rehydration ratio, ascorbic acid, -carotene, lycopene, and color parameters (L*, a, *, and b*) of freeze-dried and hot-air dried powdered samples all showed a decreasing trend, according to the results. | [25] |
| | Oven drying, sun drying and shade drying | * After storage, shade dried and oven dried samples were found to retain the majority of the nutritious properties of tomato powder.<br>* On the other hand, oven and sun drying were faster than the shade drying method. | [26] |
| Dipping in potassium metabisulphite and blanched prior to sulphiting for 30 seconds | Open sun drying, solar drier drying, hot air drying (60 °C at air velocity of 0.13 m/sec) and osmotic dehydration | * Osmotic dehydration produced better final products that retained natural color and nutrients while using a simple procedure that consumed minimal energy.<br>*It was observed that samples dried osmotically scored highest for color and texture. | [27] |

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| Dipping into ascorbic acid + citric acid (EPSA) and dipping into sodium metabisulfite (EPSM) after ethyl oleat + potassium carbonate | Hot air drying (at 65, 75 and $85^0$C drying temperatures and 1.5 and 2.5 m/s air velocity), vacuum drying, freeze drying and sun drying | *Maximum lycopene content was found in freeze dried and sundried followed. * Due to the high cost of freeze drying, a hot air-drying approach (at 65°C drying air temperature and 1.5 m/s drying air velocity) following EPSA pretreatment can be offered as a drying method for tomato. * In addition to the extended drying time, all color values for vacuum drying procedures were found to be lower than others. | [54, 57] |
| | Freeze-dried (-$50^0$C, 5pa, for 24h ) and hot-air-dried (at $80^0$C for 2hrs and then shifted to $60^0$C for 6hrs | *The amount of lycopene was highest in of tomatoes with hot air dryer. * Methanolic extract (ME) from freeze-dried tomato exhibited the maximum reducing power, while butylated hydroxy anisole (BHA) and a-tocopherol had the lowest. * MEs from hat air dryer tomatoes had the maximum ferrous ion chelating power, while BHA and a-tocopherol had no ferrous ion chelating power. | |
| Dipping in Potassium metabisulfite (KMS) solution and ascorbic acid solution | Solar and sun-dryer | *Sulfur dioxide content of 740 mg/Kg d.w. recorded for solar dried tomato pretreated with KMS. * KMS pre-treated solar dried tomato powder particles were more convex and circular in shape | [56] |
| | Direct sunlight, solar cabinet dryer, and electric oven set at $60^0$C temperature and 1.0m/s air speed | *Samples dried under direct sunlight retained the best brightness, redness and yellowness. * More vitamins A and C were found to be retained in solar dried samples than in samples dried by other methods. * Drying resulted in a considerable rise in protein content and a significant loss of lycopene.. | [34] |
| Dipped in boiling water for 5 min and plunged into cold water | Oven drying, sun drying and shade | *The study shows that oven drying is preferably method. *Oven and sun drying were faster than the shade drying method | [26] |
| Tomato washed with chlorine at 20 ppm, and cut into 10-mm thick slices and then blanched for 1 min at 90°C | Sun drying, solar drying and oven drying at 50, 55 and 60°C | * In terms of lycopene content, ash content, and ascorbic acid retention, solar and sun-dried samples outperformed oven-dried ones. * When compared to solar and sun-dried samples, tomato dried in an oven at 60°C had the lowest microbial counts and was higher in carotenoids and total solids. | [55] |
| Tomato pulp (brand KARAMBI, Brazil) was blended with 10DE malt dextrin (10% dm) and SiO2 (1% dm) | Spray drying, feed flow rate (127-276 g/min), air inlet temperature (200-$220^0$C) and the atomization speed (25,000-35,000 rpm) | * Moisture content, solubility, wettability consistency, and color were the responses studied, although only the color parameter was significantly changed by the parameters. * All the samples became significantly darker and less red with an increase of the variables under study. A low atomization speed (25,000 rpm) and lower inlet air temperature ($220^0$C) produced the powders with a higher color index (a/b) and less darkening. | [35] |
| Ripe tomatoes were blanched at 85˚C for 1 minutes followed by striping the skin and cut into slices | Sun drying (28- 34.8°C), Oven drying($60^0$C), Vacuum drying ($65^0$C), Spray drying | *Spray type of driers that can remove moisture rapidly from drying chambers. * It was discovered that drying tomatoes in a vacuum dryer provided some nutritional benefits, but that the drying period was relatively long. | [36] |

## Packaging, storage stability and sensory quality of tomato powder

Processing and preservation refer to a collection of physical, chemical, and biological procedures used to extend the shelf life of food while preserving its color, texture, flavor, and, most importantly, nutritional value. Food preservation is achieved by destroying enzymes and microorganisms using heat (blanching, pasteurization), or preventing their action by removal of water, increasing acidity or using low temperatures. During tomato season, enormous amounts of tomatoes are condensed into tomato paste, which is then reconstituted into goods like tomato sauce, ketchup, and other value-added items [50]. Drying is also another way of extending the post-harvest shelf life of tomato. Pizza, diverse veggies, and spicy recipes all use dried tomato products as significant ingredients [51].

Color fading and acceptability loss are common in dehydrated tomato products, owing to lycopene isomerization and oxidation. Drying processes, pre-drying treatments, and storage conditions, including packaging material, all influenced lycopene levels in dried tomato powder. Dehydrated and powdered tomatoes, in general, have low lycopene stability unless adequately processed, rapidly packed, and stored in optimal storage conditions. Various studies showed that significant oxidative damage can occur during storage of dried tomatoes. The general result of shelf-life studies is that dried tomatoes can experience significant lycopene degradation; degradation reactions are accelerated by high temperature, oxygen, and light exposure, as well as low moisture content and water activity (aw).

Dried vacuum-packed tomatoes present the following major changes during their shelf life: a) Vitamin degradation; which occurs through a variety of mechanisms, such as hydrolysis under the action of light, heat or acid; direct oxidation by oxygen or by participation in other oxygen reduction reactions. b) Changes in colors; which occur due to a large number of different reactions, especially oxidation of carotenoids. c) Sensory changes; In tomato-based products, color is one of the main quality parameters. The darkening of the product to a reddish-brown is due to the oxidation of carotenoid pigments and the formation of dark compounds, in addition to the browning effect of the Maillard reaction. These changes are dependent on storage temperature, oxygen availability, packaging type, pH, and product activity.

***Table 5***

| **Process Conditions** | | **Packaging Materials** | **Storage Stability** | **Sensory Quality** | **Reference** |
|---|---|---|---|---|---|
| **Pretreatments** | **Dryers Methods** | | | | |
| The tomato was washed with sterile, distilled water to remove dirt and soils, cut into slices with thickness of 10 mm | Dried at 60, 65 and 70$^0$C in oven | *Polyethylene-packaged dried tomato powders stored at ambient temperature (25 ± 2°C) | *The total fungal load and lightness of the two tomato kinds rose at 60°C dried plum tomato powder at all temperatures, but titratable acidity, pH, ascorbic acid, lycopene, redness, and yellowness increased as the storage period increased to 8 weeks. | | [27] |
| Cut into 8mm thickness slices using sharp stainless steel knife | Drying temperature 70 $^0$C, 80$^0$C and 90$^0$C in oven | | | *Dried tomatoes with good physical and sensory properties could be obtained through oven drying at 70$^0$C at 7 hrs of duration. | [28] |
| Dipping in KMS, $CaCl^2$ and NaCl | Dried in oven at 68$^0$C | *Packed in HDPE bag and stored at ambient temperature | * Tomato powder was safe to eat for up to two months when stored at room temperature. | | [29] |
| Ripe tomatoes were subjected to two different blanching temperatures, namely 60$^0$C and 100$^0$C hot water blanching for 1 minute | Sliced tomato dried at 50, 55 and 60$^0$C, using oven flow air dryer | *Polystyrene cups, polyvinylchloride (PVC) trays, pouches made from polypropylene and triple laminated aluminum bags (PE/Al/PET) | * Dried tomato powder wrapped in triple layered Aluminum foil pouches could be stored for six months at 31°C and 65.5% relative humidity without losing quality. | * Drying and powdering at 550°C for 48 hours yielded a product with good physicochemical and organoleptic qualities. | [30] |

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| Tomatoes were washed, diced and heated at 80°C for 20 seconds to inactive the enzymes | Tomato paste consisting 25% solids obtained by vacuum concentration at 50°C was used as a feed to the spray dryer | *Powders were packaged in aluminum foil bags | *Storage temperatures (0, 25, and 37°C) for 5 months • Color parameters (L*, a*, b*), glass transition temperature (Tg) and pH decreased significantly • While 5-Hydroxymethylfurfural (HMF), browning degree (BD) and titratable acid (TA) increased significantly at 25 and 37°C after 5months • Sucrose, fructose and total sugar (TS) exhibited significant reduction only at 37°C. • Free amino acids, L-ascorbic acid and solubility of tomato powder underwent significant reduction and total color change ΔE significantly increased after 5months regardless of storage temperatures | | [31] |
| Soaking tomato in a solution salt (5.85%), and citric acid (6.00%) and sodium metabisulfite and ascorbic acid in the proportion of 100:1,500 mg/l | Forced air drying for 12 hrs and vacuum packing | *Product was vacuum-packed in a coextruded nylon-polyethylene | *Storage at two temperatures: room and at 4°C. • The degradation rate of lycopene is four times higher in the product stored at room temperature than 4°C. • The microbiological quality of vacuum-packed dried tomatoes was maintained over a period of 180 days for tomatoes stored under $4^0$C and 90 days for tomatoes stored at room temperature. | *Dried vacuum-packed tomatoes stored at room temperature presented characteristics desirable to consumers for 90 days. | [31] |
| 1% calcium chloride (CaCl2) and 0.2% potassium metabisulphite (KMS) for 10 minutes | Dried at 60 $^0$C for 26 hours in cabinet drier | * Laminated Aluminum Foil, HDPE, and Medium Density Polyethylene were used in the packaging, which was stored for six months. | *Tomato powder is stored in laminated aluminum foil at room temperature for up to six months to ensure optimal hygienic quality and nutritional content such as protein, fat, crude fiber, ascorbic acid, lycopene, and -carotene. | | [32] |
| (CaCl2, (KMS), (CaCl2 +KMS), and (NaCl) | Solar drier and continuous conveyor (tunnel) drier | *Metalized polyester film and low-density poly ethylene (LDPE) | * The optimal technique was determined to be the subsequent storage of the product in metalized polyester bags. | * Both packaging options provide a 6-month shelf life extension in good condition. | [47] |
| No any pretreatment | Oven dried | *Polyethylene nylon | *Tomato powder can be stored in an airtight polyethylene bag at room temperature for a viable duration of three to six months with maximum conservation of sanitary and nutritious properties without additional pretreatment. | * Moisture, fiber, and ash content increase as storage time increases, but protein, lipid, carbohydrate, and calorie content decreases as storage time increases. | [33] |
| Dipped in boiling water for 5 min and plunged into cold water (blanching) | Oven sun and shade dryings | *Glass jar, plastic container and polythene | * Glass jars or plastic containers might be used to store the processed powder for up to 12 weeks without diminishing its commercial appeal. | * After storage, shade dried and oven dried powder tomato samples were found to preserve the majority of their physical and sensory features. | [34] |

**Dried tomato-based food products and market values**

Tomato juice, tomato puree, tomato ketchup, tomato chutney, tomato sauces, tomato powder, tomato ready-to-eat goods, tomato paste and instant tomato soup are all examples of tomato value-added products. tomato soup is a normally consumed for its smooth texture and provides instant satiety effect. Tomato soups on the market are often made by dry blending of ingredients, with tomato powder and thickening agent making up the majority of the recipe. The rheological characteristics and color features of tomato soup are crucial factors in determining consumer acceptance. Color is frequently determined by the level of lycopene breakdown during processing and binding arrangements with other molecules of soup, whereas flow behaviors are usually affected by ingredients and the temperature of the soup (Barry-Ryan, 2011a, b, 2012). Globally, tomatoes are graded as an essential agricultural crop and an indispensable part of the daily human diet. Despite the fact that tomatoes are consumed fresh, sauces, powder, juice, and ketchup account for 80% of total tomato production. Tomato powder is made by dehydrating fresh tomatoes to create a fine tomato powder. The market for tomato powder has been developing at a modest rate with considerable growth rates over the previous few years, and it is expected to rise significantly in the anticipated period 2021 to 2028. Tomato powder is one of the most prominent ingredients in fast food products. As a tastemaker and flavoring component, tomato powder is becoming more popular in these products. This will help the market expand. The worldwide tomato powder market report offers a comprehensive analysis of the industry. The research provides a thorough examination of key segments, trends, drivers, restraints, the competitive landscape, and other important market aspects.

Tomato powder is the most skillful way of storing dehydrated tomatoes. Tomato powder is a unique substitute for tomato juice; tomato sauce and paste add flavor to recipes. Tomato powder has a wide range of applications in the food and beverage industry due to its rich flavoring quality. The growing desire for healthy and natural ingredients in the food industry has led in items like tomato powder, which contains a high amount of vitamins A, C, and K, becoming more popular as an ingredient in packaged foods. Tomato powder is a dried powder made from tomatoes that is used as an ingredient in a variety of culinary and beverage products. The main element fueling the market growth of tomato powder is the growing demand for natural constituents in food products and drinks. Moreover, the increase of the application markets such as infant nutrition, bakery and confectionery, beverages, and convenience food products is also boosting the market growth. Furthermore, dried tomato powder grants a widespread shelf life as compared to fresh tomatoes; thus, tomato powder is gaining demand as a proper replacement for fresh tomatoes. These factors have positively anticipated propelling the growth of the global tomato powder market.

Bakery and confectionery, dairy and frozen sweets, beverages, newborn nutrition, sweet and savory snacks, curries, gravies, and soups are among the applications for tomato powder. The market is divided into bakery and confectionery, dairy and frozen desserts, beverages, newborn nutrition, sweet and savory snacks, curries, gravies, and soups, and Others, depending on the application. The Curries, gravies and soups segment holds the largest market share during the forecast period. The need for this segment is being fueled by the multiple properties that allow it to be used as a flavoring, coloring, and aromatic element (Verified market research report, 2021).

## Conclusion

Combining various drying technologies with improved pretreatments prior to drying yields the best results in terms of both tomato powder quality and environmental effect. Recent research has focused on the application of pretreatment technologies for drying intensification in order to improve traditional drying performance in terms of product quality and energy savings. As a result, the correct drying processes and mathematical process optimizations can cut energy usage, operational expenses, and produce higher tomato powder quality. Thermal drying methods (direct sun dryer, indirect solar dryer, hot air) have considerable negative effects on shrinkage, color, texture, and final powder quality, but they are cost-effective. Pretreatment is a frequent operation performed on tomato powders before drying to accelerate drying rate, preserve quality, and reduce microbial burden. Diverse pretreatment techniques reviewed here, all of them have merits and demerits. Due to migration from tissue into osmotic solution, osmotic agent dehydration reduced the initial water content, drying time, and energy consumption, but was averse to tomato powder quality (such as loss of minerals, vitamins, and pigments components). Pretreatments that involve dipping tomatoes in various chemicals offer the benefit of speeding up the drying process and maintaining food quality; nevertheless, residues in the food may pose a food safety risk. Future research needs on the effects of diverse pretreatments with different drying methods on the quality of tomato powder.

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