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New insights in the production of fruit leather

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Abstract
Fruits are rich source of energy, vitamins, minerals, and dietary fiber. However, the time required to prepare them poses a significant obstacle to increased consumption. Fruit bars and fruit leathers have emerged as convenient alternatives to fresh fruits, offering a higher nutritional value and packing more nutrients per serving. Fruit leathers, in particular, are thin, flexible sheets bursting with intense fruit flavor and nutritional benefits. They are made by combining fruit puree with other ingredients like sugar, hydrocolloid (pectin), acid, color, and preservative (potassium meta-bisulphite), followed by dehydration. This review paper provides a comprehensive overview of fruit leathers, covering their ingredients, preparation process, different types of drying methods, as well as the role of packaging and storage in ensuring optimal quality. Dehydration, the most critical stage in fruit leather production, determines the quality and shelf life of the final product. This paper presents valuable insights into the preparation of fruit leathers, including the ingredients' roles, processing methods, and the significance of packaging and storage to maintain their nutritional value and health benefits.

Keywords: Fruit leather, fruit, antioxidants, health benefits

Introduction

Fruits and their derivatives offer a wide range of health benefits due to their rich content of bioactive compounds such as polyphenols, flavonoids, carotenoids, and vitamins. These compounds possess various properties such as antioxidant, anti-inflammatory, anti-proliferative, anti-carcinogenic, anti-diabetic, and anti-viral, which contribute to improved health and well-being (Deepika *et al.*, 2022) [10]. Furthermore, fruits can act as a healthy alternative to added sugars, reducing the risk of non-communicable diseases such as obesity, type 2 diabetes, heart disease, dental caries, and certain cancers (Walia *et al.*, 2022) [66]. Certain fruits like santol, figs, and bilberries contain unique bioactive compounds that offer additional health benefits. Thus, incorporating fruits and their products into our diets can be an effective way to promote healthy aging and prevent age-associated diseases (Pires *et al.*, 2020) [46].

Fruit losses and the resulting financial losses are significant issues (Gross *et al.* 2000). Various factors impact fruit post-harvest losses, such as physical, physiological, mechanical, and sanitary conditions. Fruit weight loss can occur after harvest due to pathological rots, insect and mite damage, and illnesses caused by non-infectious pathogens. The overall post-harvest loss of horticultural crops, including fruits, depends on harvest stage, storage, transportation, and marketing. An FAO report shows that 1.3 billion tonnes of food produced for human consumption are wasted annually. Food losses are more prevalent in low-income countries, while food waste is more common in high- and middle-income countries. While food losses in industrialised nations are just as significant as those in developing countries, post-harvest and processing losses account for more than 40% of these losses in the latter, while retail and consumer losses account for more than 40% of these losses in the former (Gustavsson *et al.*, 2011) [25]. These inefficiencies can be reduced by processing and preserving fruits to create various value-added products such as fruit leather, fruit juices, nectar, fruit jam and jelly, wine, toffee, fruit puree, fruit pulp, and sliced fruit. The shelf life of fruits can be extended, and losses reduced through various methods. Modern fruits have a short harvest season and are prone to deterioration, even when kept in cold temperatures. Therefore, the best way to preserve fruits is to create fruit products from them.

Fruit leather is crucial because it is a value-added product made from fruit waste or losses that would otherwise be considered waste, leading to environmental issues. For instance, kiwi fruit losses can be utilised to create fruit leather, which is a more economically valuable product (Zakipour-Molkabadi *et al.* 2011) [69].

Blue elderberry, an underutilised fruit, can also be used to make value-added products such as fruit leather (Uhl, K.R., Fyhrie *et al.* 2022) [64]. Producing fruit leather also reduces waste disposal issues and adds value to the product for food and other industrial applications (Ravani A & Joshi *et al.* 2014) [50]. As a result, fruit leather is a vital product that can contribute to a sustainable and circular economy.

Fruit leather is a flexible and chewy snack, similar to a fruit roll-up, and is composed of various fruits with a skin-like consistency. The production process involves pureeing the fruit, spreading it thinly and uniformly on a flat surface, and allowing it to dry. This results in a concentrated and chewy fruit product that can be stored for an extended period compared to fresh fruit (Zakipour *et al.*, 2022). A variety of fruits, such as kiwi, pineapple, apple, red dragon fruit, and white camplong water apple, can be used to make fruit leather (Mardiyana *et al.*, 2022) [42]. The properties of fruit leather can be influenced by several factors, including the fruit type, concentration of margarine, citric acid, and hydrocolloids, as well as the drying temperature.

Fruit leather is a convenient and portable snack high in protein and fiber and can serve as a substitute for natural fruits with high nutritional value (Sukasih *et al.* 2022) [60]. Compared to candies and boiled sweets, fruit leather is a healthier and more convenient snack alternative. It is low in fat and high in carbohydrates and fiber.

Fruit leather can be made using a single fruit or a combination of fruits. Apples, bananas, pineapples, peaches, guavas, papayas, mangos, sapotas, grapes, strawberries, pomegranates, kiwis, red dragon fruits, white camplong water apples, and water apples are some of the commonly used fruits. The choice of fruit can influence the texture, flavor, and nutritional content of the fruit leather.

Fruit leather is a convenient and nutritious snack made by dehydrating pureed fruit into a leathery sheet. It is rich in vitamins, minerals, phytochemicals, and proteins that aid in boosting immunity (Ijaj *et al.*, 2021). Compared to candies and boiled sweets, fruit leather is a healthier snack alternative, naturally low in fat and high in fiber and carbohydrates (Bandaru & Bakshi, *et al.* 2020) [7].

Whey protein can be added to fruit leather to enhance its nutritional value. Whey protein offers numerous health benefits, including boosting immunity, reducing cholesterol levels, and lowering blood pressure (Khandelwal & Bhasker, 2022) [31]. Fruit leather can be made from a single type of fruit or a combination of fruits, and it can be dried using different methods, resulting in variations in the quality of the leather. Researchers have studied the optimal fruit blending proportions and the effects of drying methods and temperatures on the organoleptic and physiochemical properties of mixed fruit leather (Srinivas *et al.*, 2020) [59].

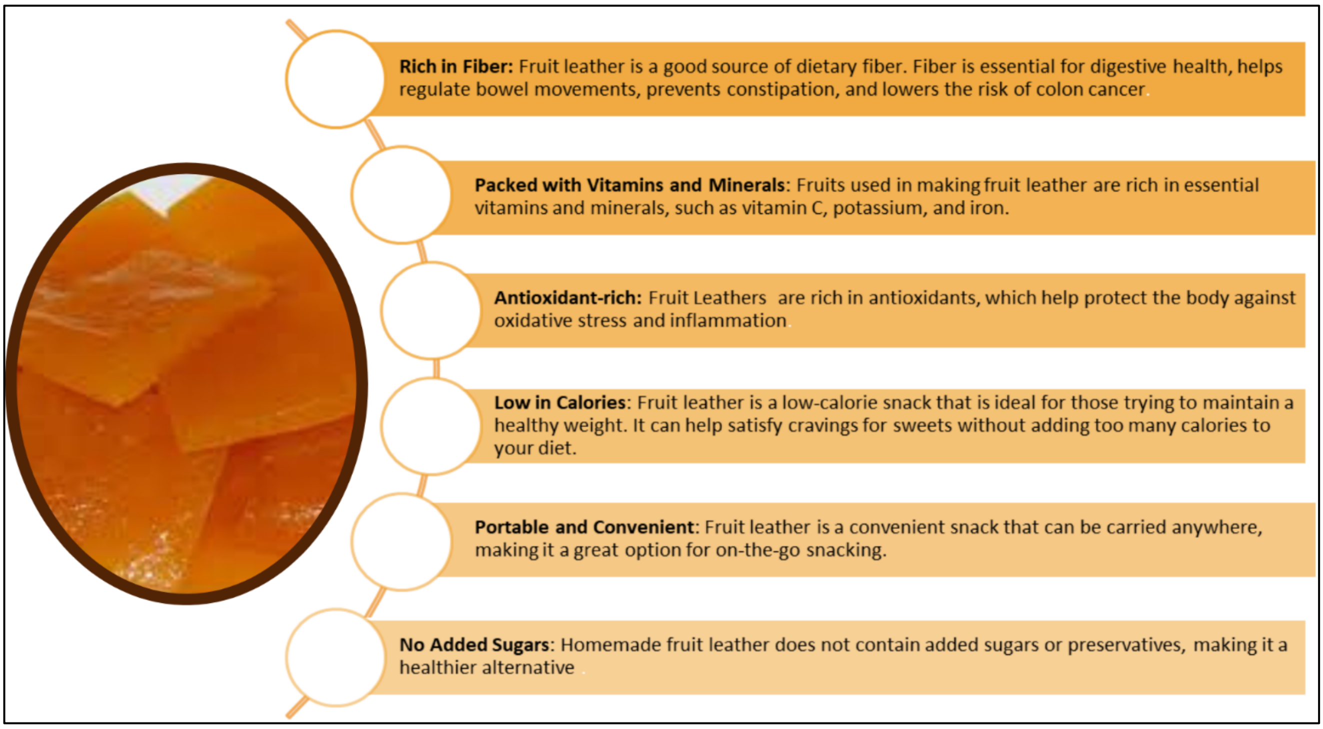

Fig 1: Health Benefits of Fruit leather

Roles of Ingredients

The ingredients utilized in crafting fruit leather are of utmost importance as they combine and interact to yield the final product. Typically, fruit pulps are blended with the appropriate measures of sugar, pectin, acid, and colorants prior to being dehydrated to produce sheet-like fruit bars. At times, thickeners like starch, pectin, gelatin, alginate, gums, and cellulose derivatives may be included to facilitate the even spreading of pulp and drying process, which could enhance the production of fruit leathers made from specific fruits. Prebiotics and other substances such as sulfur dioxide and sorbic acid may also be incorporated to augment the product's stability (Bandaru & Bakshi, 2020) [7]. Additionally, other ingredients such as chopped nuts, coconut, or spices can be added to modify the taste and flavor profile of the fruit leather (Madusanka *et al.* 2017) [41].

Addition of Hydrocolloids

Hydrocolloids are complex carbohydrates that, when mixed with water, create viscous solutions or gels. In the food industry, hydrocolloids are widely used as additives to modify the rheology and texture of aqueous suspensions. They are often utilized as thickening, stabilizing, and gelling agents. Fruit leather production commonly employs hydrocolloids such as pectin, carrageenan, and agar to enhance the texture, consistency, and shelf life of the end product. Pectin, a natural hydrocolloid found in fruits, is often utilized to thicken and gel fruit purees. Carrageenan and agar, both extracted from seaweed, are utilized to improve the texture and stability of fruit leather. Hydrocolloids are valued for their properties of high water retention, gelling, thickening, stabilizing, and emulsifying. (Lu *et al.* 2021; Albuquerque *et al.* 2016 [2]; El-Sattar 2013).

The production of fruit leather can involve the use of various hydrocolloids, such as pectin, agar, carrageenan, and gelatin. According to a recent study by Lu *et al.* (2021), each hydrocolloid type possesses distinct functional properties that can impact the resulting fruit leather. For example, a study on roselle-based fruit leather found that xanthan gum, maltodextrin, and locust bean gum significantly contributed to the fruit leather's extensibility (Shafi *et al.*; Yemenicioğlu, A., Farris *et al.*, 2020) [68]. Another study on date-tamarind fruit leather reported that the addition of hydrocolloids, such as starch, pectin, dextrin, or guar gum, impacted the texture of the fruit leather, leading to increases in hardness and gumminess and decreases in cohesiveness, resilience, and springiness (Al-Hinai *et al.*, 2013) [3]. Hydrocolloids, known for their properties as thickeners, gelling agents, texturizers, stabilizers, and emulsifiers, are widely used in the food industry and have applications in edible coatings and flavor release (Albuquerque *et al.*, 2016) [2].

Hydrocolloids have the potential to enhance the texture of fruit leather by imparting gelling and stabilizing properties. By increasing the firmness and gumminess of the product, hydrocolloids can result in a firmer texture, as noted by Pd *et al.* (2017). Additionally, the incorporation of hydrocolloids can impact the drying kinetics of fruit leather, influencing its drying time and mass diffusion coefficient, as observed by Gomez-Perez *et al.* (2020) [21].

The variety and concentration of hydrocolloids employed can significantly affect the color and texture of the fruit leather. The use of hydrocolloid-based edible coatings has been found to be helpful in maintaining the texture of the fruit by reducing respiration rates and preserving better fruit firmness during storage, according to studies by Kurniadi *et al.* in 2022 [37] and Tontul *et al.* in 2018 [62].

Overall, hydrocolloids play a crucial role in improving the texture and stability of fruit leather, rendering it a healthier and more convenient alternative to candies and confections, as highlighted by Mphaphuli *et al.* (2020) [43].

Table 1. Summarizing the hydrocolloids commonly used in the production of fruit leather and some examples of fruits they are used with (Kurniadi *et al.* in 2022 [37] and Tontul *et al.* in 2018 [62]; Gomez-Perez *et al.* in 2020) [21].

Table 1: Summarizing the hydrocolloids commonly used in the production

Hydrocolloid	**Fruits**	**Properties Improved**	**Reference**
Kappa-carrageenan	Guava, banana	Texture, color, tensile strength	Tontul *et al.* in 2018 [62]
Gum Arabic	Guava, banana	Texture, color, tensile strength	Tontul *et al.* in 2018 [62]
Pectin	Date, mango	Texture, flavor, gelling properties	Kurniadi *et al.* in 2022 [37]
Carboxy methyl cellulose	Date, mango	Texture, gelling properties	Kurniadi *et al.* in 2022 [37]
Xanthan gum	Pomegranate	Texture, mouthfeel, stability	Gomez-Perez *et al.*
Locust bean gum	Pomegranate	Texture, mouthfeel, stability	Gomez-Perez *et al.*

Addition of low molecular weight sugars

Low molecular weight sugars, also known as monosaccharides or disaccharides, are small-sized carbohydrates composed of one or two sugar units. They are widely used in the food industry as sweeteners, humectants, and texturizers due to their ability to enhance taste, texture, and shelf life of food products. These sugars are also an important source of energy and carbohydrates in the human diet. To quantify low molecular weight sugars, chemical derivatization-liquid chromatography/multiple reaction monitoring/mass spectrometry is a commonly used method (Han *et al.* 2016).

Glass transition temperature and diffusion properties of low-molecular-weight sugars have been investigated using molecular dynamics simulation, where trehalose showed a higher value of Tg and the ability to form hydrogen bonds with water molecules compared to sucrose at the same moisture content (Guo-hu, 2014) [24]. As the moisture content increased, the value of Tg in both sugar models decreased significantly, resulting in more facile diffusion of water molecules into the sugar systems and an increased chance of interaction with sugar molecules.

In the production of fruit leather, sorbitol and total sugar are commonly used to enhance the physicochemical properties. Sorbitol acts as a humectant, preventing the fruit leather from becoming too dry and brittle, while total sugar improves the texture and taste of the final product. For example, in the production of guava-banana fruit leather, sorbitol is used as a sweetener, and in mango-based fruit leather enriched with Natal plum, total sugar is used to sweeten the final product (Kurniadi *et al.* in 2022 [37]; Mphaphuli *et al.* in 2020 [43]). Moreover, the addition of low molecular weight sugars can increase the nutritional value of fruit leather, as they provide a source of carbohydrates and energy.

Overall, low molecular weight sugars play a significant role in the food industry, and their diverse functions make them a valuable ingredient in fruit leather production.

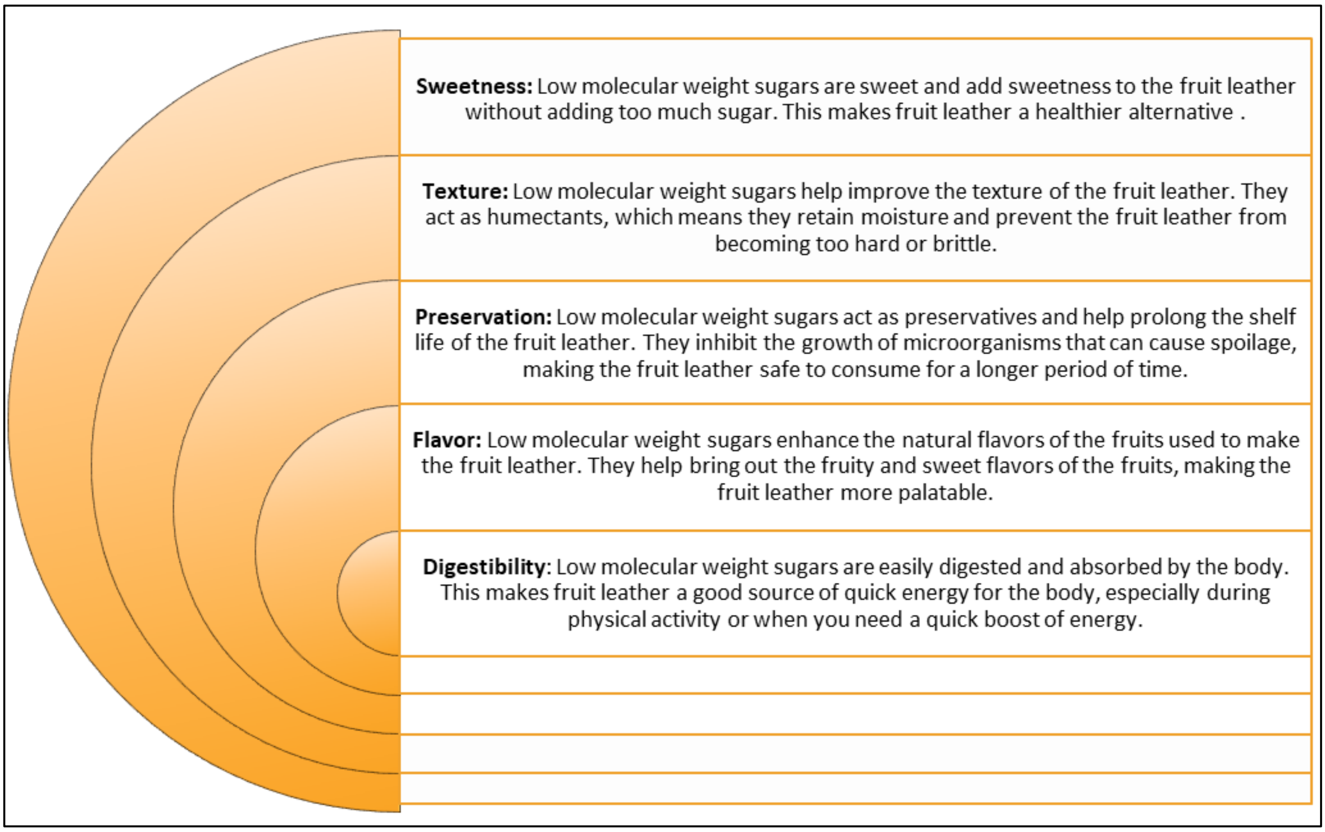

Fig 2: The Uses of low molecular weight sugars in fruit leather preparation

Addition of prebiotics

Prebiotics are non-digestible dietary fibers that promote the growth and activity of beneficial bacteria in the gut, leading to improvements in host health. These selectively fermented ingredients are found in a variety of foods, including chicory root, Jerusalem artichoke, garlic, onions, asparagus, bananas, apples, flaxseeds, and oats. Prebiotics are distinct from probiotics, which are live microorganisms that provide health benefits when consumed in adequate amounts.

According to de Vrese and Schrezenmeir's (2008) definition, prebiotics are carbohydrates that promote the development or activity of a specific bacteria in the colon, thus enhancing the health of the host through their fermentation by gut microbiota. Dehydrated fruit leathers are an effective carrier of prebiotics and probiotics and are viewed as healthful by consumers due to their positive effects on health and favorable sensory qualities (Rego *et al.*, 2013).

Agave genus plants, primarily used in the development of alcoholic beverages, contain fructans that act as osmo protectants and reserve sources of carbohydrates for the plant's energy during drought conditions. These fructans are utilized by gut bacteria such as Lactobacillus and Bifid bacterium, leading to their growth and enhancement of biological functions in the host. Daily intake of agave fructans aids in preventing gastrointestinal disorders, protecting the brain, decreasing oxidative stress, aiding mineral absorption, and regulating metabolic processes (Andrade *et al.*, 2019; Espedes *et al.*, 2014; Di Bartolomeo & Van den Ende, 2015; Franco-Robles & Lopez, 2016; Urías-Silvas *et al.*, 2008).

In summary, prebiotics play a crucial role in promoting gut health and host well-being. Foods rich in prebiotics and agave fructans, in particular, have numerous health benefits and can be effective carriers of prebiotics and probiotics.

Inulin is a type of non-structural carbohydrate that can be found in various foods, including leeks, onions, wheat, asparagus, garlic, Jerusalem artichoke, and chicory root. It is a nutritional component that has been frequently used in the development of new functional products, and has been added to many foods to improve their technological characteristics. Inulin and oligofructose are fructans that plants use as storage carbohydrates, and have a linear structure composed of fructose units linked together by β-2-1 bonds. These compounds meet the criteria for being classified as prebiotics, and have been extensively investigated and utilized in various food applications either individually or in combination.

The addition of combinations of agave fructans, inulin, and oligofructose has been found to affect the mechanical qualities of dried apple leather, particularly its hardness and stickiness. Agavins, which are reserve carbohydrates found in Agave plants, have become increasingly popular as prebiotic ingredients for functional foods in recent years. Agavins have a more complicated structure compared to inulin, consisting of highly branched fructans with a predominance of (2-1) and (2-4) bonds. These technical properties make agavins distinct from inulin, as noted by Espinoza-Andrew and Uras-Silva (2012) and Mancilla-Margalli and López (2006).

Fruit Leather and its processing

Fruit purees and concentrates of juices are commonly utilized in the development of fruit leather, which is a dehydrated product made by processing different fruits. This process provides an effective way to overcome fruit losses and increase their shelf life. Fruit leathers are modernized, fruit-based snacks created by combining acid, sugar, and high methoxyl pectin to form a gel-like texture. Fruit bars are available in flexible sheets and are consumed as candy or a snack. These products are chewy, flavorful, tasty, lightweight, and convenient to store, making them appealing and essential to consumers (Ruiz *et al.*, 2012).

Eating fruit leather is a practical and cost-effective alternative to consuming fresh fruit, as it provides several essential nutritional components such as fiber, carbohydrates, and minerals. Fruit leathers are an effective means of promoting the consumption of fruit solids, particularly among children and young adults, as they are visually appealing and do not require refrigeration to prevent bacterial growth. Various fruits can be utilized in the preparation of fruit leather. Apples are the most commonly used fruit due to their high pectin concentration (0.15-0.25 kg/kg dry matter), according to Demarchi SM (2014) [53].

Moreira GEG (2006) and Simo RS conducted a study on mango leather, while Valenzuela and Aguilera (2015) produced fruit leather from apples and investigated the factors affecting stickiness. They found that high molecular sugars, such as maltodextrin and starch, reduced stickiness and improved drying. Chen and Martynenko's (2018) research revealed that drying blueberry leather at different temperatures results in better retention of bioactive components, particularly anthocyanins. Diamante *et al.* (2014) observed that fruit leather can be dried at temperatures ranging from 30 to 80°C. Ayalew *et al.*, (2020) studied the formulations and characteristics of fruit leather based on Annona muricata L. fruit and Avena sativa flour.

The preparation of fruit leather typically involves three main steps: preparing the fruit puree or concentrated juice, adding the necessary ingredients, and drying. Heat treatment is crucial in the first step, as it is required to deactivate enzymes, such as polyphenol oxidase, that can cause enzymatic browning during peeling, cutting, and pulping.

In 2020, Basumatary *et al.* created pulp and leather from the wild olive (Elaeagnus latifolia) and investigated the effects of heat treatment on the texture and sensory properties of the prepared fruit slab. The researchers subjected the fruit pulp to different heat treatments (60°C for 0–45 min) and assessed its quality characteristics. The results showed that heat treatment softens the fruit's skin and decreases microbial contamination but also degrades some of its nutrients.

In another study, Tontul and Topuz (2018) [62] prepared pomegranate leather using both heated and non-heated fruit pulp, and compared the resulting products in terms of their bioactive component concentrations, browning, and textural qualities. They found that leathers made from non-heated pulp had higher bioactive component concentrations, less browning, and better texture compared to those made from heated pulp. The researchers also highlighted that the heating of fruit pulps could produce some harmful substances, such as hydroxymethylfurfural (HMF) and acrylamide.

Hydroxymethyl furfural (HMF) is a well-known marker of nonenzymic browning and is often used to assess the deteriorative changes that occur when food is overheated and/or stored. In fresh meals, the HMF level is very low, but in processed meals, it is present at high levels and is frequently employed as a quality indicator. Measuring the HMF level is crucial because it indicates how much the processed items were heated during processing and is considered a quality indicator for concentrated food products. It is worth noting that both HMF and acrylamide are considered potentially cancer-causing to humans, or they may be converted into cancer-causing chemicals by humans (Capuano and Fogliano, 2011; Zhang *et al.*, 2008). The tolerated daily dose for acrylamide for neurotoxicity was calculated by Tardiff *et al.* (2010) as part of a safety review and was found to be 40 μg/kg/day.

The second step in the production of fruit leather is the addition of ingredients, which is crucial for improving its quality. Fruit leathers tend to stick to the drying structure, packaging materials, fingers, palate, and teeth due to the small molecular weight of organic acids, sugars, and other chemicals present in the pulp. To mitigate this problem, high molecular weight substances such as starch, maltodextrin, gums, and pectin (hydrocolloids) need to be added to the fruit pulp.

Valenzuela and Aguilera (2015) used maltodextrin in the production of apple fruit leather, which reduced its stickiness and resolved processing and packing issues.

In the production of fruit leather, the addition of ingredients is a crucial step that can significantly impact the final product's quality. Due to the small molecular weight of the organic acids, sugars, and other chemicals present in fruit pulp, fruit leathers tend to attach to various surfaces, such as the drying structure, packaging materials, fingers, the palate, and teeth. To address this issue, high molecular weight substances such as starch, maltodextrin, gums, and pectin (hydrocolloids) are commonly added to the fruit pulp (Valenzuela and Aguilera, 2015).

Studies have shown that the addition of wheat starch to orange fruit leather can increase the mixture's viscosity, leading to a shear-thinning behavior (Azam *et al.*, 2018). Similarly, the addition of hydrocolloids such as carboxymethyl cellulose, pectin, guar gum, gum acacia, and sodium alginate has been found to improve the extensibility and texture of fruit leather while also decreasing the drying rate of mango pulp (Gujral and Brar, 2003) [57]. Ofos pectin has been shown to slow the drying rate of pineapple and mango leathers (Gujral *et al.*, N.D.).

Prebiotics and low-molecular-weight sugars, such as honey, sucrose, and glucose syrups, have also been used in the production of fruit leathers. However, these molecules have sticking problems, which can impact the final product's quality. To address this issue, studies have explored the effects of oligofructose, inulin, and agave fructans alone and in combination on the physicochemical and sensory properties of fruit leathers (Simal *et al.*, 2018). The study found that drying time was much shorter at higher microwave power levels, resulting in rapid mass reduction. Various quality standards, such as dehydration behavior, texture, color, water activity, and sensory attributes, were used to evaluate the generated fruit leather.

In summary, the addition of ingredients such as hydrocolloids, starch, and prebiotics can significantly impact the quality and texture of fruit leather. These substances can improve extensibility, decrease the drying rate, and address sticking problems. Proper evaluation of the physicochemical and sensory properties of fruit leather can help ensure that the final product meets the desired quality standards.

Different Processing Methods

The process of dehydration, which involves completely removing water from the desired end product, is also known as drying. High water content promotes microbial activity and, as a result, deteriorates the product. Therefore, different techniques are employed to reduce moisture content, prolong the product's shelf life, and retain its nutritional value. Dehydration of fruit pulp concentrates the original flavour and results in a stable product with a favourable quality-volume ratio, long shelf life, low packaging cost, and reduced handling weight (Khan *et al.*, 2014).

During drying, some differences in the product's color, texture, flavor, and odor may occur due to chemical and biological characteristics. Fruit bars are usually dried at temperatures ranging from 30 to 80 degrees Celsius for up to 24 hours to reach a final moisture content of 12 to 20 percent (Demarchi *et al.*, 2013; Sharma *et al.*, 2013). However, depending on the type of food, dried foods may still contain 2 to 30% water.

Conventional air heating is a slow process because of poor heat transfer and low thermal conductivity in the product's interior section. To address this issue and achieve quick and efficient thermal processing, various alternative drying techniques have been developed. Microwave dryers are gaining popularity in the food industry due to their speed and uniformity.

Hot air oven

The preparation of drying typically involves the use of a common drying technique, which is known for its ability to quickly dry fruit and produce high-quality dried fruit (Maskan *et al.*, 2002). This technique requires a high temperature and is both affordable and popular in the food industry. Heat and mass transfer are the primary factors involved in drying, which is achieved by having hot air flow across or parallel to the moist fruit puree. The amount of air required to dry the wet material depends on several factors, including the thickness of the product (ranging from 0.2 to 13 mm), air temperature (ranging from 45 to 121 °C), relative humidity (ranging from 3.5 to 50%), and air velocity (ranging from 0.7 to 7.4 m/s). To determine the temperature and ratio within the dryer, a temperature and ratio sensor is typically used.

Infrared drying

Infrared drying is a distinct technique for drying fruit leather that can accelerate the drying process and improve the quality of the final product. The principle of infrared drying involves the conversion of infrared rays into heat, which then radiates from the hot surface to the surface of the material being dried. According to Jaturonglumlert and Kiatsiriroat (2010), the use of infrared can benefit both the development of fruit bars and the drying process for thin layers. Due to its high heat transfer coefficient, infrared drying can increase drying efficiency by two to five times or more. Additionally, it can create a clean working environment and save space. However, infrared drying is only suitable for thin layer drying and is less effective for thicker products due to its limited penetrating power.

Table 2: Microwave drying

S. No	Fruit	Texture	Reference
1	Pomegranate	Hardness – 21.48 to 8.37 Chewiness – 17.97 to 5.60	Tontul I *et al.*, (2017)
2	Blackthorn	-	Suna S, *et al.*, (2019)
3	Peaches	Hardness force- 0.579 kg.	Roknul *et al.*, (2019)
4	Mulberry	As moisture content decreases, chewiness increases	-

Vacum Drying

Vacum drying is a Low-temperature drying technique that involves the evaporation of water at low temperatures, resulting in a significant decrease in the air's oxygen content and, consequently, high drying rates. Yilmaz *et al.* (2014) reported that pomegranate leather retains phenolic components, anthocyanin, and ascorbic acid more effectively under vacuum. In a study comparing the effects of hot air, vacuum, and air drying, Ruiz *et al.* (2019) found that vacuum drying is faster than hot air and infrared drying, and drying at 60°C under vacuum results in the highest retention of phenolic components and antioxidant activity. Drying conditions, product thickness, and operation temperature can affect the drying rate and final product quality in various ways. Vacuum drying has a higher drying rate and better preservation of phenolic, anthocyanin, and ascorbic acid, which can be attributed to the faster drying conditions and oxygen-deficient medium in terms of drying kinetics and product quality.

Freeze drying

Freeze-drying is considered to be one of the most advanced techniques for producing high-quality dried products. The process involves the direct sublimation of ice under reduced pressure to create a frozen dried product. Originally developed for preserving thermally sensitive biological materials by sublimating frozen water, this method uses low temperatures to maintain the physiologically active compounds in the food. In recent years, freeze-dried food, particularly fruits such as berries, has become increasingly popular. Although it requires a lot of energy and is a time-consuming process, the use of low temperatures and the absence of air during processing limit degradation reactions and microbiological activity, resulting in a high-quality final product. The freeze-drying process results in minimal loss of beneficial chemicals such as anthocyanin and other polyphenols, making it the preferred method among other drying techniques.

Reactance window (RW) drying

In recent times, the refractance window drying method has garnered significant attention due to its many perceived benefits. This process involves the drying of purees and liquids that are spread over a thin and transparent infrared film, which effectively creates a "window" through which the drying process occurs. RW drying is a more recent non-thermal technique that has been used to dry products such as heat-sensitive purees and slices of fruits and vegetables (Martnez *et al.*, 2012). In fact, Rostami *et al.* (2017) has discussed the possibility of utilizing RW drying to produce meat powders. This direct drying method has found numerous applications in various industries, including pigment handling, pharmaceuticals, nutraceuticals, cosmetics, algal, and pharmaceuticals, among others. (GW Dryers, 2017; Nindo *et al.*, 2003b; Caparino *et al.*, 2012 [8]; Oritz-Jerez *et al.*, 2015) [44].

Using this drying process that can be used to produce fruit and vegetable puree powders, flakes, or sheets. The puree is spread over a flexible support with a controlled thickness, and drying is performed at a temperature below 70°C. Due to the moderate drying temperatures and short drying times, there is little nutrient loss, and the sensory qualities of the final product are excellent. RW drying was used to produce the first fruit leather, and according to Tontul and Topuz (2017), it is the most promising method for producing high-quality fruit leather. For instance, when drying pomegranate leather using RW instead of hot air or microwave-assisted hot air, better results can be achieved in terms of color and texture, bioactive chemical content (such as ascorbic acid and anthocyanin), and nonenzymatic browning processes.

Electrohydrodynamic drying

Electrohydrodynamic drying (EHD) is a promising new drying technique that employs a high voltage electric field to interact with dielectric food material, producing a corona wind that uses less energy than traditional drying methods and produces dried food products with acceptable sensory quality. By creating a significant voltage difference between the emitter electrodes, EHD generates airflow that ionizes the air locally due to the emitter's high curvature and voltage, resulting in corona discharge. The resulting corona (ionic) wind is produced by the ions drifting to the collector and colliding with neutral air molecules at speeds ranging from 10-1-101 m s-1. This airflow enhances the wet product's ability to remove moisture by accelerating convective mass transfer rates. However, some studies have suggested that increased convection is not the only process responsible for the enhanced drying rate (Bajgai *et al.*, 2006 [5]; Singh *et al.*, 2012; Zhang *et al.*, 2017). EHD is a non-thermal drying method with a wide range of applications for heat-sensitive materials. It occurs at room temperature, requires minimal energy, has a simple design, and consumes less energy. According to Chen and Martynenko, the enzyme activity in blueberry leather produced using EHD drying decreased. However, the bioactive ingredients and product color were adversely affected by oxidation processes caused by the ozone generated by corona discharge.

Quality Evaluation of fruit leathers

Physicochemical features

Fruit leathers have various physicochemical features that can affect their quality. The color, water activity, and texture of fruit leathers can be affected by the drying method and temperature used. The nutritional content of fruit leathers, including antioxidant capacity, phenolic substances, and vitamin C, can also be affected by the drying method and temperature used (Ruiz et al 2014 [53]; Diong, E.L. 2018). The chemical composition of fruit leathers, including pH, total acidity, brix, humidity, reducing sugars, and content of total phenolic compounds, can be evaluated to determine their quality (Azeem *et al.* 2021) [4]. The sensory properties of fruit leathers, including their taste, smell, and appearance, can also be evaluated to determine their acceptability to consumers. Overall, the physicochemical features of fruit leathers can affect their quality and acceptability, and various parameters should be evaluated to ensure the production of high-quality fruit leathers. (Azeem *et al.* 2021[4]; Fonseca *et al.* 2015) [18].

Phytochemical properties

It includes Total phenolic content, Ascorbic Acid content, Total Flavonoid Content and Antioxidant properties.

Antioxidant Activity

Fruits and vegetables contain various antioxidant components, including vitamins C and E, carotenoids, and polyphenolic compounds such as flavonoids. Polyphenolics are abundant secondary metabolites in plants. Flavonoids comprise flavanols, flavonols, and anthocyanins, and are found in a variety of fruits and vegetables. The most common flavanols in fruits are catechin and gallocatechin, which can exist as monomers or polymerize to form condensed tannins or proanthocyanidins (Garcia-Alonso *et al.*, 2004) [19]. Anthocyanins are important pigments in flowers and fruits. Several techniques are available for measuring antioxidant activity. Radical scavenging assays, ferric reducing assays, or other methods can be used to inhibit the oxidation of oils, emulsions, low-density lipoproteins, or liposomes (Roberts and Gordon, 2003) [51]. Trolox (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid) equivalent antioxidant capacity (TEAC) is a commonly used method to describe the antioxidant potential of fruits, vegetables, and chemicals, expressed in molar units.

Mechanical Features

The texture of any fruit leather is largely determined by the amount of moisture present. Several tests are conducted to evaluate the textural properties, such as tensile tests, puncture tests, compression tests, and cut or shear tests. Among these tests, the tensile test is the most commonly used for fruit bars, as it primarily measures tensile strength and elongation capacity. Elongation capacity refers to how the product behaves during chewing. Fruit leather should be able to withstand handling and processing without breaking. According to Tontul and Topuz (2018), it is essential to take necessary precautions while incorporating any ingredient, considering its potential impact on the fruit leather's elasticity and resistance to deformation.

The puncture test is utilized to assess how the fruit product responds to incisor teeth after being bitten into, while the pierce test is used to determine the hardness and stickiness of the product. For instance, González-Herrera *et al.* (2016) [22] employed the pierce test to investigate the effect of inulin, oligofructose, and agave fructans on the texture of apple-based leather. Their findings indicated that only agave fructans improved the texture of apple leather, resulting in the lowest hardness rating. Additionally, the compression test is conducted to describe the mouth's sensation using the hardness parameter. Modification of texture can be achieved by incorporating different ingredients into the fruit leather formulation.

Tontul and Topuz (2018) reported their findings on the development of pomegranate bar using three different drying methods: hot air drying, RW drying, and microwave-assisted hot air drying. They found that microwave-assisted hot air drying resulted in the least desirable texture, potentially due to the formation of small pores during the drying process. Roknul Azam *et al.* (2018) utilized both hot air-assisted radio frequency drying and hot air-assisted microwave drying for the production of peach leather.

Simo *et al.* (2019) conducted a study to investigate the influence of storage-related relative humidity on the mechanical properties of mango bar using the shear test to simulate the movement of the incisor teeth when the product is placed in the mouth. They found that simultaneous analysis of force and sound curves was useful for predicting the crispness of the final product. The mango leather that was conditioned at the lowest relative humidity had a weak structure and required the least amount of force and energy to shear. The crunchy samples exhibited several indicators of product crispness, including a high sound pressure level and a large number of force and sound peaks.

Thermal features

Due of the fruit's thermal qualities, physiochemical reactions happen during processing. Foods' physical stability while being stored is determined by their glass transition temperature (TG). Fruit leather typically has low TG values because of its high molecular weight. The experiment was carried out on apple fruit leather by Valenzuela and Aguilera (2015) to ascertain that the Tg value at 44% RH was 22.06 °C and that the addition of 5% glucose led to a lower Tg value (Tg = 26.97 °). Tg rises as the product's molecular weight increases. fruit leather packaging must always have a high barrier for gases and water vapour. Laminated packaging was found to be suitable for preserving fruit leather throughout storage. According to Valenzuela and Aguilera's research, the amount of maltodextrin added is directly related to the TG, which reduces the stickiness of the material.

Sensory features

Sensory evaluation refers to the consumer's liking or disliking of a fruit product based on characteristics that completely depend on their senses during consumption. These characteristics include the product preparation process, storage requirements, and various processing characteristics that are relevant to consumer reactions. Ultimately, sensory evaluation is an important tool for determining a product's marketing potential. The acceptability of a fruit product is influenced by the different fruits that are used in its preparation.

In a study by Torres *et al.* (2016) [9], apple leather was found to have higher acceptance than quince leather, which had a sour taste. On the other hand, Concha-Meyer *et al.* (2016) [9] reported that the overall acceptance of strawberry and kiwi leather was satisfactory. Strawberry leather was particularly well-liked due to its vibrant color, potent aroma, and sweet flavor. Fruit leather is typically chewy in texture when served. Imo *et al.* investigated how relative humidity affects the sensory assessment of mango leather and found that samples with reduced humidity were crispier and more preferred. The addition of components to fruit leather can also affect its acceptability. Torres *et al.* found that adding maqui berry extract to apple leather diminished its acceptance primarily due to its color. These findings suggest the importance of considering various factors that can influence the acceptability of fruit leather products.

Color

Bhagya Raj and Dash (2020) utilized a colorimeter to determine the color parameters (L, a, and b) of fruit leather samples. Measurements were taken at five different locations on the surface of each sample, and the color parameter readings were repeated three times to obtain mean values.

Microbiological properties

Consumer safety is determined by the created items' microbiological state. Common microorganisms cannot develop in leather due to moisture and low pH, but some of them can, including yeast, mould, lactobacillus, and aerobic bacterial spores, which are more resistant to these conditions than other microorganisms

Role of packaging

The packaging material plays a crucial role in the storage, long-distance transportation, and maintenance of fruit leather until the point of consumption. The packaging material must meet various standards, such as material costs, social and environmental awareness, and pollution control laws. Common materials used in the packaging of fruit leather include high-density polyethylene, polypropylene, low-density polyethylene, polyester, butter paper, and aluminum foil. These materials have varying degrees of tensile strength, elasticity, and storage capacity, which affect their ability to maintain the quality and shelf life of the product.

Packaging materials serve to protect fruit leather from chemical, physical, and biological changes caused by environmental factors such as exposure to gases, moisture, or light. They also act as barriers against insects and pests, preventing disease and spoilage. Additionally, packaging materials serve as shields against mechanical harm, preventing damage from blows, crushing, or other impacts. In today's competitive market, innovative packaging materials can also help boost sales.

Safety Regulations

The standards for fruit bar/toffee are defined in Regulation 5.3.19 of FSSAI's Food Products Standards & Food Additives regulations, 2011. Fruit bar is prepared by mixing fruit pulp or puree with nutritive sweeteners, preservatives, condiments, and other appropriate ingredients, and then dehydrating the wet puree to form a leathery sheet that can be cut into desired shapes or sizes.

The preparation of fruit leather involves various stages such as selection of raw materials, washing and cleaning, peeling and cutting, preparation of puree, heat treatment, and so on. The mixing of different raw materials is a crucial stage in maintaining the quality of the final product. Hydrocolloids play an essential role in the preparation of fruit leather, as they have the ability to produce dispersion when water is added. They are applied to improve the textural properties of the final product by thickening or gelling substances that can bind water molecules (Rascón-Daz *et al.*, 2012).

According to Y.B. Chen and Sin (1997), pectin, a hydrocolloid, forms a gel structure that leads to the formation of a hard texture. The addition of other ingredients such as pectin and sugar can also affect the texture of the final product, as noted by Phimpharian *et al.* (2011). Patel *et al.* (2017) have used different ratios of pectin to banana-papaya and observed that the fruit leather had a harder texture, likely due to the fact that pectin exhibits higher gelling properties. However, using pectin in high concentrations can lead to undesirable stiffness, flexibility, chewability, and changes in sensory and textural properties. While the organoleptic addition of pectin has been found to improve the texture of the product, adding high concentrations of pectin content results in better cross-linking of the polymer and thus increases the hardness of the gel.

Apart from the role of ingredients in the preparation of fruit leather, the drying process also plays a vital role in the development of the final product. Various methods can be used to dry the wet fruit puree, such as sun drying, hot air

oven drying, tray drying, microwave drying, etc. However, each of these methods can have an impact on the final product's texture, color, moisture content, and other nutritive properties.
After the development of the final product, packaging becomes a necessary process to store and transport the product safely. The packaging material should be in accordance with environmental conditions and cost-effective. It enhances the shelf life of the product and helps to boost the sales of the particular product. However, different products require different types of packaging, depending upon their physical and physiological nature and susceptibility to microbial decay.

Conclusion
In conclusion, fruit bars are a highly nutritious and popular food product. The production process involves several steps, including sorting, washing, peeling, and cutting the fruits into slices that are then blended with various additives. The resulting fruit puree is cooked or blanched to deactivate enzymes, and then dried using a variety of methods, including convective, microwave, and vacuum drying. Despite the availability of advanced drying technologies, there are still challenges in producing high-quality fruit leather, such as lengthy processing times, high energy consumption, and inappropriate drier designs. Quality assessment of fruit leather is essential to ensure its acceptability, and parameters such as physicochemical, phytochemical, mechanical, thermal, sensory, and microbiological properties can be evaluated. Proper packaging is also crucial in preserving the quality and extending the shelf life of the prepared fruit leather. Overall, continued research and innovation are needed to address the challenges and improve the production and quality of fruit leather.

Conflict of interest
The authors declare no conflict of interest.

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