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DRYING TECHNOLOGY – CURRENT RESEARCH AND INDUSTRIAL APPLICATIONS

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Review Based Book Chapter

DRYING PROCESS IN FRUITS AND VEGETABLES INDUSTRIES

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REVIEW BASED BOOK CHAPTER

DRYING PROCESS IN FRUITS AND VEGETABLES INDUSTRIES

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Abstract

Fruit and vegetables are vital parts of a human diet due to their high nutritional value. These food groups are the main source of micronutrients, fiber and important phytochemicals. Due to high moisture content (80%), loss and waste in fruits and vegetables are the highest among all types of foods, and may reach up to 60%. In this regard, drying process is an important parameter in fruit and vegetable industries used for processing or preservation purposes. A number of drying techniques have been developed over the years to turn perishable commodities into stabilized goods by preserving quality attributes, increase shelf life, and reduce transport weight. Advanced drying techniques such as solar, microwave, vacuum, infrared, freeze and spray dryings have been developed around the globe as being successfully used for various fruits and vegetables. Moreover, dried products of fruit and vegetables are broadly used by the industries related to confectionery, bakery, in sweets and distilling industries in the development of versatile by-products including sauces, teas, puddings, and food supplements for infants as well as children. The effect and applications of these drying techniques in fruit and vegetable industries are discussed in this chapter.

Keywords

Fruits, Vegetables, Drying Techniques, Preservation, Industrial Applications

1. Introduction

Fruits and vegetables are essential components of the human diet and there is considerable evidence that their ingestion has health and nutritional advantages [1]. Fruits and vegetables are widely recognized for their high nutritional value, which includes micronutrients (vitamins and minerals), dietary fibers and contains a wide range of phytochemicals that individually or combination are beneficial to human health [2]. The nutritive importance of fruits and vegetables along with their potential health benefits shows in Table 1.1. The World Health Organization (WHO) recommends consuming five to eight servings (400-600 g) of fruits and vegetables each day. In order to lower the risk of cardiovascular disease, cancer, poor cognitive function, and other diet-related disorders as well as to prevent micronutrient deficiencies [3].

Table 1.1 Nutritive value and potential health benefits of fruits and vegetables

Nutrients	Sources	Human health benefits	References
1. Micronutrients			
Vitamin C (ascorbic acid)	Broccoli, cabbage, citrus fruits, guava, kiwifruit, leafy greens, pineapples, potato, strawberry, tomato, watermelon	Scurvy prevention, wound healing, cardiovascular disease, healthy immune system	[2]
Vitamin E (tocopherols)	Avocado, nuts (such as almonds, nuts, peanuts, pistachio, walnuts), green leafy vegetables	Cancer, diabetes, heart disease, immune system, LDL oxidation	
Vitamin K	Crucifers (such as broccoli, sprouts, cabbage), green onions, nuts, leafy greens	Osteoporosis, synthesis of procoagulant factors	
Vitamin B9 (folate)	Dark green vegetables (such as spinach, mustard greens, lettuce, broccoli, sprouts)	Birth defects, cancer, heart disease	
2. Dietary Fibers			
Dietary fibers	Most fruits and vegetables	Decrease the risk of chronic diseases such as cardiovascular disease, type 2 diabetes mellitus, cancer and weight lose	[4]
3. Phytochemicals			
Phenolic acids	Seeds, fruits and leafy green vegetables	Prevents cardiovascular diseases, anti-inflammatory and anticancer	[5]
Flavonols	Kale, onion, lettuce, and tomatoes	prevent cardiovascular diseases, heart related disorder, prevents blood clotting and human gingival diseases	[6]
Flavones	Tomatoes, onions, lettuce and kale	Cardiovascular properties and neuroprotective	[7]
Flavanones	Lemons, oranges and grape fruits	Reduced lipid level and prevents cardiovascular	[8]

		diseases	
Anthocyanidin	Radish, beetroot, berries, strawberries and cherries	Antimicrobial properties, anticancer and antidiabetic activities, prevents cardiovascular disease	[9]
Resveratrol	Grapes, berries and wine	Lowers blood pressure, helps in preventing cardiovascular diseases and skin cancer	[8]
Lignans	Seeds (flax, pumpkin, sunflower, poppy, sesame), barriers	Reduced risk of osteoporosis, breast cancer, menopausal symptoms, and heart problems	[10]
Tannins	Legume seeds, peas, some leafy and green vegetables	Anti-inflammatory, anti-oxidant, anti-cancerous, and anti-microbial properties	[11]

Food is essential for both human survival and the ecosystem. It can be eaten either raw or processed to provide value-added goods. However, a growing concern has led to an increase in global food waste due to exponential rise in population and instability in supply chains [12]. Globally, around 1.3 billion tonnes of food are lost or wasted each year, and this figure is growing [13]. According to FAO [14], stages where possible causes of food loss and waste occurred are shown in Figure 1.

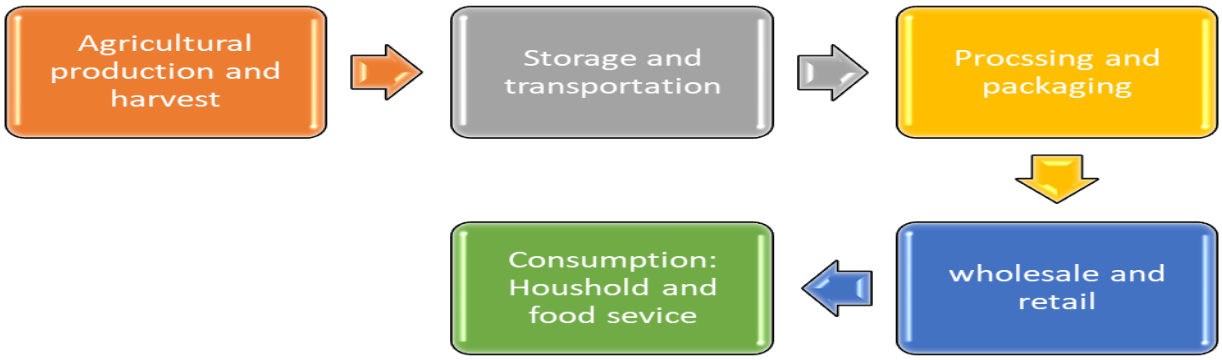

Figure 1 Possible causes of food loss and waste [14]

Fruit and vegetables are one of the most consumed commodities globally, accounting for more than 42% of total food wastage [13]. Food and Agriculture Organization (FAO)

has estimated that losses and waste in fruits and vegetables are the highest among all types of foods, and may reach up to 60% [15]. Figure 2 depicts the amount of food waste caused by each food item, together with overall waste percentage in fruits and vegetables.

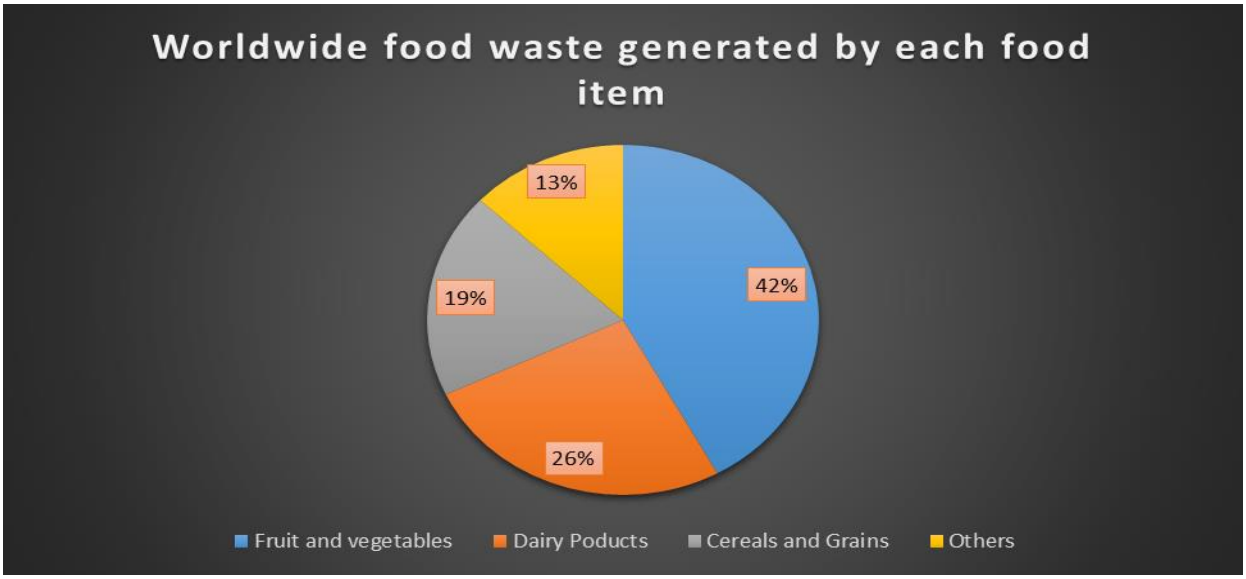

Figure 2 Worldwide food waste generated by each food item

Fruits and vegetables have grown more valuable commercially, and growing them on a large scale for market has become important sector of the agricultural industry [16]. Fresh fruits and vegetables contain more than 80% water and considered as extremely perishable items that degrade quickly [17]. Post-harvest losses and wastages plague the whole supply chain of perishable food commodities [18]. About 30% to 50% losses have been reported in fruits and vegetables from the farm gate to consumer's level. Losses result in unacceptable levels of food insecurity among the world's population. These commodities require suitable transportation, handling, and storage facilities in order to reach a consumer in a fresh form because of their short shelf life and perishable nature [17, 18]. After harvest, post storage procedures are necessary to keep the product fresh and preserve its nutritional content. Storage solutions available across the world demand a low temperature for product preservation; yet, their increased cost and lack of availability in many locations are significant limits [19]. One of the main objectives of food processing or preservation is to turn perishable commodities,

including fruits and vegetables, into stabilized goods that can be kept for long periods of time to minimize postharvest losses [16]. Factors that Influence postharvest quality are represented in Table 1.2. Drying is an important process for preservation of food components and it is widely applicable in food sectors [20]. Different types of drying techniques are suitable to reduce losses and to preserve fruits and vegetables with maintained quality [17].

Table 1.2 Postharvest factors that influence quality of fruits and vegetables

Factors	Description	References
Intrinsic factors	Related to inherent characteristics, such as • Genetic factors, • Maturity stage in harvest • Susceptibility to physiological disorders	[21]
Extrinsic factors	Related to development's ambient and technologies, such as • Handling (harvest, package, transportation, storage, and commercialization) • Technological (control of temperature, relative humidity, irradiation, chemical treatments)	[21]

2. Drying Techniques in Fruit and Vegetables Industries

Drying is one of the oldest and widely used method of food preservation. It involves the removal of moisture from a product due to couple heat and mass transfer. The elimination of moisture reduces several moisture-mediated deteriorative processes and stops the development and reproduction of microorganisms that cause decay [16]. The preservation of fruits and vegetables through drying dates back many centuries due to preserve quality attributes, increase shelf life, and reduce transport weight of fruit and vegetable. The poor quality and product contamination lead to the development of alternate drying technologies [19, 22]. A number of drying techniques have been developed over the years. These different types of drying techniques and the impact of drying on selected fruits and vegetables preservation and quality discussed below.

2.1. Solar Drying

Solar drying is one of the oldest applications of solar energy; hence goods are exposed to direct sunlight by being put on the ground. Agricultural products were traditionally

dried mechanically, which was time-consuming and expensive. Additionally, the dried goods from those dryers weren't fully hygienic. Therefore, with no energy cost, the solar dryer technology offered a new, safer, and healthier way to dry fruits and vegetables [23]. A solar dryer was used to dry fruit and vegetables because foods have a high primary moisture content; if it remains at the same level, the product will deteriorate and decrease its quality [24]. Numerous types of solar dryers have been developed with various designs such as chamber based, rack/tray type, bin, and tunnel type for agricultural products [25].

Solar drying is used to improve the color, taste and appearance of the products. Solar drying is lowering the possibility of microbial development, as well as preventing insect infection, contamination with foreign objects, and toxin buildup. The solar drier developed was able to produce 48 °C to 54 °C average drying temperature [26]. Solar dryers are classified according to the mode of air circulation, such as natural circulation known as passive dryers and forced circulation dryers also called active dryers [27]. According to the study passive type solar dryers have property of natural heated air movement that is easily constructed, and inexpensive. These are used to dry various fruits (bananas, pineapples, and mangoes) and vegetables (potatoes, carrots, and French beans) in small batches [17].

2.2. Microwave Drying

A different drying technique that has gained favor in recent years for a number of commercial food items is microwave drying (MWD). It can be regarded as a rapid dehydration process significantly reducing the drying time, up to 89% according to certain authors. A MW drying process consists in three drying phases (1) a heating-up period during which the product's temperature rises over time as MW energy is transformed into thermal energy inside the wet materials (2) thermal energy is employed for moisture vaporization and transmission during a quick drying phase (3) reduced drying rate period during which the local moisture is reduced to a point that the energy needed for moisture vaporization is lower than the thermal energy induced by MW [28].

Microwave technology is used to quickly dry fruits and vegetables, and electromagnetic radiation plays a significant role in both the internal and external heating of the product [17]. Numerous studies have demonstrated the benefits of microwave-assisted fruit and vegetable drying. Excellent quality was identified in dried carrots in terms of color, shrinkage, and rehydration ability [29]. Microwave-dried raisins were found to be of higher quality than hot air-dried samples in terms of color, damage, blackness, sugar crystallization, stickiness, and uniformity [30]. Compared to convection drying, microwave drying has a number of benefits, but there are some drawbacks as well that are presented in Table 2.1.

Table 2.1 Advantages and limitations of microwave drying [29]

Advantages	Limitations
Higher drying rate	Product texture may be affected
Lower operating costs	High initial costs for industrial scale dryer
Short drying time	Partial loss of aroma and negative sensory changes
Reduced energy consumption	Specific sample size and shape may be required for effective drying

2.3. Freeze Drying

Freeze drying (FD) has become an important technology used to extend shelf-life and to preserve food nutritional quality [31]. Drying different fruits and vegetables using the freeze-drying technique is a useful method. Freeze drying is the sublimation of an ice fraction, which is the process by which water transforms from a solid into a gas. Due to very low temperature all the deterioration activity and microbiological activity are stopped and provide better quality to the final product [17, 19]. Recently, the market for organic products is increasing. Therefore, the use of freeze drying of fruits and vegetables is not only increasing in volume but also diversifying [19]. Sanchez et al. [32] showed that, encapsulated freeze-dried cherry juice in powdered form produced a higher stability of total monomeric anthocyanin during storage at 38 °C.

When compared to guava powder made by vacuum and heat pump dryers, FD-produced guava had the best porosity, colour, rehydration, and vitamin C retention. The heat pump dryer only managed to preserve 25% of the vitamin C, compared to 63% for the FD [33]. FD reduced the drying time for the development of banana chips

with the assistance of infrared radiation treatment and additionally dipping of acid improves color retention and produced crispiness [34]. Additionally, FD increased the number of flavonoids and anthocyanins in red onions during extraction and preserved those substances (flavonoids and anthocyanins) in their powder form for up to six months of storage [35]. It has been reported that berries (blueberries, tart cherries, strawberries, and cranberries) dried using FD retained more phytochemicals, such as antioxidants, ascorbic acid, and phenolic contents, compared to berries dried using air drying (AD), which produced worse quality [36]. FD showed improved preservation of chemical profiles, antioxidant activity, and cellular structure due to its less extreme heating. However, had relatively higher energy consumption and drying time [37].

2.4. Vacuum Drying

Vacuum drying is a novel technology that allows obtaining a high-quality final product while preserving its original nutritional value. Vacuum drying is performed under low pressure conditions. The heat transfer effect is produced by the convection or radiation method. The use of vacuum guarantees a sparing effect on the product being dried due to the low values of drying temperatures [38]. Vacuum drying technology is an important process for drying highly heat-sensitive and perishable commodities, which are widely used in the pharmaceutical as well as in food products and biotechnology The methods of vacuum drying can be analyzed based on the physical parameters utilized for applying heat and eliminating water vapor [17, 39]. It can dry products more quickly, at a lower temperature, with better rehydration capacity and less energy use. It also helps preserve product color, flavor, and other contents including vitamins and volatile aromas as shown in Table 2.2 [17]. Fernando and Thangavel [40] compared the quality of coconut which is dried through VDT and found it superior as compared to the product that was conventionally dried.

Table 2.2 Effects of vacuum drying on the quality of different fruits and vegetables

Fruit/vegetable	Effect	Reference
Beetroots	High quality product with no color degradation	[41]
Carrots	Positive impact on drying time and quality improvement	[42]
Apples	Had no effect on the	[43]

	compositions of slices that were enhanced with quercetin	
Dates	Maintains overall quality with no color degradation of their pulp	[44]
Mangoes	enhances color parameter, drying consistency, and reduced drying time	[45]
Potato	High drying rate and reduced moisture percentage with assistance of infrared	[46]

2.5. Spray Drying

Making fruit and vegetable juice powders is a viable way to cut costs associated with shipping, storage, and packaging. Juices from fruit and vegetable can be preserved from weeks to months while powdered products produced from fruit and vegetable juices can be preserved from months to years depending on packaging. Spray drying is the most cost-effective method for quickly dehydrating food while preserving quality and turned liquid goods directly into powder [47]. SD is widely utilized in industry, particularly in the production of fruit and dairy products [47, 48]. The spray-dried product is highly stable, because of its low moisture content and water activity. The typical ranges for spray-dried fruit and vegetable powders' moisture content and water activity are 2–5% and 0.2–0.6, respectively [47].

It was discovered that spray drying method was 4-5 times less expensive than freeze-drying. Furthermore, compared to FD, it was demonstrated that using the SD technique to dehydrate chokeberry juice into powders improved the retention of total phenolic components, total flavonoids, and total monomeric anthocyanin [49, 50]. Izidoro et al. [51] concluded that because of the high temperature and atomization nature of the spray drying approach, green banana starch solubility, swelling power, and water absorption capacity are increased. In another study banana was dried into powder using modified spray dryer and result showed that banana powder retained its color and flavor [52]. Quek et al. [53] produced spray-dried watermelon powder with best colorimetric results, low moisture content, low water activity and good lycopene and ß-carotene contents in powder. Phoungchandang and Sertwasana [54] spray dried the

ginger juice. Goula and Adamopoulos [55] studied the performance of a modified spray dryer for tomato powder preparation under various operating conditions.

2.6. Infrared (IR) Drying

Infrared drying is based on a property of water to absorb infrared radiation [56]. The fundamental idea of an infrared dryer is to heat and dry materials that contain moisture by using radiations. These radiations enter exposed materials and increase their internal temperature [17]. Infrared drying has great advantages over traditional air drying. Studies have shown that infrared has an effective moisture diffusivity and a higher thermal sensitivity than air drying [57].

Zhu and Pan [58] study showed that the high radiation intensity and apple thin slices had faster increase of product temperature, and quicker moisture removal. According to another study irradiated surface evaporates significantly more water than that which is not heated by IR energy [59]. Nimmol et al. [60] examined the behavior of heat transport and drying in bananas using infrared radiation and low-pressure superheated steam. IR drying could be a favorable way to drying carrots. One of the ways to shorten the carrot slice drying time is to supply heat by IR radiation [61].

3. Drying Applications in Selected Fruit and Vegetable Crops

3.1. Potatoes

Potato (Solanum tuberosum L.) belongs to *Soulanacea* family. After corn, wheat, and rice, potatoes are the fourth-largest food crop, and they are widely grown and eaten all over the world [62]. The Food and Agriculture Organization (FAO) reported that global potato output was around 3.68 108 t in 2018 and the top five potato producers worldwide were China, India, the United States, Ukraine, and the Russian Federation [63]. The important amino acids histidine and lysine, which are limited in grains, are abundant in potato tubers along with vitamins, dietary fiber, minerals, and other nutrients [64].

Due to their short dormancy period and high moisture content, fresh potatoes have a limited shelf life and are sensitive to deterioration. Drying is one of the most widely used

methods for potato preservation and processing [64, 65]. Potato drying is believed as a better method of storage as well as the best choice for value-added product development which ultimately enhances profitability [17]. In order to increase the nutritional content of flour-based foods, the dried potato powder can be used as a thickening to enhance flavour and colour as well as to partially replace wheat flour [62]. Different drying methods, such as microwave drying, high voltage electric field drying, vacuum heat pump drying, and freeze drying were available for fruit and vegetable products [63].

One of the most popular drying techniques for agricultural products has been hot-air drying. However, its two main drawbacks are the low quality of its dried goods and the lengthy drying process [66]. Supmoon and Noomhorm [67] studied hot-air-assisted with infrared drying to produce potato chips that is health-friendly instead of traditional deep-fat drying method. In previous studies, infrared drying offered a faster rate of drying, a lower proportion of shrinkage, and also a lessened colour degradation [17]. Potato slices were successfully dried using far infrared radiations and vacuum technology; the process was very energy-efficient, uniformly heated, and produced a high-quality end product [46]. The most important aspect of thermal mode drying is temperature optimization; drying potatoes at 70°C in a microwave-vacuum dryer results in a reduced moisture percentage but degrades the quality in terms of visual colour. However, after 150 minutes of drying at 50 and 60 degrees Celsius, the visual colour quality was adequate, although drying at 50 degrees required more time [68].

3.2. Carrots

Carrot (*Daucus carrota* L.) is one of the important vegetables grown throughout the word [69]. The carrot is widely utilized in human nutrition because to its high level of fiber, b-carotene, and vitamins A, B1, B2, B6, and B12. Its water content ranges from 86% to 93%, and it is highly vulnerable to moisture loss, which shortens its shelf life [17]. Carrots can also be stored for a long time by drying them. Dried carrots are used as an ingredient in various food products, such as soups, sauces, ready-meals as well as healthy snacks [70]. Therefore, numerous researchers have looked at the effects of

various drying techniques and dryers such as vacuum dryer, microwave and hot-air drying on the drying of carrots [17].

A novel drying technique using a combination of ultrasound and vacuum dehydration was developed to shorten the drying time and improve the quality of carrot slices. The high content of carotene is a unique property that makes dried carrot slices an excellent candidate for developing oil free, healthy snack foods. However, the nutritional value must be well preserved and a puffed texture should be generated in the drying process [42].

Kocabiyik et al. [70] dried carrot slices from initial moisture content of 8.52 kg water kg−1 dry matter to 0.11 kg water kg−1 dry matter by infrared dryer however, Shrinkage, rehydration ratio and colour parameters were found to be affected by process variables. A two-step microwave drying procedure and its impact on carrot quality were described by Wang and Xi [71]. It was shown that utilizing a lower power level during the second drying cycle can successfully minimize the loss of β-carotene.

3.3. Tomatoes

Tomato is the world's most commonly commercially produced vegetable. The world tomato production reached 124,111,781 metric tons [72]. Epidemiological studies have shown that consumption of tomatoes lowers the incidence of certain malignancies and cardiovascular diseases, demonstrating that tomatoes are unquestionably a functional diet [73]. Tomatoes are consumed fresh as well as in a processed form, around 80% of the crop is processed to create value-added products including tomato juices, ketchup, and sauces. Tomatoes can be preserved in a variety of ways, including canning, drying, and processing. To store tomatoes for an extended period of time, they can be dried and turned into flakes or powder. Different techniques, including hot air, sunlight, microwave, and freeze drying have been employed [17, 72].

Industrial processing of tomatoes to a final moisture content of <15% often involves high temperatures (60–110 °C) for a period of 2–10 h in the presence of oxygen, and therefore, the products show some oxidative damage and during the production of dried tomato halves and tomato pulp at high temperatures, significant ascorbic acid

losses have been shown [74]. Air-drying is reported to have little effect on the lycopene content of tomatoes [75].

3.4. Spinach

Spinach (Spinacia oleracea L.) is a cool season annual vegetable. This widely used vegetable can be eaten raw, cooked, or baked in a variety of recipes. Spinach is a good source of many important vitamins, minerals fiber and carotenoids but low in calories [76]. Table 3.1 shows nutritional composition of spinach. Spinach is a vegetable that rapidly perishes after harvest, which is consumed only in the product season. Like other leafy greens, spinach has high water content. Drying is one of the preservation methods that has the capability of extending the consumption period of spinach [77]. It has been shown that a variety of dehydration methods, including microwave, hot-air, freeze, infrared, convective, and high electric field drying, can be used to dry spinach into dried flakes or powder [17, 78]. The powdered or flakes of dried spinach are lighter in weight and can be used in a variety of recipes. Tray drying or cabinet drying, which allow for temperature control and produce results nearly identical to FD, are more cost-effective than freezing spinach to dry it [78]. The best quality of spinach in terms of colour and ascorbic acid values were obtained in the drying period with 750 W microwave power [76].

Table 3.1 Nutritional composition of spinach

Nutrients	Composition	Reference
Moisture	91% - 92%	[79] [80]
Lipid	0.4% - 0.6%	
Protein	2.9%	
Carbohydrate	2%-10%	
vitamin A	469 µg/100 g	
Vitamin C	30 to 155 mg/100 g	
Vitamin K	378-483 µg/100 g	
Vitamin E	12.3 µg/100g	
Vitamin B9	140 -194 µg/100 g	
Iron	4-35 mg/100 g	
Magnesium	58 mg/100 g	
Potassium	633 mg/100 g	
Zinc	0.5-4.25 mg/100 g	

3.5. Bananas

Bananas are the most widely grown fruit crop and play a significant role in the production of horticulture fruit crops in tropical and subtropical regions of the world. It is regarded as a superfood (high energy food) in terms of nutrition since it is rich in minerals, nutrients, carbs, and phenolics and carotenoids, two bioactive components that support human health [81]. The postharvest losses during the whole supply chain of bananas reach up to 40% due to inadequate techniques used by growers at harvesting as well as inappropriate postharvest management. Bananas stored at low temperatures can cause a number of problems when it comes to preservation; nonetheless, drying is seen to be the greatest method for producing by-products that can be stored for a long time, such as flour and flakes [17]. Dried banana powder has many advantages when compared with raw bananas. Dried bananas have higher quality and longer shelf life and can be used for instant cooking. Products with additional value can be made using the dried banana powder [82, 83].

According to a study, developing value-added products will be a useful strategy to prevent the exploitation of bananas. Dried banana powder can be used to make snacks, fast mixes, dietary meals, etc [84]. Kabeer et al. [82] results showed that freeze-drying was the best technique to preserve nutrients present in ripe banana. Flour from unripe bananas is produced by using various drying techniques because of its positive impact on the human health as it increases the intake of unavailable carbohydrates, which may reduce the risk of non-communicable diseases [85].

Banana peels which account for approximately 38% of the fruit weight, are considered as waste with no value. The peels have been found to have significant antioxidant, antibacterial, and antibiotic qualities. They also have a high phenolic content and high dietary fibre level. Since drying has an impact on both manufacturing costs and material quality, it is a crucial step in preparing beginning material for additional processing. The microwave drying method is recommended for drying banana peels at an industrial scale [86].

3.6. Apples

Apples (Malus domestica L.) are one of the most widely grown fruits in the world. Quercetin glycosides, a naturally occurring antioxidant molecule from the flavonoid family with anti-cancer and heart-protective qualities, are abundant in apples [17]. Apples are eaten raw or processed into a variety of foods such juice, marmalade, jam, dried apples, etc. Moreover, dried apples are also used in the preparation of baby food [87].

Freeze drying is considered as a best technique for the preservation of quality characteristics of apples [88]. Lately, apple powder made by hot-air drying at 70°C showed colour retention and increased total phenolics, antioxidant capacity, and free radical scavenging activity [89]. In an experiment utilizing the microwave vacuum drying (MVD) technology for drying apple slices, showed a notable enrichment with quercetin derivatives through vacuum impregnation. MVD and FD of apples significantly retained its total quercetin glycoside content but AD showed a negative impact on quality attributes during drying; caused loss (44%) of quercetin glycoside and undesirable changes [43]. Doymaz [87] studied drying behavior of green apples and showed best results in describing thin-layer drying of apple slices. Moreover, pretreated samples with citric acid solution had a higher effective moisture diffusivity than the other samples.

3.7. Mangoes

Mango (Mangifera indica L.) is the most commercially important fruit in the Anacardiaceae family. Rich in antioxidants including pro-vitamin A and vitamin C, it has a high nutritional value to go along with its sensory quality in terms of flavour and taste. Mango, like other fruits and vegetables, has a short shelf life due to its high moisture content [90]. A study showed that, in comparison to hot air and freeze drying, microwave drying at 350 W may produce mango slices of excellent quality with the added benefit of a shorter drying time [91]. Vacuum-assisted osmotic drying resulted in lower losses of sucrose and fructose than the conventional osmotic drying technique [17]. Combining hot-air drying with microwave vacuum drying can greatly improve mango slices by reducing drying time and improving colour quality. Since the size of

samples also has an effect on the drying uniformity and efficiency, the application of different drying techniques to larger samples should be considered in the future study [45].

3.8. Dates

Date palm (Pheonix dactylifera L.) is valued for its socioeconomic and historic significance, making it the primary crop throughout the Middle East and North Africa [92]. Date fruit is remarkably popular for their delicious sweety taste, dietary and medicinal values. It is a good source for carbohydrates (70–80%), dietary fiber (6.4–11.5%), protein (2.3–5.6%), minerals (0.10–916 mg/100 g dry weight) and vitamins (C, B1, B2, B3 and A) [93]. Dates are vulnerable to microbial deterioration due to their high moisture content when harvested, it is best to dry them before storing them. Drying is among the most traditional methods of food preservation used to increase product shelf life. Open sun drying method is traditionally used to produce dried dates as it is cheap and cost effective. However, it gives low quality products as a result of contamination from foreign materials (litters, dust, soil and sand particles) and insect infestation. Some of the problems related to sun drying can be overcome using solar dryers [94]. According to a study when dates are vacuum-dried, the moisture level of the product is reduced from 15% to 5% and the product's colour quality is good [44]. Seerangurayar et al. [94] investigated the effect of solar drying methods on the color and textural attributes of Khalas dates at three ripening stages and concluded that, all ripening phases, dates dried in forced convective drying showed the best colour and texture characteristics when compared to dates dried in open sun drying. İZLİ and Technology [95] determined drying characteristics and to compare the dried fruit quality by using three drying methods convective (60, 70 and 80 °C), microwave (120 W) and freeze drying. This study showed that microwave drying can produce high quality date slices with the additional advantage of reduced drying times compared to convective and freeze drying.

4. Conclusion

The drying process for fruits and vegetables is a critical method used to extend their shelf life while retaining nutritional value and flavor. Through this process, water is removed from the produce, inhibiting the growth of microorganisms and enzymes that

cause spoilage. This preservation technique is cost-effective and can be done using various methods such as sun drying, microwave drying, freeze-drying, vacuum drying, spray drying and infrared (IR) drying. Many of the new drying techniques developed internationally found to be more efficient in energy use and time as compared with traditional drying techniques. Each method has its advantages and limitations. Sun drying and air drying are traditional and accessible but may take longer and can be affected by environmental conditions. Freeze-drying involves freezing produce and then removing the ice through sublimation, maintaining flavor and nutrients exceptionally well but requires specialized equipment and is costlier. Microwave drying has higher drying rate and short drying time but product texture may be affected and partial loss of aroma and negative sensory changes are seen.

In conclusion, the drying process for fruits and vegetables is a valuable preservation technique. Choosing the appropriate drying method depends on factors like cost, equipment availability, desired quality, and intended use of the dried produce. Regardless of the method used, proper storage is crucial to maintain the quality and safety of dried fruits and vegetables.

Author Contributions

Conceptualization; validation; writing—original draft preparation, writing-review and editing, and..; visualization: T.R.

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Conflicts of Interest

The author declares no conflict of interest.

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