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REVIEW OF RECENT WORK ON TOMATO PROCESSING: A CASE STUDY ON QUALITY OF DRIED PRODUCTS

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ABSTRACT

Tomatoes are a highly popular vegetable known for their nutritional and health benefits. Their high initial moisture content makes them susceptible to postharvest deterioration, necessitating preservation techniques. 80% of global tomato production is processed into value-added products such as ketchup, powders, sauces, and juices. This article reviews recent tomato processing research focusing on drying techniques. Drying techniques, such as solar and open sun, hot air, microwave, heat pump, fluidized bed, infra-red, osmotic dehydration, freeze-drying, and spray-drying, have been developed and used to reduce losses, preserve tomatoes, and maintain their nutritional quality. The quality of the dried tomato products is evaluated based on parameters such as colour, nutritional content, texture, and rehydration ratio. This review discusses the various drying techniques and the influence of processing conditions on the nutritional content and colour of the final product. The review provides valuable insights into the potential of different drying techniques for tomato processing and offers suggestions for improving tomato preservation and processing technologies.

Keywords: tomato processing, drying techniques, Preservation, Nutritional content, Quality evaluation

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INTRODUCTION

Tomatoes (*Lycopersicon esculentum*) are second to potatoes, as the world's most-produced and consumed vegetable crop, with an estimated global production of 186.821 million metric tons in 2020 (FAOSTAT, 2021). China is the leading producer of tomatoes with an estimated annual production of 64.768 million T, equivalent to 34.67% of the world's total production on 1.11 million ha of land. India is the second largest producer of tomatoes, with an estimated 20.573 million Tons produced on 0.81 million ha of land. Turkey was ranked third with a total production estimate of 13.204 million T cultivated on approximately 0.18 million ha of land. Other top tomato producing countries are the USA, Egypt, Italy, Iran, Spain, Mexico, Brazil, and Nigeria, as presented in Table 1 (FAOSTAT, 2021). are characterized as one of the most popular vegetables owing to their numerous nutritional and health benefits. Tomato is a rich source of minerals, proteins, vitamins, essential amino acids (leucine, threonine, arginine valine, lysine, histidine), monounsaturated fatty acids (linoleic and linolenic acids), carotenoids (lycopene and β-carotenoids) and phytosterols (β-sitosterol, campesterol, and stigmasterol), details presented in Table 2 (Ali *et al*., 2021). Recommended diet of tomatoes reduces the risk of possible deficiencies and helps maintain a healthy lifestyle. Tomatoes are associated with reduced risk of cancer, cardiovascular and chronic diseases, and recently improved skin, brain, and bone health (Burton-Freeman and Reimers, 2011). Fruits can be eaten fresh as salads or processed into other forms. 80% of global production goes into processing for value-added products such as tomato powders, ketchup, sauces, and juices. Ways to preserve tomatoes include canning, drying, and processing (Comfort *et al.*, 2019).

After harvest, tomatoes have a high initial moisture content (≥90%), which makes them susceptible to postharvest deterioration (Nikita *et al.*, 2021). Posts-harvest techniques are necessary to keep the commodity fresh and retain its nutritional quality after harvest. Storage techniques available worldwide require low temperatures to preserve this fresh commodity (Sagar and Kumar, 2010), however, higher cost and lack of availability locally is a major limitation. Because of this, different drying techniques have been developed and successfully used as an alternative means to reduce losses, to preserve the commodity, and reduce shipping volume and weight while maintaining its inherent quality.

Table 1 Major tomato growing countries in the world (2020) estimates

Major tomato growing countries in the world (2020)

Country	Production (million tons)	Area (million ha)	Yield (ton/ ha)
China	64.768	1.11	58.4
India	20.573	0.81	25.3
Turkey	13.204	0.18	72.6
USA	12.227	0.11	110.7
Egypt	6.731	0.17	39.4
Italy	6.247	0.10	62.6
Iran	5.787	0.13	44.8
Spain	4.312	0.06	77.8
Mexico	4.137	0.08	48.7
Brazil	3.753	0.05	72.2
Nigeria	3.693	0.84	4.4

Source: FAOSTAT 2021

Drying both tomatoes and tomato processing wastes can yield valuable products. Dried tomatoes can be served as raw materials for various commercial products and as ingredients for different functional foods. The global sun-dried tomatoes market was valued at approximately USD 15,915.2 million in 2021 and is expected to rise to USD 19,994.6 million by 2030 at a CAGR of 2.6% during this forecast period (Laura, 2022). Dried forms of tomatoes have a large demand in culinary activities. Tomato waste is also an integral part of fertilizers and livestock feeds. Tomato powders can be used as a thickening agent in the production of ketchup (Silva *et al*., 2019; Belović *et al*., 2018). Studies indicate dried tomatoes as potential ingredients for developing functional foods, e.g., high lycopene powders are used for food colouring and antioxidant agents (Lavelli and Torresani, 2011). Tomato powder to bread formulation is a source of hydrocolloid and lysine (Majzoobi *et al*., 2011).

Moreover, Chin (2020) found that adding tomato to sausage increases its anti-microbial and antioxidant properties and shelf life extension. The use of dried tomato in sausage also increases its water absorption capacity. It improves its sensory properties. Producing dried forms with high-quality attributes similar to fresh tomatoes in appearance, texture, nutritional content, flavour, and reconstitution properties is a major challenge (Nikita *et al*., 2021).

Table 2 Nutritional composition of fresh tomato fruits

Parameter	Concentration	Range
Moisture %	91.18 ± 6.83	68.03 - 96.17
Energy (kcal/100g)	34.67 ± 18.74	18.00 -75.00
Protein (g/100g)	17.71 ± 5.40	10.50 - 25.03
Fat (g/100g)	4.96 ± 1.19	3.63 - 5.39
Carbohydrates (g/100g)	5.96 ± 1.37	3.92 - 8.00
Total sugar (g/100g)	50.60 ± 3.69	47.00 – 56.48
Ash (g/100g)	8.75 ± 1.69	5.90 - 10.60
Total fiber (g/100 g)	11.44 ± 9.31	1.32–19.36
β-carotene (µg/100 g)	9942.16 ± 264.74	3677.42–10,206.90
Lycopene (µg/100 g)	8002.50 ± 243.54	5020.00–11,110.00
Vitamin A (IU/100 g)	614.44 ± 248.18	267.33–833.00
Potassium (mg/100 g)	403.02 ± 254.41	16.63–1097.00
Calcium (mg/100 g)	105.21 ± 22.76	48.47–162.0
Phosphorus (mg/100 g)	300.99 ± 32.12	173.00–379.31
Iron (mg/100 g)	4.55 ± 2.18	1.50–6.45
Sodium (mg/100 g)	70.38 ± 12.20	56.90–80.65
Ascobic acid (mg/100 g)	36.16 ± 29.64	10.86–85.00
Linoleic acid (g/100g)	49.40 ± 4.16	46.33–54.10
Linolenic acid (g/100g)	10.17 ± 4.46	4.26–15.53
β-sitosterol (mg/kg)	720.00 ± 175.64	520.00–1000.00
Stigmasterol (mg/kg)	387.50 ± 88.71	260.00–510.00
Campesterol (mg/kg)	147.50 ± 31.13	100.00–18.00
Threonine (g/100g)	1.37 ± 0.97	0.40–2.34
Valine (g/100g)	2.49 ± 2.09	0.40–2.49
Methionine (g/100g)	0.57 ± 0.45	0.12–1.02
Isoleucine (g/100g)	2.13 ± 1.73	0.40–3.86
Leucine (g/100g)	2.80 ± 2.28	0.52–5.07
Phenylalanine (g/100g)	1.77 ± 1.36	0.41–13.12
Histidine (g/100g)	1.93 ± 1.71	0.22–3.64
Lysine (g/100g)	2.45 ± 1.95	0.50–4.40
Arginine (g/100g)	2.33 ± 2.02	0.31–4.34

Preparation of tomatoes for processing involves the following few steps: separating tomatoes from green, unfit ones, and other materials, followed by grading according to size, and washing to get rid of pesticide residue, surface microbes, dirt, insects, and larvae. The tomatoes are soaked at 54ºC for 3 minutes for the purpose loosen any adhered particles on the surface of the tomato before washing. Soaking is performed in flumes and adding wetting agents, lye solution, detergents, or caustic soda, followed by rinsing. The final step is trimming (Gould, 2013). steps are generally used for tomato processing. For drying purposes, tomatoes could be sliced, halved, quartered, or chopped to a desired shape and blanched before drying, depending on the drying technique.

Drying of tomatoes is achieved via various methods, which include but are not limited to solar and open sun, hot-air, microwave, heat pump, fluidized bed, infra-red, osmotic dehydration, freeze drying, spray drying as reported (Ashebir *et al*., 2009, Chawla *et al*., 2008, Correa-Filho *et al*., 2019).

Evaluation Parameters of Tomato Drying

Drying systems are generally evaluated based on the final product's quality and the economic implications of the drying process.

1. Quality attributes of Tomatoes

a) Colour

Colour is the human perception of light waves reflected from the surface of any material. is the first noticeable characteristic of food (Rajkumar, 2007). considering drying, colour changes can easily be noticed, as seen in tomatoes, which usually lose brightness during drying, making it unappealing. Colour is usually defined by a 3-dimensional colour space, i.e., $L*$, $b*$, and $a*$. bright-coloured product will have a higher value of $L*$ and minimum ΔE. Colour can also be measured in terms of Chroma value C and a hue value representing the intensity and the browning level, respectively (Abano *et al*., 2012). Changes usually occur due to non-enzymatic browning (milliard reactions), loss in pigments, or hydrolysis of sugar (Jorge *et al*., 2018). *et al*. (2018) observed a decrease in colour intensity, a decrease in brightness $L*$, and a decrease in chroma value as drying temperature increased when cherry tomato was dried at different temperatures (60ºC, 65ºC, and 70ºC. Similarly, oven drying caused more colour changes in dried samples compared to freeze drying (Jorge *et al*., 2018). In microwave and infra-red drying, change in colour increase with an increase in the microwave and infra-red power (Izlii and Isik, 2015; Celen and Kahveci, 2013; Kocabiyik *et al*., 2014). Shorter process time reduced colour changes in dried samples even at high temperatures of 70ºC (Dorouzi *et al*. 2018).

b) Nutritional content

Tomatoes are vegetables endowed with numerous nutrients, among which lycopene, β-carotene, ascorbic acid, phenolic content, flavonoids, and antioxidants have gained wide interest in the research world. It is the principal unsaturated pigment, giving Colour to tomatoes. It acts as an antioxidant, antimutagenic, and anticarcinogenic agent (Pfander, 1992). Drying lycopene content presents a dual nature, and it increases in some drying methods and decreases with other drying methods. The lycopene content of tomatoes is mainly influenced by moisture, temperature, drying time, and the presence of oxygen (Nikita *et al*., 2021). It is well known for its provitamin A activity. Lycopene is also observed to increase in some drying methods and decrease in others. *et al*. (2013) observed that tomato beta-carotene degradation increases with temperature. Acid is the most heat-sensitive compound that can be used as an indicator in processing. Drying methods have led to a complete loss of ascorbic acid as the degradation rate becomes higher when products are exposed to a higher temperature for a long period in the presence of oxygen (Nikita *et al*., 2021). Moreover, phenolic contents in tomatoes improve their antioxidant capacity. The increase or retention of these compounds is mainly governed by treatment temperature, duration, and availability of air.

c) Texture

Fresh tomato texture is different from dry tomato texture. There is limited available literature on the textural properties of dried tomatoes. Texture arises due to changes in the microstructure on drying. Cell walls, case hardening, and tissue collapsing lead to the changes observed (Joshi *et al*., 2008, 2009) studied the effect of different drying methods on the texture of dried tomatoes. It was observed that osmotic pretreatment softens the tissues. Air-dried samples had the lowest firmness, followed by hot air-dried, vacuum, and then the fresh ones, which had the highest firmness. The texture profile of tomatoes dried under varying temperatures shows that slices dried at 60ºC gave a superior texture profile regarding masticability, hardness, and crispness, as shown in Figure1 (Moreno and Díaz-Moreno, 2017).

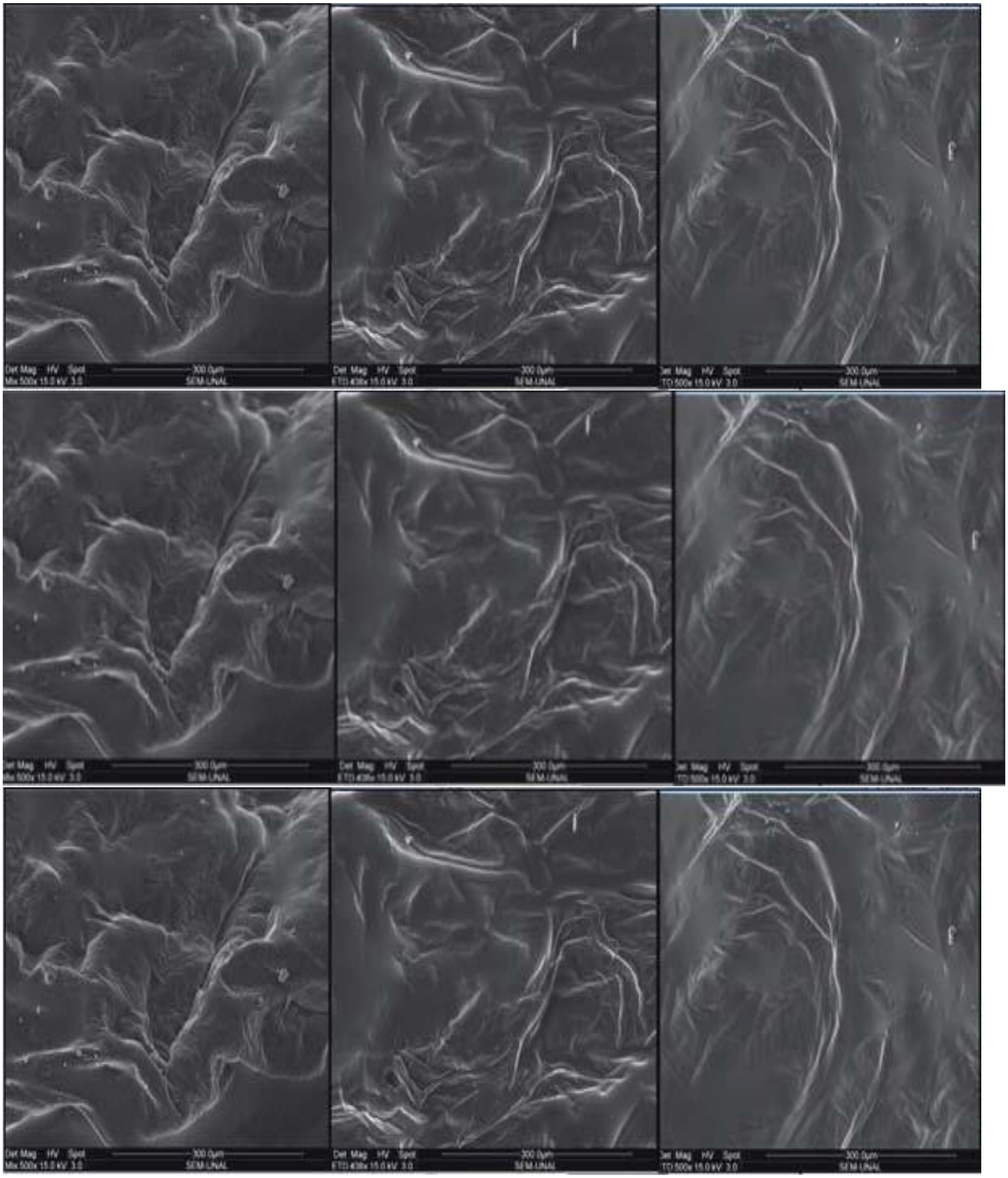


Figure 1 Microphotographs of the dehydrated tomato pulp at 50, 60, and 70°C.Case studies of texture should be provided (Moreno and Díaz-Moreno, 2017).

d) Rehydration ratio

A high rehydration ratio is one of the most desirable properties of dried products. It shows how many water molecules the dried product can take soaking in warm water. The rehydration ratio tends to decrease as drying proceeds. The rehydration ratio of dried slices increases with increased temperature (Sacilik, 2007).

rehydration ratio is determined using the Peleg model, as Horuz *et al*. (2017) mentioned. The rehydration ratio of solar cabinet-dried tomato slices was higher than that of open sun-dried samples (Rajkumar, 2007).

2. Economic attributes of Tomatoes

Drying is one of the most energy-consuming unit operations involved in food processing. In determining a particular drying method to manufacture dried tomatoes in an economically feasible way. Equal consideration is given to the energy consumed and the quality of the final product desired. Örvös et al. (2014) developed an equation to determine the energy consumption required for drying tomato slices. Transfer coefficient was used to determine the energy demand for conventional drying of tomato halves (Figure2). Efforts have been made towards reducing the energy consumed during tomato drying. Pump dryers reduce energy consumption by as much as 40-50%. It is also observed to consume less energy in drying tomatoes (Kocabiyik *et al*., 2014).

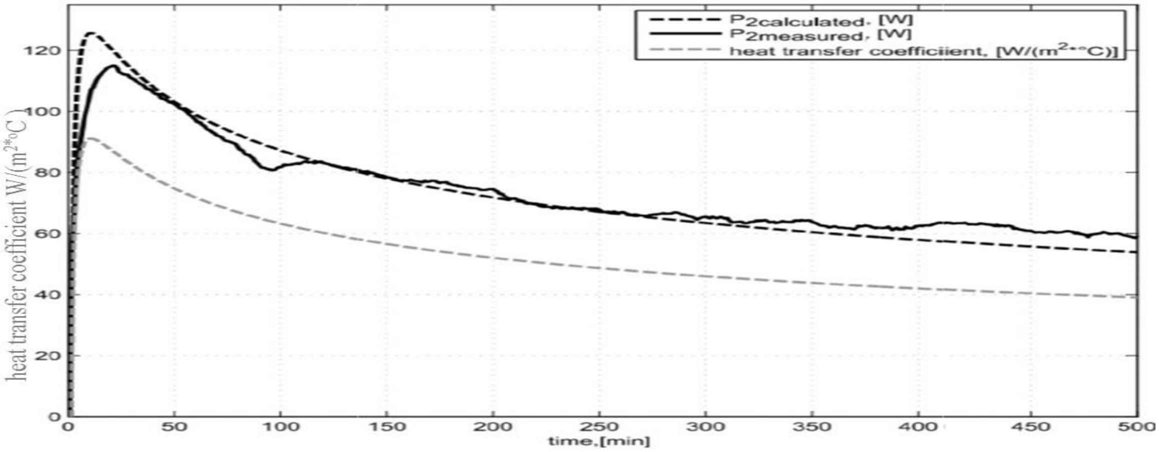


Figure 2: Thermal power demand and heat transfer coefficient vs. drying time for convectional drying of halved tomatoes

4. Tomato Drying Techniques

a) Sun and solar drying

Open Sun drying (Figure 3) is the oldest drying technique available for tomatoes and other agricultural products. To be dried, it is spread directly on the ground or into thin layers of mat, tray, or concrete floor, exposing the tomato halves to open sun and wind. Temperature varies between 25-60ºC, relative humidity between 24-65%, and time required to reduce moisture below 15% wet basis, varies from 3-20 days (Rajkumar *et al*., 2007) depending on initial moisture content, external drying condition, and variety of cultivar. However, exposure to sunlight for a long period causes loss of important nutrients such as lycopene, β-carotene, phenolic contents, ascorbic acid, and poor colour preservation. Defects associated with open Sun drying of tomatoes include spoilage due to microorganisms' growth and non-uniform drying (Abhay *et al*., 2020). Generally, the minimum water activity aw at which microorganisms can grow is 0.60 however, aw of dried tomatoes is generally at 0.70 (Barta, 2006). Due to this, some microorganisms including food-borne pathogens in the form of fungi and bacteria can survive open sun drying of tomatoes, which could lead to food-borne outbreaks (Beuchat et al., 2013). To eliminate some of these defects associated with open sun drying researchers have developed several alternative methods of drying tomatoes using solar energy like the one shown in Fig. 4.

Figure 3. Sun drying of tomato halves
Source: FAO (2019)

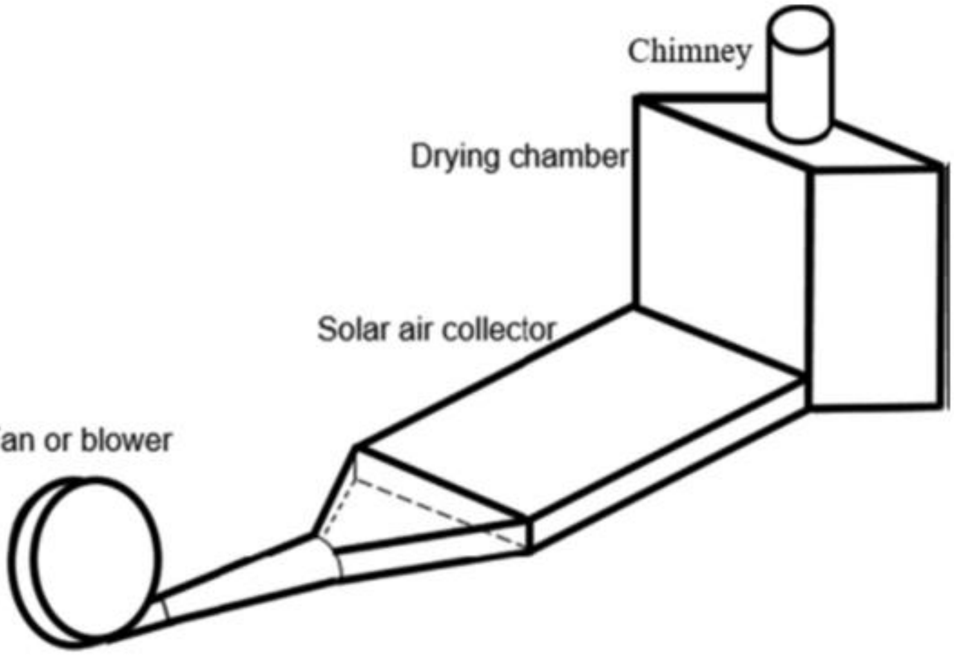


Figure 4: Forced convection indirect solar dryer setup
Source: Abhay *et al*. (2020)

Solar cabinet drying (Okaiyeto et al., 2020), solar tunnel drying (Sacilik, 2007), concentrator-based solar drying (Ringeisen et al., 2014), fabricated solar dryer (Mohsen et al., 2019), solar hybrid dryers (Reyes et al., 2014), and vacuum-assisted solar drying (Rajkumar, 2007) are a few alternatives to open sun drying. These newer techniques greatly reduce the time required to dry tomatoes considerably. Okaiyeto *et al*. (2020) found that cabinet drying reduced drying time by approximately 50%, and tunnel drying reduced total drying time by a day (Sacilik, 2007). The use of concentrators and solar dryers reduce drying time by 21% (Ringeisen *et al*., 2014). A 56% reduction in total drying time was obtained using solar-fabricated dryers compared to open sun-dried tomatoes. In contrast, hybrid dryers reduced drying time by six days. The reduction in drying time depends on atmospheric conditions and is subject to variation. With newer techniques, solar dyers generally produce inferior-quality dried samples compared to other drying methods. The rehydration ratio of solar cabinet-dried samples was lesser than those dried by microwave, vacuum, and heat pump dryers (Gaware *et al*., 2010).

However, sun-dried tomato powder was superior to oven-dried samples regarding vitamin content retention (Adenike, 2012). Drying is one of the most inexpensive methods of drying tomatoes and processing waste (Allison *et al*., 2016). Solar drying techniques that could be used to dry tomatoes with the potential of giving rich dividends and premium quality products include the application of innovative solar conduction dryers (Chavan *et al*., 2020).

Hot air drying (HAD)

HAD is a commonly used method for drying tomatoes in the commercial industry. Tomatoes using these techniques have been widely explored for their effect on drying kinetics and the quality of the dried products. In this process, heat is transferred to the tomato surface by convection. Heat is then transferred to the interior through the surface, which causes the internal moisture of the fruit to diffuse to the surface and spread into a gas phase. Figure 2 shows a typical setup of a hot air-drying system. The driving force for heat transfer is the temperature difference, while mass transfer occurs due to the difference in vapour partial pressure between the drying air and the material. In hot air, it is achieved at temperatures above 55ºC. The drying rate has been found to increase with an increase in air velocity and temperature. To Santos-Śanchez *et al*. (2012), the temperature has a greater (88.47%) impact on the drying rate than velocity (4.6%) when tomatoes were dried in a rotating tray. The velocity and temperature and reducing the size shorten the total process time. However, this has detrimental effects on the quality of the dried tomatoes. At elevated temperatures, ascorbic acid is lost drastically (Jorge *et al*., 2018). *et al*. (2013) found that 75.12% ascorbic acid was lost when tomato was dried at 60ºC for 9 hours. Toor and Savage (2006) observed that 30% and 28-38% of the total phenolic content and antioxidant activity were lost when the tomato was dried at 42ºC for 18 hours. The rehydration ratio is also reduced when hot air is used in drying tomato slices (Gaware *et al*., 2010). Akanbi *et al*. (2006) observed that large shrinkage and tissue hardening occurred when dried at 60 and 70ºC for 10 hours. However, these effects were negligible when dried at 45oC for 16 hours. Colour is another physical characteristic affected, as high temperatures lead to non-enzymatic browning (Ashebir *et al*., 2009). Abano *et al*. (2011) observed a total loss in compounds responsible for the flavour of tomatoes on drying. A possible way to improve product quality is by using hot air drying and other techniques. Rotation of trays while drying has proved useful in minimizing loss in ascorbic acid, total phenolic content, and lycopene content. Similarly, Fernades *et al*. (2016) observed that ultrasound-assisted was useful in reducing total drying time and preserving vitamin E content.

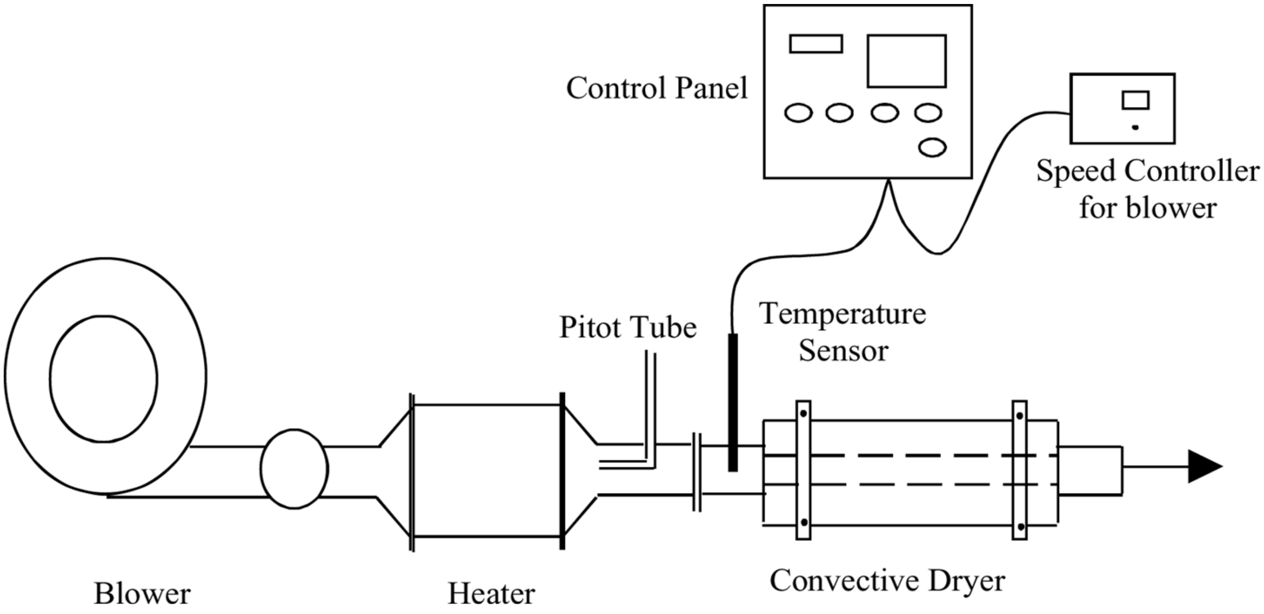


Figure 4. Hot air dryer (HAD) set up for tomato dehydration
Source: Gaware *et al*. (2010).

Microwave drying

The last two decades have witnessed a tremendous increase in the use of microwave technology in the food processing industry. Microwave drying uses electromagnetic radiation (915 2450 MHz) for heating the product. Microwave heating is known to reduce total drying time to a large extent. Askari *et al*. (2009) observed a reduction in drying time by 26% compared to hot air drying. The microwave power greatly influences the drying time. Increasing the microwave power from 120 to 180 w reduced the total drying time by 46.4% (Izli and Isik, 2015). However, tissue structure destruction occurs at a microwave power of 500 w and above due to a high vapour pressure gradient between the internal and external structures. It was found that microwave power below 360 w yields higher $L*$ & $a*$ and lower hue angle, which are highly desirable qualities of dried tomatoes (Celen and Kahveci, 2013).

Similarly, Microwave power of as low as 90 W yields products resembling fresh ones in appearance and chemical properties. Exposing the products to the same power supply at the later part of drying, when there is less water in the products, results in non-uniformity and unnecessary burning, leading to products with poor quality in terms of colour uniformity, rehydration capacity and textural attributes. However, applying a vacuum within the pressure range of 0.04-0.06 MPa while drying in the microwave was observed to resolve these issues, even when the microwave power was increased to 700W Abano *et al*. (2012). Figure3 is a schematic diagram of a laboratory microwave vacuum dryer. An artificial neural network could predict the optimum temperature and power ranges required for drying tomatoes with minimal thermal damage (Poonnoy *et al*., 2007).

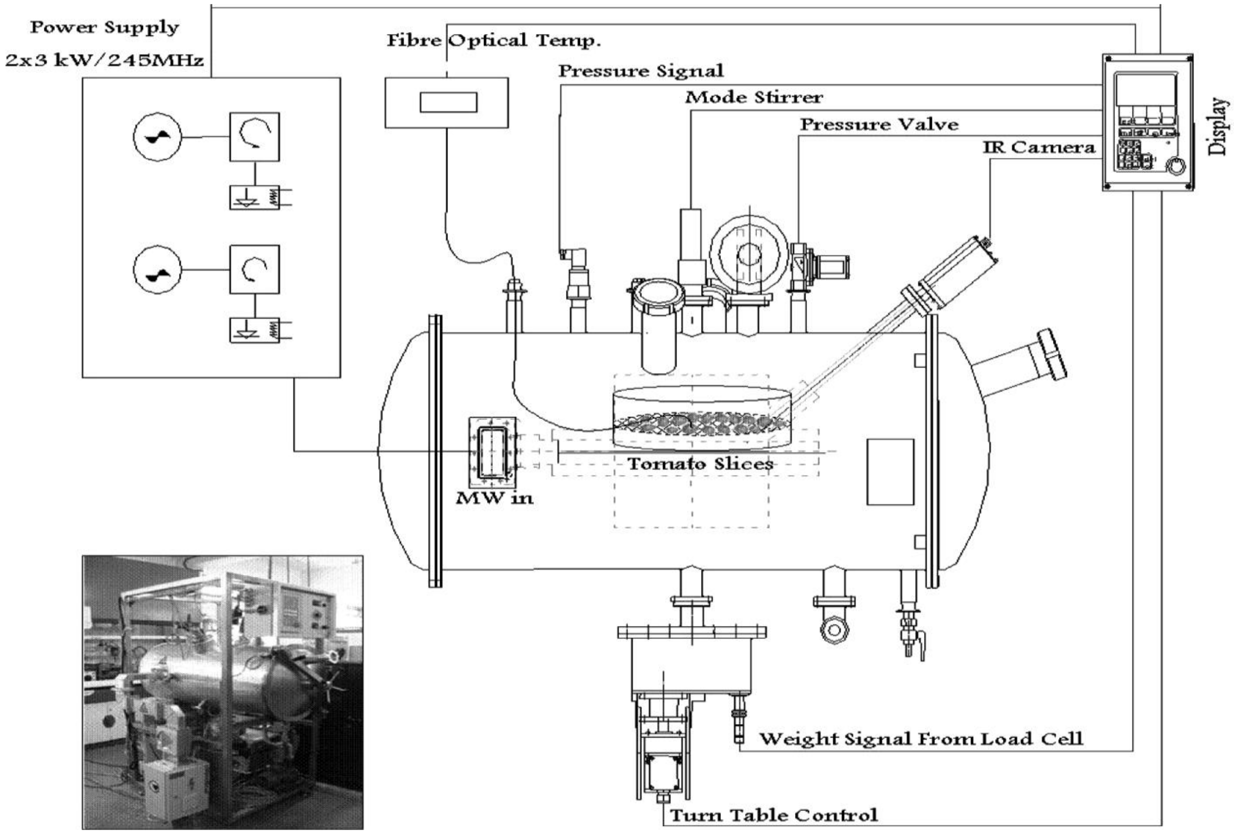
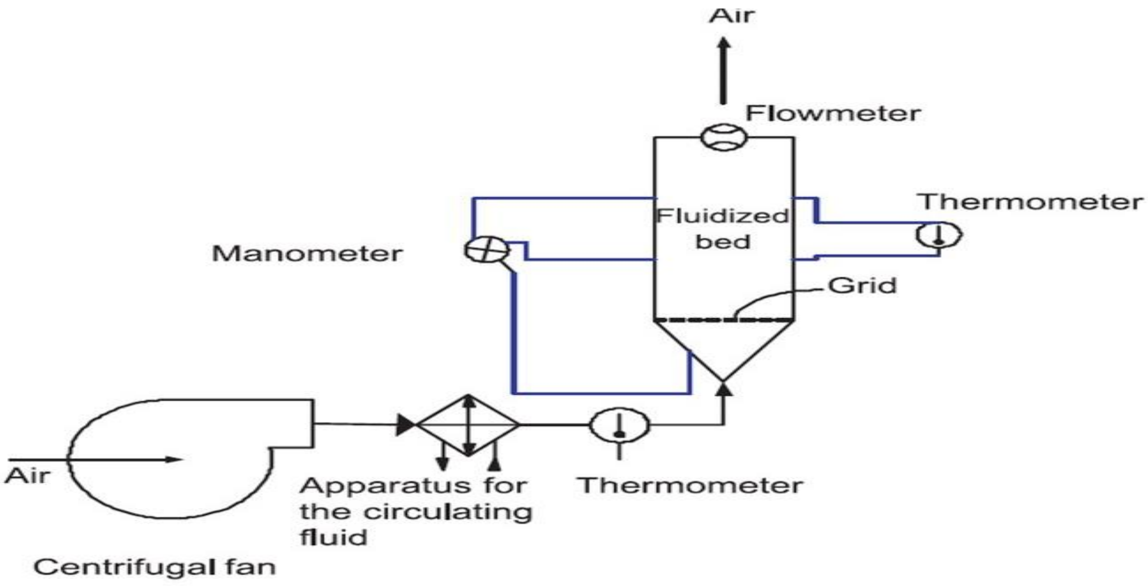


Figure 5 Schematic diagram of laboratory microwave vacuum dryer MVD
Source: Gaware *et al*. (2010)

Fluidized bed drying

Fluidized bed drying has only been successfully used to dry tomato processing waste. It involves placing materials to be dried on trays; the hot air at critical velocity is used to maintain the material in a fluidized state (Figure 4). The Drying time of tomatoes was shorter than that of hot air drying at a given temperature. It was also found that it is more efficient in drying tomato pulp and retained more lycopene than cabinet and tray drying (Chawla *et al*., 2008). Similarly, a fluidized bed produces dry fruit particles of improved quality with improved rehydration ratio and qualities than in continuous belt-driers (Bauman and Ukrainczyk 2005). However, more degradation of lycopene, β-carotene, and ascorbic was observed due to oxidation due to excess air used to achieve fluidization (Albanese *et al*., 2014).



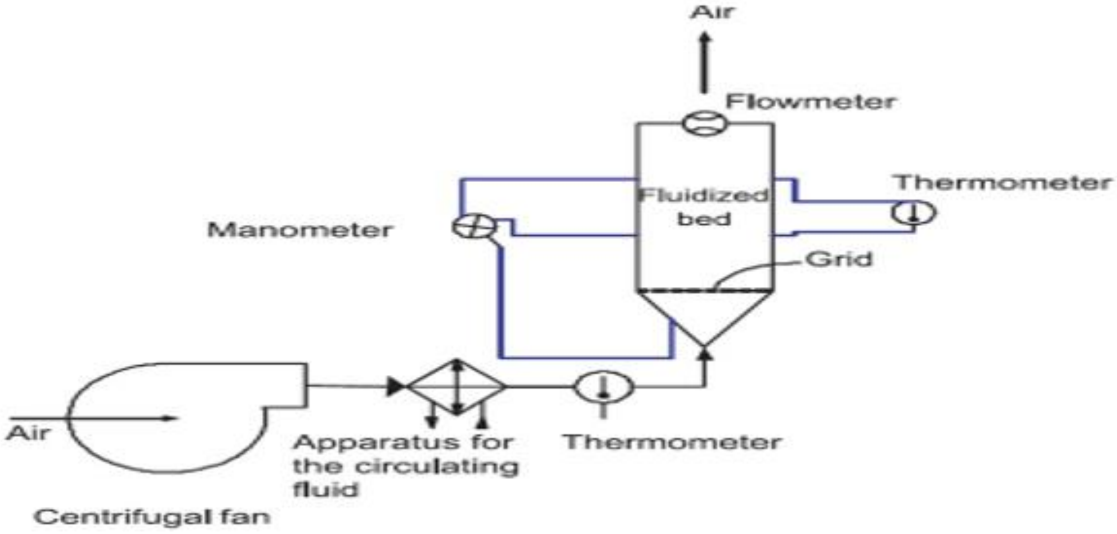


Figure 6 Experimental Setup of Fluidized Bed drying
Source: Bauman and Ukrainczyk (2005)

Heat pump drying (HPD**)**

A heat pump works on the refrigeration principle by cooling a stream of air, thereby condensing the water (Krishna & Abhijit, 2012). The basic principle of operation is depicted in Figure 4. It is a low-temperature process operated from -20°C to 70 °C, so it is a more energy-efficient technology (Jangam *et al*., 2008). Using this type of dryer makes higher retention of heat-labile compounds possible. Aware and Thorat (2011) reported that retention of allicin using HPD was better than other thermal drying methods. HAD has the advantage of lower energy consumption; a 40-50% reduction in energy consumed was obtained by Queiroz *et al*. (2004), who also found that dried tomato qualities were comparable to fresh ones. Gaware *et al*. (2010) observed the rehydration ratio of HPD-dried tomatoes to be higher than that of hot air and solar cabinet-dried samples. Similarly, the flavour profile of HPD-dried samples indicates retention of fresh aroma, comparable with that of freeze-dried and fresh samples (Jeyaprakash *et al*., 2016).

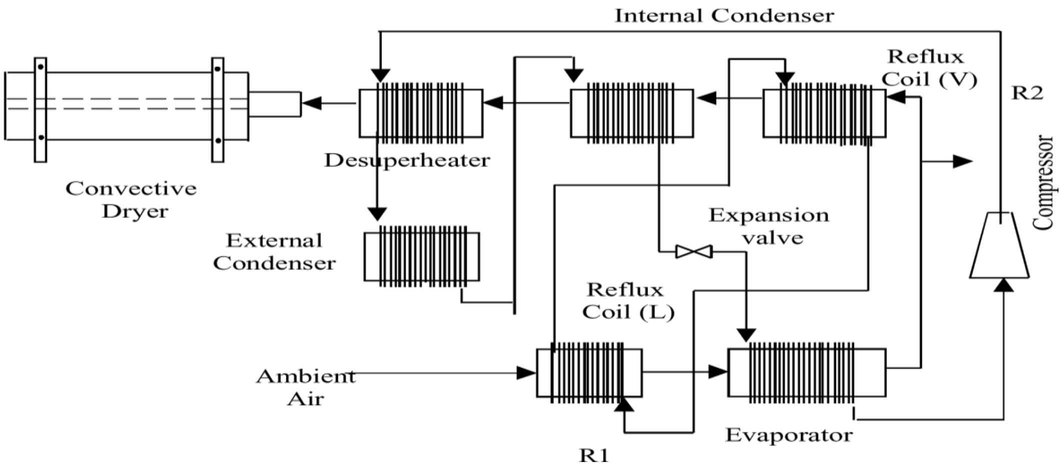


Figure 7. Heat pump dryer (HPD) for tomato dehydration
Source: Gaware *et al*. (2010)

Infrared drying

Infrared radiation has become the best alternative for drying perishable commodities (Doymaz, 2012). An infrared dryer exposes the material to a high beam of infrared radiation. Here, the radiations penetrate the exposed material's inner part, raising the internal temperature rapidly (Hebbar and Rostagi, 2001). An experimental setup for short infrared drying of sliced tomatoes is given in Figure 5 (Kocabiyik *et al*. 2015). It offers a significant advantage to agriculture products over traditional dryers. The Lycopene content of the dried tomato was reported to increase while the β-carotene and the ascorbic acid were reduced on drying (Kocabiyik *et al*., 2014). A 29-364% increase in lycopene content was observed, while loss of vitamin C and β-carotene was as high as 51%. Similarly, Kocabiyik *et al*. (2016) observed a 207-337% higher lycopene content and a 3-51% total loss in ascorbic acid when tomato slices were dried in an Infrared dryer. The use of infrared in drying tomatoes is mostly in combination with other drying techniques rather than using it alone (Nikita *et al*., 2021).

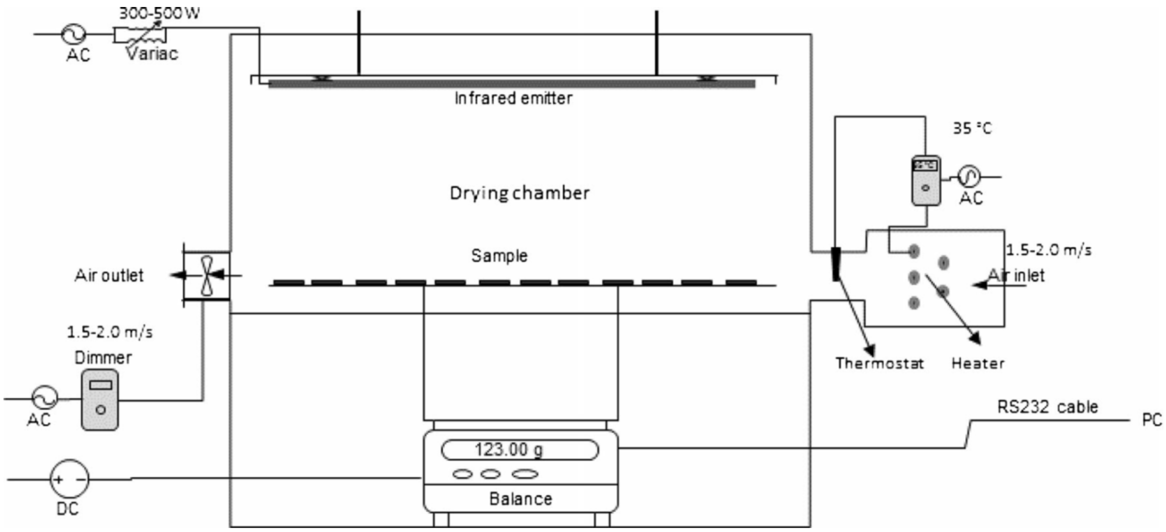


Figure 8 Experimental setup of the infrared dryer
Source: Kocabiyik *et al*. (2014).

Osmotic dehydration

Osmotic dehydration is characterized as a partial drying technique mostly used for pretreatment. In Osmotic rehydration, products to be dried are immersed in a hypertonic solution to suck out water from tissues by osmosis, as shown in Figure 6. Common osmotic agents used are salts and sugars due to their high osmotic power. Water loss increases as solute concentration increases (Souza *et al*., 2007; Escher *et al*., 2018). Osmotic pretreatment positively affects dried product quality as it affects physical and chemical properties. However, the osmotic agents determine the drying rate and final product quality. Tonon *et al*. (2007) discovered salt to cause more water loss than sucrose due to higher water-lowering capacity. Osmotic pretreatment reduces the drying time of the further process. Brooks *et al*. (2008) observed osmotic treated tomato slices having a higher drying rate than untreated samples. Osmotic pretreatment also positively affects the products' physical and chemical properties. The β-carotene and lycopene content of osmotically dehydrated tomatoes is higher than that of fresh ones (Goula and Lazarides, 2012). Osmotic pretreatment can further be enhanced by ultrasound treatment and pulsed vacuum treatment. Ultrasound and vacuum treatments aid in faster mass transfer (Corrêa *et al*., 2015; Corrêa, 2016).

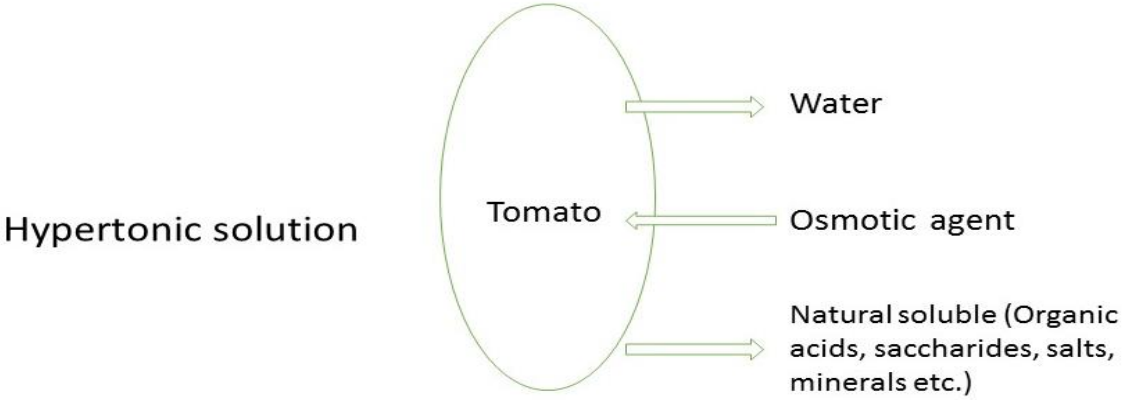


Figure 9. Mass transfer in fruits or vegetables during osmotic dehydration.
Source: Ramya and Jain (2016)

Freeze drying

Freeze drying was introduced to prevent the loss of heat-sensitive nutrients. Here, the operating temperature is below the freezing point of water as opposed to other drying methods. The tomato slices are dried below the freezing point of water, and the frozen water then sublimes out on applying appropriate pressure. However, temperature is observed to play a major role in final product quality. Freeze drying is best for its minimal effect on Color, phenolic contents, and antioxidant capacity. Gümüsay *et al*. (2015) found freeze-drying ideal for preserving phenolic acids and antioxidant activity. One of the major limitations to freeze-drying is the economic aspect involved in freezing the products coupled with the long process time Tan *et al*. (2021). Hydroxymethyl furfural, a very harmful chemical harmful to human health, is formed as a byproduct of freeze drying (Jorge *et al*., 2018). Freeze drying also leads to poor structural qualities of dried tomatoes, which results from large ice crystal formation. However, this can be prevented by restricting the temperature between the product collapse temperature and the glass transition temperature (Lopez-Quiroga *et al*., 2020). Unlike other methods, lycopene content decreased due to low temperatures (Bilek *et al*., 2019). This loss can be reduced by the introduction of vacuum pretreatment together with individual quick freezing (Tan *et al*., 2021).

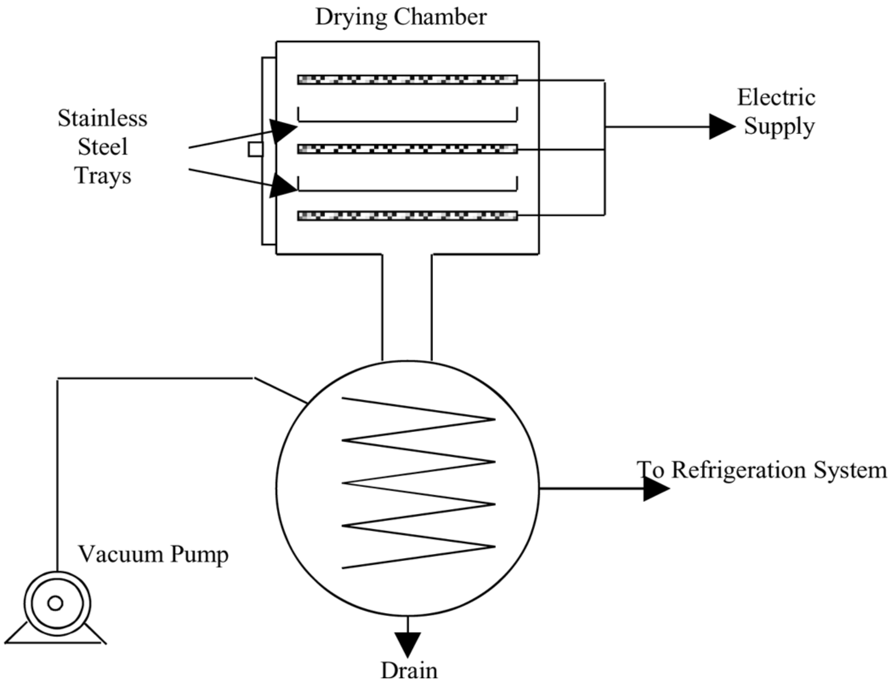


Figure 10. Schematic diagram of freeze dryer
Source: Gaware *et al*., (2010)

Spray drying

Spray-drying encapsulation is a common technology for producing powders from tomatoes. These powders are integral to ketchup, pigments, bread, sausages, and dough (Nikita *et al*., 2021). Spray drying involves atomizing liquid feed into fine droplets; mixing these spray droplets with a heated gas stream allows the liquid to evaporate, leaving behind dried solids. Finally, the powder is separated from the gas stream and collected. Due to its high sugar content, tomato pulp has a low glass transition temperature, which causes it to stick in the drying chamber, resulting in yield loss.

Similarly, Bhandari *et al*. (2015) mentioned tomato pulp as being difficult to dry using this technique due to caking and agglomeration. However, optimum feed formulations have been observed to improve product generation. Numerous studies suggest that the chemical and physical properties of the powder are determined by feed concentration, inlet air temperature, the use of wall material, flow rate, and solid content. The airflow rate has little or no effect on the quality (Al-Asheh *et al*., 2003). Aswathy *et al*. (2019) observed that a low feed flow rate and air inlet temperature with a higher carrier agent concentration leads to a product with better lycopene retention and antioxidant activity. The feed's inlet air temperature and solid content affect solubility and bulk density most (Al-Asheh *et al*., 2003). Increasing the feed concentration improves the physical nature of the powder; however, it leads to the accumulation of residue in the drying chamber, thereby reducing yield (Goula and Adamopoulos, 2004). A future trend to address the issues of low yield and poor powder quality is the introduction of nano-spay dryers equipped with ultrasonic atomizers and electrostatic separation. These will enable the production of powder nanoparticles with narrow size distribution (Seid *et al*., 2021).

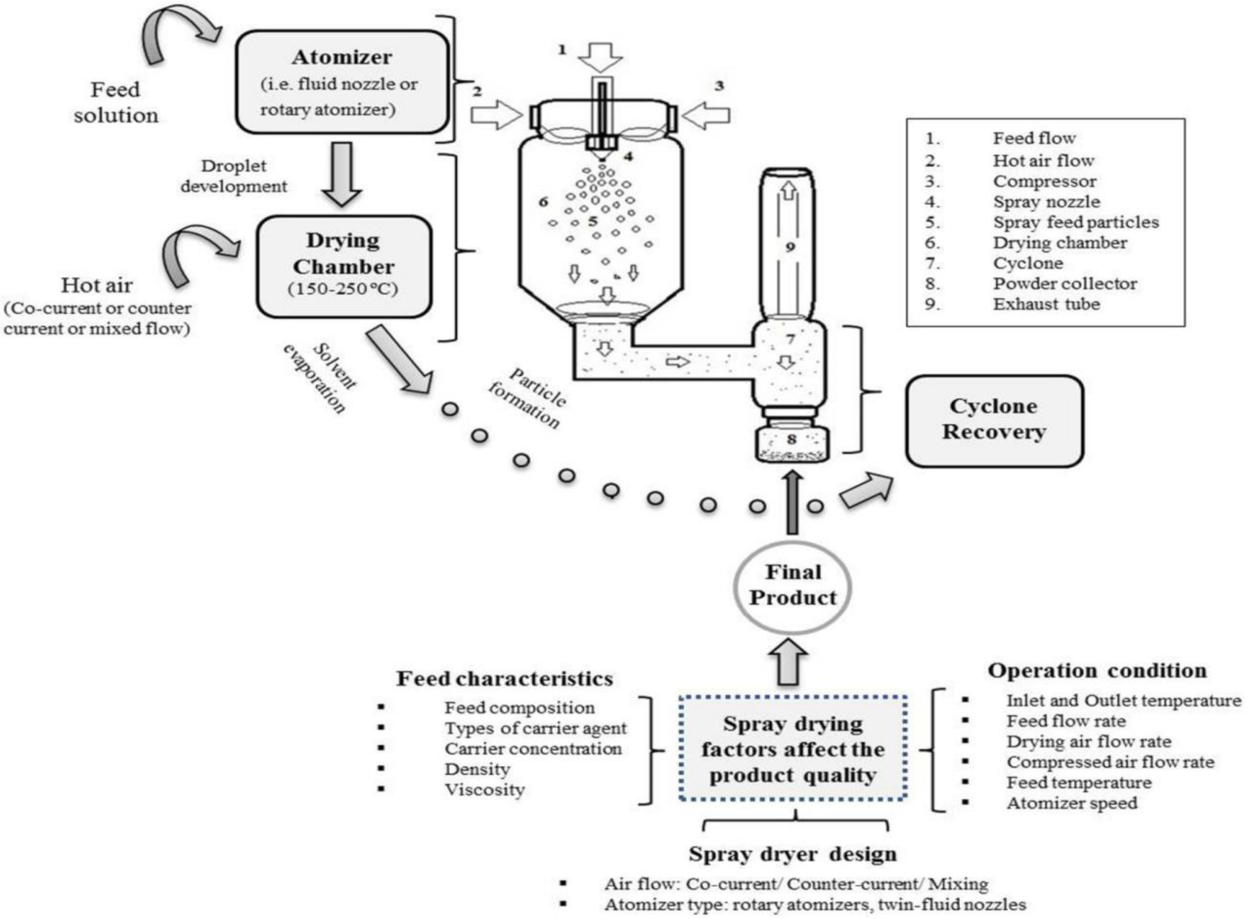


Figure 11. Schematic diagram of spray drying and product quality affecting factors.
Source: Mohammad and Wei (2017)

Different pretreatment techniques, mostly blanching, have been developed to reduce loss in quality attributes (Jorge *et al*., 2018). Samples with better physical attributes and improved rehydration ratio were obtained when the tomato was blanched and treated with brine solution (Sacilik *et al*., 2007). Pretreatment with alkaline ethyl oleate reduced drying time by 8.45- 12.05 %

Instead of increasing the temperature to achieve the same effect, which will compromise product quality (Doymaz 2007). However, the quality of dried forms of tomatoes is still a concern globally, which the application of an appropriate drying method could solve. Temperature and time are the major factors contributing to the final quality of the dried product, especially when tomato and pomace are dried with or without air (Nikita *et al*., 2021). Therefore, a pretreatment/ drying technique that has an inherent ability to eliminate oxygen and regulate temperature could solve challenges associated with dried tomato quality.

Emerging Technologies

Reports indicate that there are potential drying techniques that could be used in drying tomatoes. These potential drying methods possess the capabilities above of oxygen elimination as well as temperature regulation. These methods include Pulsed Vacuum drying and Vacuum steam pulse blanching.

Pulsed Vacuum Drying (PVD)

PVD is a novel drying technology recently introduced to the drying community. During PVD operation, the drying chamber pressure is successively changed between atmospheric pressure and vacuum state until drying is completed. The alternating pressure results in a tunnelling effect that enlarges and interconnects the micro-pores in the material, thereby enhancing moisture transfer during the drying process (Wang *et al*., 2018). The oxygen-deficient drying chamber also prevents oxidative reactions, enhancing product quality in terms of Color and other chemical properties (Xie *et al*., 2017). Weipeng *et al*. (2017) divided the PVD process into three stages, as seen in Figure 9b: (1) Vacuum generation stage, when chamber pressure drops from point a to b with the air solenoid valve closed while the vacuum valve is open (2) vacuum stage, at this stage pressure in the chamber is maintained at a preset value (3) Vacuum decreasing stage with air solenoid valve open while vacuum is valve closed. Chamber pressure rises to atmospheric pressure quickly and is sustained for a specific time. PVD has been successfully used for drying lemon, grape, Poria cocos, wolfberry, and rhizome discrete (Weipeng *et al*., 2017; Wang *et al*., 2018; Xie *et al*., 2017). However, PVD has not been tested on tomato halves.

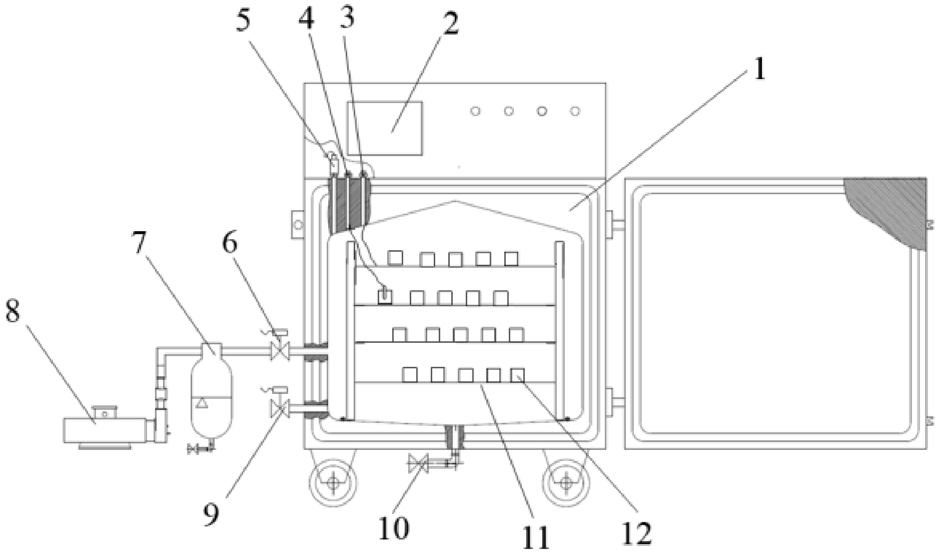


Figure 12a. System structure chart of PVD. 1, Drying chamber; 2, touch screen; 3, electric heating panel temperature sensor; 4, material internal temperature sensor; 5, pressure sensor; 6, vacuum valve; 7, airtight condenser; 8, vacuum pump; 9, air solenoid valve; 10, drain solenoid valve; 11, electric heating panel; 12, product.
Source: Wang *et al*. (2018)

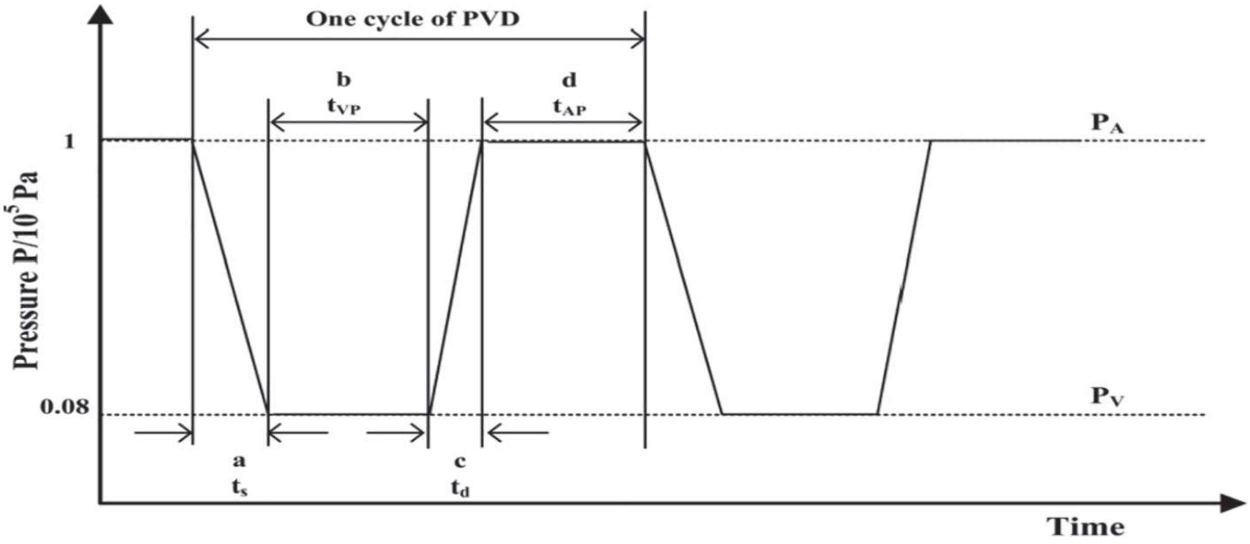


Figure 12b. Schematic diagram of drying chamber pressure change kinetics during pulsed vacuum drying. The highest pressure in the drying chamber, PV- the lowest pressure in the drying chamber, tAP- the duration at the highest pressure, tVP- the duration at the lowest pressure, the time required during alternation of PV, and td e the time required during alternation of PA.
Source: Wang *et al*. (2018).

Vacuum steam pulse blanching (VSPB)

VSPB is an emerging blanching technology with the advantages of high blanching efficiency with zero blanching wastewater and uniform heating (Pei *et al*., 2021). VSPB cycle consists of three stages (Fig 10b): The Vacuum stage, the steam entering stage, and the steam holding stage. The vacuum stage is characterized by removing air and water vapour, followed by the steam entering stage, where the material comes into direct contact with steam at high temperatures; this raises the temperature of the samples in the blanching tank evenly and rapidly. The last stage is the steam holding when the steam temperature decreases. As a result, its effect on blanching material weakens. After this stage, the three processes above must be repeated (Wang *et al*., 2021). VSPB encourages the release of gases from tissues and provides a low-oxygen environment that could inhibit some undesirable oxidation that often leads to quality deterioration. VSPB inactivated peroxidase and polyphenol oxidase enzymes; it mitigates cell damage and reduces nutrient loss in beetroot (Zhang *et al*., 2021). Wang *et al*. (2021) mentioned that VSPB could soften the texture and reduce the drying time of carrots by modifying the micro ultra-structure of the samples, degradation of pectin polysaccharides, and changes in water state. Similarly, Wang *et al*. (2022) observed an improvement in total phenolic and antioxidant activities when ginger was blanched with VSPB.

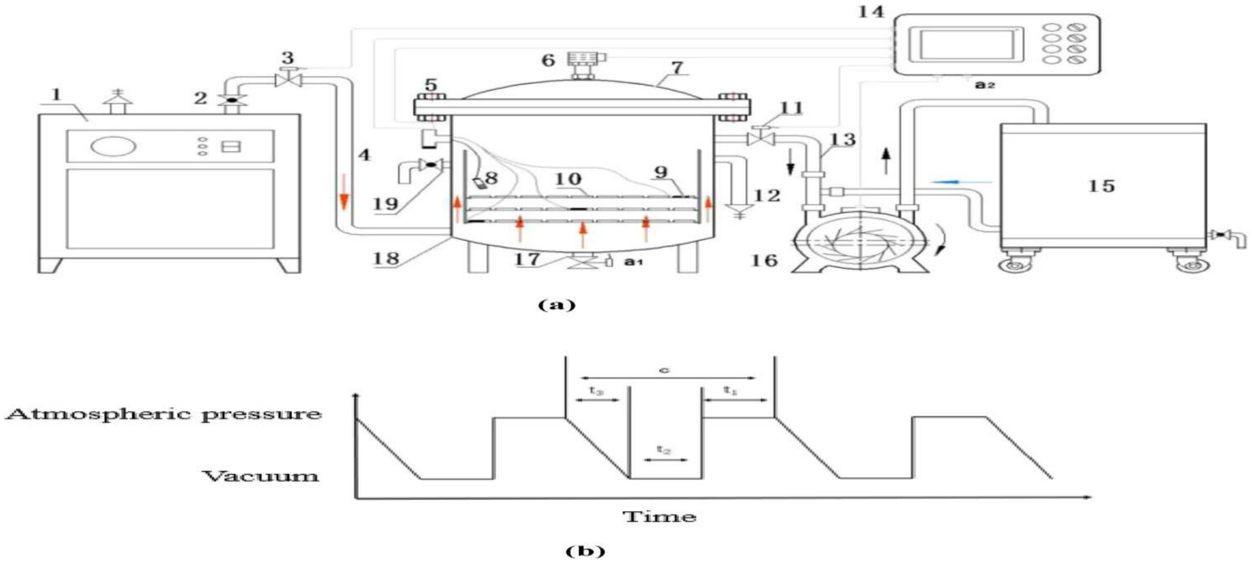


Figure 13a and b Schematic diagram of equipment used for vacuum-steam pulsed blanching (a) and Schematic diagram of pressure changes during VSPB processing (b). (1) Superheated steam generator, (2) Superheated steam ball valve, (3) Steam Solenoid valve, (4) Steam intake pipeline, (5) Bolt and nut, (6) Pressure sensor, (7) Lid of the blanching chamber, (8) Chamber temperature sensor, (9) Material temperature sensor, (10) Material, (11) Vacuum electromagnetic valve, (12) Safety valve, (13) Vacuum Pipeline, (14) Main control unit, (15) Water tank, (16) Vacuum pump, (17) Solenoid valve for releasing condensate, (18) Blanching chamber body, (19) Ball valve pressure relief Atmospheric pressure holding time (t1), vacuum holding time (t2). Time from atmospheric pressure to vacuum (t3) and one cycle(c) Source: Weipeng *et al*. (2017).

CONCLUSION

The article reviews recent works on tomato processing and drying techniques. Tomatoes are highly produced and consumed due to their nutritional and health benefits, and approximately 80% of global production is used for processing. Different drying techniques are developed to reduce losses, preserve the commodity, and maintain quality, such as solar and open sun, hot-air, microwave, heat pump, fluidized bed, infra-red, osmotic dehydration, freeze drying, and spray drying. The final product's quality and the drying process's economic implications are evaluated based on Color, nutrients, texture, and rehydration ratio. Colour, nutritional content, and texture are the major factors determining the acceptability of any dried tomato product. The review provides valuable insights into the various tomato drying techniques and parameters essential for producing high-quality tomato products for consumption.

The review also discusses two emerging technologies for drying tomatoes: Pulsed Vacuum Drying (PVD) and Vacuum Steam Pulse Blanching (VSPB). Pulsed Vacuum Drying (PVD) is a novel technology where the pressure in the drying chamber is alternated between atmospheric pressure and vacuum state to enhance moisture transfer and improve product quality. PVD has been successfully used for drying lemon, grape, Poria cocos, wolfberry, and rhizome dioscoreae, but its application on tomato halves has not been tested yet. Vacuum Steam Pulse Blanching (VSPB) is another emerging blanching technology that offers high efficiency with no waste water and uniform heating. The VSPB cycle involves three stages: the vacuum stage, the steam entering stage, and the steam holding stage. VSPB promotes gas release from tissues, creates a low-oxygen environment, and inhibits oxidation, improving product quality. VSPB has been shown to inactivate enzymes, mitigate cell damage, reduce nutrient loss in beetroot, and modify the micro ultra-structure of samples like carrot and ginger. PVD and VSPB promise to enhance the drying and blanching processes for tomatoes and other food products.

REFERENCE

Abano, E.; Ma, H.; and Qu, W. (2011). Influence of Air Temperature on the Drying Kinetics and Quality of Tomato Slices. *Journal of Food Processing Technology*, 2, 2–9. DOI: 10.4172/2157-7110.1000123.

Abano, E.; Ma, H. and Qu, W. (2012) Influence of Combined Microwave-Vacuum Drying on Drying Kinetics and Quality of Dried Tomato Slices. *Journal of Food Quality*, 35, 159–168. DOI: 10.1111/j.1745-4557.2012.00446. x.

Abhay B. L., Chandramohana V.P., Rajua V.R.K., and Venkatesh M. (2020). A review on indirect type solar dryers for crops – Dryer setup, performance, energy storage and important highlights. *Applied Energy*, 258, 114005, https://doi.org/10.1016/j.apenergy.2019.114005

Adenike, A. B. (2012). The Effect of Pretreatment and Drying on Some Vitamin Contents of Tomato Powder. *Food Science Technology*, 13(2), 156–160.

Akanbi, C. T.; Adeyemi, R. S. and Ojo, A. (2006). Drying Characteristics and Sorption Isotherm of Tomato Slices. *Journal of Food Engineering*, 73, 157–163. DOI: 10.1016/j.jfoodeng.2005.01.015.

Al-Asheh, S.; Jumah, R.; Banat, F. and Hammad, S. (2003). The Use of Experimental Factorial Design for Analyzing the Effect of Spray Dryer Operating Variables on the Production of Tomato Powder. *Food and Bioproducts Processing*, 81, 81–88. DOI: 10.1205/096030803322088215.

Albanese, D.; Adiletta, G.; D0 Acunto, M.; Cinquanta, L. and Di Matteo, M. (2014). Tomato Peel Drying and Carotenoids Stability of the Extracts. *International Journal of Food Science and Technology*, 49, 2458–2463. DOI: 10. 1111/ijfs.12602.

Ali, M.Y.; Sina, A.A.I.; Khandker, S.S.; Neesa, L.; Tanvir, E.M.; Kabir, A.; Khalil, M.I.; Gan, S.H. (2021). Nutritional Composition and Bioactive Compounds in Tomatoes and Their Impact on Human Health and Disease: A Review. *Foods*, 10, 45. https://dx.doi.org/10.3390/ foods10010045

Aware, R.; Thorat, B. (2011). Garlic under Various Drying Study and Its Impact on Allicin Retention. *Drying Technology*, 29, 1510–1518. DOI: 10.1080/07373937.2011.578230.

Ashebir, D., Jezik, K., Weingartemann, H., & Gretzmacher, R. (2009). Change in colour and other fruit quality characteristics of tomato cultivars after hot-air drying at low final-moisture content. *International Journal of Food Sciences and Nutrition*, *60*(7), 308–315. https ://doi. org/10.1080/09637 48090 3114128

Askari, G.; Emam-Djomeh, Z.; and Mousavi, S. (2009). An Investigation of the Effects of Drying Methods and Conditions on Drying Characteristics and Quality Attributes of Agricultural Products during Hot Air and Hot Air/Microwave-Assisted Dehydration. *Drying Technology*, 27, 831–841. DOI: 10.1080/07373930902988106.

Aswathy, S.; Suresha, G.; Sneha, N. and Sadananda, G. (2019). Microencapsulation of Lycopene Rich Cherry Tomato Powder Using Spray Drying. *International Journal of Conservation Science*, 7, 2270–2277.

Barta J (2006) In Sinha N (ed) Fruit drying principles. Handbook of fruits and fruit processing, 2nd edn. Wiley-Blackwell, USA.

Belovi_c, M.; Torbica, A.; Lijakovi_c, I. P.; Tomi_c, J.; Lon_carevi_c, I. and Petrovi_c, J. (2018). Tomato Pomace Powder as a Raw Material for Ketchup Production. *Food Bioscience*, 26, 193–199. DOI: 10.1016/j.fbio.2018.10.013.

Beuchat, L. R.; Komitopoulou, E.; Beckers, H., Betts, R. P.; Bourdichon, F., Fanning, S. and Ter Kuile, B. H. (2013). Low-water activity foods: increased concern as vehicles of food-borne pathogens. *Journal of Food Protection*, 76(1):150–172. https:// doi. org/ 10. 4315/ 0362- 028X. JFP- 12- 211

Bhandari, B. (2015). Handbook of Industrial Drying, Edited by AS Mujumdar: CRC Press: Boca Raton, FL; ISBN: 978-1-4665-9665-8. 2015, Taylor & Francis.

Bilek, S. E.; De girmenci, A.; Tekin, I. and Yılmaz, F. M. (2019). Combined Effect of Vacuum and Different Freezing Methods on the Quality Parameters of Cherry Tomato (Lycopersicon esculentum Var. Cerasiforme). *Food Measure*, 13, 2218–2229. DOI: 10.1007/s11694-019-00142-3.

Bauman I. and Ukrainczyk M. (2005). Time and speed of fruit drying on batch fluid beds. *Sāadhanā,* 30(5), 687–698 DOI: 10.1007/BF02703515

Burton-Freeman, B. and Reimers, K. (2011). Tomato Consumption and Health: Emerging Benefits. *American Journal of Lifestyle Medicine*, 5, 182–191. DOI: 10.1177/1559827610387488.

Chavan, A.; Vitankar, V.; Thorat, B. (2020). CFD Modeling and Experimental Study of Solar Conduction Dryer. *Drying Technology*, 1–14. DOI: 10.1080/07373937.2020.1846051.

Celen, S. and Kahveci, K. (2013). Microwave Drying Behaviour of Tomato Slices. *Czech Journal of Food Sciences*, 31, 132–138. DOI: 10.17221/30/2012-CJFS.

Corrêa, J.; Viana, A. D.; de Mendonc¸a, K. S. and Justus, A. (2016). Optimization of Pulsed Vacuum Osmotic Dehydration of Sliced Tomato. *Drying Energy Technology*, 63, 207–228. DOI: 10.1007/978-3-319-19767-8_11.

Corrêa, J. L.; Justus, A.; de Oliveira, L. F. and Alves, G. E. (2015). Osmotic Dehydration of Tomato Assisted by Ultrasound: Evaluation of the Liquid Media on Mass Transfer and Product Quality. *International Journal of Food Engineering,* 11, 505–516. DOI: 10.1515/ijfe-2015-0083.

Correa-Filho, L. C.; Lourenc¸o, S. C.; Duarte, D. F.; Mold~ao-Martins, M. and Alves, V. D. (2019). Microencapsulation of Tomato (Solanum Lycopersicum L.) Pomace Ethanolic Extract by Spray Drying: Optimization of Process Conditions. *Applied Sciences*, 9, 612. DOI: 10.3390/app9030612.

Comfort, O. O., Adams, U. I. and Promise, A. N (2019). A Review on Postharvest Storage, Processing and Preservation of Tomatoes (Lycopersicon esculentum Mill). *Asian Food Science Journal. 6(2): 1-10. DOI: 10.9734/AFSJ/2019/44518.*

Chawla, C.; Kaur, D.; Oberoi, D.; Sogi, D. (2008). Drying Characteristics, Sorption Isotherms, and Lycopene Retention of Tomato Pulp. *Drying Technology*, 26, 1257–1264. DOI: 10.1080/07373930802307225.

Dorouzi, M., Mortezapour, H., Akhavan, H. R., Moghaddam, A. G. (2018) Tomato slices drying in a liquid desiccant-assisted solar dryer coupled with a photovoltaic-thermal regeneration system. *Solar Energy*, 162, 364–371

Doymaz, I. (2012). Infrared drying of sweet potato (*Ipomoea batatas* L.) slices. *Journal of Food Science and Technology*, *49*(6), 760–766. https :// doi.org/10.1007/s13197-010-0217-8

Demiray, E.; Tulek, Y. and Yilmaz, Y. (2013) Degradation Kinetics of Lycopene, b-Carotene and Ascorbic Acid in Tomatoes during Hot Air Drying. *LWT - Food Science and Technology*, 50, 172–176. DOI: 10.1016/j.lwt.2012.06.001.

Engin D., Yahya T. and Yusuf Y. (2013). Degradation kinetics of lycopene, b-carotene and ascorbic acid in tomatoes during hot air drying. *Food Science and Technology.* 50, 172-176

Escher, G. B.; Coelho, S. R. M.; Christ, D. (2017). Optimization of Osmo-Convective Dehydration Process for Dry Tomato Production. *Journal of Food Processing and*

Preservation, 41, e12932. DOI: 10.1111/jfpp.12932.

Food and Agriculture Organization Corporate Statistical Database [FAOSTAT] (2018). Database of the Organisation of the United Nations. 2018. http://fao.org [30/10/2018].

Food and Agriculture Organization [FAO] (2019). Sun-dried tomato processing in Nubaria. CA5206EN/1/08.19

Fernandes, F. A.; Rodrigues, S.; Garcıa-Perez, J. V. and Carcel, J. A. (2016). Effects of Ultrasound-Assisted Air-Drying on Vitamins and Carotenoids of Cherry Tomatoes. *Drying Technology*, 34, 986–996. DOI:10.1080/07373937.2015.1090445.

Gaware, T.; Sutar, N. and Thorat, B. (2010). Drying of Tomato Using Different Methods: Comparison of Dehydration and Rehydration Kinetics. *Drying Technology*, 28, 651–658. DOI: 10.1080/07373931003788759.

Goula, A. M. and Adamopoulos, K. G. (2004). Spray Drying of Tomato Pulp: Effect of Feed Concentration. *Drying Technology*, 22, 2309–2330. DOI: 10.1081/DRT-200040007.

Goula, A. M. and Lazarides, H. N. (2012). Modeling of Mass and Heat Transfer during Combined Processes of Osmotic Dehydration and Freezing (Osmo-Dehydro-Freezing). *Chemical Engineering Science*, 82, 52–61. DOI: 10.1016/j.ces.2012.07.023.

Gould, W. A. (2013). Tomato Production, Processing and Technology. *Elsevier; Baltimore USA*, 125–151.

Grbavcic, Z. B.; Arsenijevic, Z. L. and Garic-Grulovic, R. V. (2004). Drying of Slurries in Fluidized Bed of Inert Particles. *Drying Technology*, 22, 1793–1812. DOI: 10.1081/DRT-200032742.

Gümüsay, Ö. A.; Borazan, A. A.; Ercal, N.; Demirkol, O. (2015). Drying Effects on the Antioxidant Properties of Tomatoes and Ginger. *Food Chemistry*, 173, 156–162. DOI: 10.1016/j.foodchem.2014.09.162.

Hebbar, H. U., and Rostagi, N. K. (2001). Mass transfer during infrared drying of cashew kernel. *Journal of Food Engineering*, *47*, 1–5. https ://doi.org/10.1016/S0260-8774(00)00088-1

Horuz, E.; Jaafar, H. J. and Maskan, M. (2017). Ultrasonication as Pretreatment for Drying of Tomato Slices in a Hot Air–Microwave Hybrid Oven. *Drying Technology*, 35, 849–859. DOI: 10.1080/07373937.2016.1222538.

Izli, N. and Isik, E. (2015). Color and Microstructure Properties of Tomatoes Dried by Microwave, Convective, and Microwave-Convective Methods. *International Journal of Food Properties*, 18, 241–249. DOI: 10.1080/10942912.2013.829492.

Jangam, S. V.; Joshi, V. S.; Mujumdar, A. S. and Thorat, B. N. (2008). Studies on Dehydration of Sapota (Achras Zapota). *Drying Technology*, 26, 369–377. DOI: 10.1080/07373930801898190.

Jeyaprakash, S.; Frank, D. and Driscoll, R. (2016). Influence of Heat Pump Drying on Tomato Flavor. *Drying Technology*, 34, 1709–1718. DOI: 10.1080/07373937.2016.1174937.

Jorge, A.; Sauer Leal, E.; Sequinel, R.; Sequinel, T.; Kubaski, E. T. and Tebcherani, S. M. (2018). Changes in the Composition of Tomato Powder (Lycopersicon esculentum Mill) Resulting from Different Drying Methods. *Journal of Food Processing and Preservation*, 42, e13595. DOI: 10.1111/jfpp.13595.

Joshi, N.; Gariepy, Y. and Raghavan, G. V. (2008). Comparative Evaluation of Different Pretreatments on Tomato Slices Dried in a Cabinet Air Drier. *International Journal of Food Engineering*, 4(7). DOI: 10.2202/1556-3758.1261.

Krishna K. P. and Abhijit K. (2012). Heat pump assisted drying of agricultural produce. *Journal of Food Science and Technology*, 49(2), 142–160 DOI 10.1007/s13197-011-0334-z

Kohli, D., Champawat, P. S., Mudgal, V. D., Jain, S. K., and Tiwari, B. K. (2021). Advances in peeling techniques for fresh produce. *Journal of Food Process Engineering*, e13826. https://doi.org/10.1111/jfpe.13826

Koné, K. Y.; Druon, C.; Gnimpieba, E. Z.; Delmotte, M.; Duquenoy, A.; Laguerre, J. C. (2013) Power Density Control in Microwave Assisted Air Drying to Improve Quality of Food. *Journal of Food Engineering*, 119, 750–757. DOI: 10.1016/j.jfoodeng.2013.06.044.

Kocabiyik, H.; Yilmaz, N.; Tuncel, N. B.; Sumer, S. K. and Burak, B. M. (2014). The Effects of Middle Infrared Radiation Intensity on the Quality of Dried Tomato Products. *International Journal of Food Science & Technology*, 49, 703–710. DOI: 10.1111/ijfs.12353.

Kocabiyik H., Nese Y., Necati B. T., Sarp K. S. and Mehmet B. B. (2015). Drying, Energy, and Some Physical and Nutritional Quality Properties of Tomatoes Dried with Short-Infrared Radiation. *Food Bioprocess Technology*, 8, 516–525. DOI 10.1007/s11947-014-1418-3

Kocabiyik, H.; Yilmaz, N.; Tuncel, N.; Sumer, S. and Buyukcan, M. (2016). Foods, Quality Properties, Mass Transfer Characteristics and Energy Consumption during Shortwave Infrared Radiation Drying of Tomato. *Quality Assurance and Safety of Crops & Foods*, 8, 447–456. DOI: 10.3920/QAS2014.0550.

Laura W. (2022). Global sun dried tomatoes market to 2030- Rising trend of organic product consumption in the food industry. https://www.researchandmarkets.com/r/9vp9ao

Lavelli, V., Pompei, C. and Casadei, M.A. (2009). Quality of nectarine and peach nectars as affected by lye-peeling and storage. *Food Chemistry*, 115, 1291–1298. https://doi.org/ 10.1016/j. foodchem.2009.01.047.

Lavelli, V. and Torresani, M. C. (2011). Modelling the Stability of Lycopene-Rich byproducts of Tomato Processing. *Food Chemistry*, 125, 529–535.

Majzoobi, M.; Ghavi, F. S.; Farahnaky, A.; Jamalian, J. and Mesbahi, G. Effect of Tomato Pomace Powder on the Physicochemical Properties of Flat Bread (Barbari Bread). *Journal of Food Processing and Preservation*, 35, 247–256. DOI: 10.1111/j.1745-4549.2009.00447. x.

Mohammad R. I. and Wei C. (2017). Trends of spray drying: A critical review on drying of fruit and vegetable juices. *Trends in Food Science & Technology*, 65:49e67 http://dx.doi.org/10.1016/j.tifs.2017.05.006.

Mohsen, H. A.; Abd El-Rahmam, A. and Hassan, H. (2019). Drying of Tomato Fruits Using Solar Energy. *Agricultural Engineering International: CIGR Journal*, 21(2), 204-215.

Moreno, G., D. C. and Díaz-Moreno, A. C. (2017). Effect of Air-Drying Process on the Physicochemical, Antioxidant, and Microstructural Characteristics of Tomato cv. *Chonto. Agronomía Colombiana*, 35, 100–106. DOI: 10.15446/agron.colomb.v35n1.57727.

Min Z., Huizhi C., Arun S. M., Juming T., Song M. and Yuchuan W. (2015). Recent development in high-quality drying of vegetables, fruits and aquatic products. *Critical review in food science and nutrition.* DOI:10.1080/10408398.2014979280

Nikita S. Bhatkar, Shivanand S. Shirkole, Arun S. Mujumdar and Bhaskar N. Thorat (2021): Drying of tomatoes and tomato processing waste: a critical review of the quality aspects, *Drying Technology*, DOI: 10.1080/07373937.2021.1910832

Okaiyeto S. A.; Unguwanrimi, Y. A.; Ogijo, S. I.; Jonga, B. J. and Sada, A. M. (2020). Comparative Studies of Two Developed On-farm Solar Dryers for Vegetables. *Journal of Engineering Research and Reports*, 10(4), 26-35. DOI: 10.9734/JE'RR/2020/v10i417046

Örvös, M.; Gyula, S.; Zsombor, V. (2014). Energy Consumption of Tomato Drying. International Scientific Conference on Advances in Mechanical Engineering, 2, 1–6.

Ozlem A. G., Alev A. B., Nuran E. and Omca D. 2015. Drying effects on the antioxidant properties of tomatoes and ginger. *Food chemistry,* 173, 156-162 http://dx.doi.org/10.1016/j.foodchem.2014.09.162

Pfander, H. (1992). Carotenoids, chemistry: synthesis, properties and characterization. Methods in Enzymology, 213A, 3e13.

Poonnoy, P.; Tansakul, A. and Chinnan, M. (2007). Artificial Neural Network Modeling for Temperature and Moisture Content Prediction in Tomato Slices Undergoing microwave-vacuum drying. *Journal of Food Science,* 72, E042–E047. DOI: 10.1111/j.1750-3841.2006.00220. x.

Qiu, Z. Z. and Chin, K. B. (2020). Physicochemical Properties and Shelf-Life of Regular-Fat Sausages with Various Levels of Grape Tomato Powder Prepared by Different Drying Methods. *Food Science of Animal Resources,* 40, 722–733. DOI: 10.5851/KOSFA.2020.E47.

Ramya V. and JAIN N. K. (2016). A review on osmotic dehydration of fruits and vegetables: an integrated approach. *Journal of Food Process Engineering,* 1(1), 1745–4530 Doi:10.1111/jfpe.12440

Rajkumar, P.; Kulanthaisami, S.; Raghavan, G.; Gari_epy, Y. and Orsat, V. (2007). Drying Kinetics of Tomato Slices in Vacuum Assisted Solar and Open Sun Drying Methods. *Drying Technology,* 25, 1349–1357. DOI: 10.1080/07373930701438931.

Reyes, A.; Mahn, A.; Huenulaf, P. and Gonzalez, T. (2014). Tomato Dehydration in a Hybrid-Solar Dryer. *Chemical Engineering & Process Technology Journal*, 5, 1–8.

Ringeisen, B.; Barrett, D. M. and Stroeve, P. (2014). Concentrated Solar Drying of Tomatoes. *Energy for Sustainable Development,* 2014, 19, 47–55. DOI: 10.1016/j.esd.2013.11.006.

Sagar, V. R., and Kumar, P. S. (2010). Recent advances in drying and dehydration of fruits and vegetables: A review. *Journal of Food Science and Technology*, *47*(1), 15–26. https ://doi.org/10.1007/s13197-010-0010-8

Saini, R.K.; Moon, S.H. and Keum, Y. S. (2018). An updated review on use of tomato pomace and crustacean processing waste to recover commercially vital carotenoids. *Food Resources International*, 108, 516–529.

Sacilik, K. (2007). The Thin-Layer Modelling of Tomato Drying Process. *Agriculturae Conspectus Scientificus* , 72, 343–349.

Santos-Śanchez, N. F.; Valadez-Blanco, R.; G_omez-Ǵomez, M. S.; Ṕerez-Herrera, A. and Salas-Coronado, R. (2012). Effect of Rotating Tray Drying on Antioxidant Components, Color and Rehydration Ratio of Tomato Saladette Slices. *LWT Food Science and Technology,* 46, 298–304. DOI: 10.1016/j.lwt.2011.09.015.

Seid M. J., Cordin A., Miguel A. C. and Katarzyna S. (2021). Nano spray drying of food ingredients; materials, processing and applications. *Trends in Food Science & Technology,* 109:632–646. https://doi.org/10.1016/j.tifs.2021.01.061

Serghei. C. (2010). Effects of conventional and multistage drying processing on non-enzymatic browning in tomato. *Journal of Food Engineering,* 96, 114–118. doi:10.1016/j.jfoodeng.2009.07.002

Silva, Y. P.; Ferreira, T. A.; Celli, G. B. and Brooks, M. S. (2019). Optimization of Lycopene Extraction from Tomato Processing Waste Using an Eco-Friendly Ethyl Lactate–Ethyl Acetate Solvent: A Green Valorization Approach. *Waste Biomass Valorization*, 10, 2851–2861. DOI: 10.1007/s12649-018-0317-7.

Souza, J. S.; Medeiros, M. F.; Magalh~aes, M. M.; Rodrigues, S. and Fernandes, F. A. (2007) Optimization of Osmotic Dehydration of Tomatoes in a Ternary System Followed by Air-Drying. *Journal of Food Engineering,* 83, 501–509. DOI: 10.1016/j.jfoodeng.2007.03.038.

Souza, A.L.R., Hidalgo-Chàvez, D.W., Pontes, S.M., Gomes, F.S., Cabral, L.M.C. and Tonon,

L. V., (2018). Microencapsulation by spray drying of a lycopene-rich tomato concentrate: characterization and stability. *LWT - Food Science and Technology*, 91, 286–292.

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

Tan, S.; Ke, Z.; Chai, D.; Miao, Y.; Luo, K. and Li, W. (2021). Lycopene, Polyphenols and Antioxidant Activities of Three Characteristic Tomato Cultivars Subjected to Two Drying Methods. *Food Chemistry*, 338, 128062. DOI: 10.1016/j.foodchem.2020.128062.

Tonon, R. V.; Baroni, A. F. and Hubinger, M. D. (2007). Osmotic Dehydration of Tomato in Ternary Solutions: Influence of Process Variables on Mass Transfer Kinetics and an Evaluation of the Retention of Carotenoids. *Journal of Food Engineering*, 82, 509–517. DOI: 10.1016/j.jfoodeng.2007.03.008.

Toor, R. K. and Savage, G. P. (2006). Effect of Semi-Drying on the Antioxidant Components of Tomatoes. Food Chem. 94, 90–97. DOI: 10.1016/j.foodchem.2004.10.054.

Xie, L., Mujumdar, A. S., Fang, X. M., Wang, J., Dai, J. W., Du, Z. L., *et al*. (2017). Far-infrared radiation heating assisted pulsed vacuum drying (FIR-PVD) of wolfberry (*Lycium barbarum* L.): Effects on drying kinetics and quality attributes. *Food and Bioproducts Processing, 102*, 320–331.

Xie, Y. C., Gao, Z. J., Liu, Y. H., & Xiao, H. W. (2017). Pulsed vacuum drying of rhizoma dioscoreae slices. *Lebensmittel-Wissenschaft und -Technologie- Food Science and Technology, 80*, 237–249.

Wang, H., Fang, X. M., Sutar, P. P., Wang, J., Yu, X. L., & Xiao, H. W. (2021). Effects of vacuum-steam pulsed blanching on drying kinetics, colour, phytochemical contents, antioxidant capacity of carrot and the mechanism of carrot quality changes revealed by texture, microstructure and ultrastructure. *Food Chemistry*, *338*, 127799. https://doi.org/10.1016/j.foodchem.2020.127799

Weipeng Zhang, Zhongli Pan, Hong-wei Xiao, Zhian Zheng, Chang Chen and Zhenjiang Gao (2017): Pulsed vacuum drying (PVD) technology improves drying efficiency and quality of poria cubes, *Drying Technology*, DOI: 10.1080/07373937.2017.1362647

Wang, J., Law, C. L., Nema, P. K., Zhao, J. H., Liu, Z. L., Deng, L. Z., *et al*. (2018). Pulsed vacuum drying enhances drying kinetics and quality of lemon slices. *Journal of Food Engineering, 224*, 129–138.

Yu-Peng Pei , Sriram K. Vidyarthi , Jun Wang , Li-Zhen Deng , Hui Wang, Gao-Fei Li , Zhi-An Zheng , Min Wu and Hong-Wei Xiao (2021): Effect of vacuum-steam pulsed blanching (VSPB) on drying characteristics and quality properties of garlic slices, *Drying Technology*, DOI: 10.1080/07373937.2020.1861620

Yu-Peng Pei, Sriram K. Vidyarthi , Jun Wang , Li-Zhen Deng , Hui Wang , Gao-Fei Li , Zhi-An Zheng , Min Wu & Hong-Wei Xiao (2021). Effect of vacuum-steam pulsed blanching (VSPB) on drying characteristics and quality properties of garlic slices, *Drying Technology*, DOI: 10.1080/07373937.2020.1861620