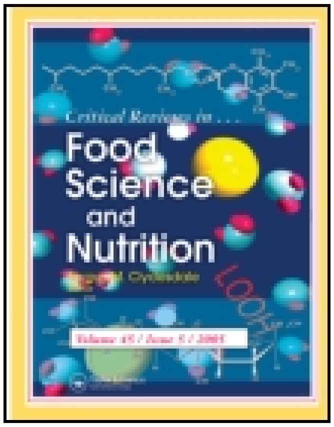

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Developments and Trends in Fruit Bar Production and Characterization

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Developments and Trends in Fruit Bar Production and Characterization

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Fruits serve as a source of energy, vitamins, minerals, and dietary fiber. One of the barriers in increasing fruit and vegetables consumption is time required to prepare them. Overall, fruit bars have a far greater nutritional value than the fresh fruits because all nutrients are concentrated and, therefore, would be a convenience food assortment to benefit from the health benefits of fruits. The consumers prefer fruit bars that are more tasted followed by proper textural features that could be obtained by establishing the equilibrium of ingredients, the proper choosing of manufacturing stages and the control of the product final moisture content. Fruit bar preparations may include a mixture of pulps, fresh or dried fruit, sugar, binders, and a variety of minor ingredients. Additionally to the conventional steps of manufacturing (pulping, homogenizing, heating, concentrating, and drying) there have been proposed the use of gelled fruit matrices, dried gels or sponges, and extruders as new trends for processing fruit bars. Different single-type dehydration or combined methods include, in order of increasing process time, air-infrared, vacuum and vacuum-microwave drying convective-solar drying, convective drying, and freeze drying are also suggested as alternative to solar traditional drying stage. The dehydration methods that use vacuum exhibited not only higher retention of antioxidants but also better color, texture, and rehydration capacity. Antioxidant activity resulting from the presence of phenolic compounds in the bars is well established. Besides this, fruit bars are also important sources of carbohydrates and minerals. Given the wide range of bioactive factors in fresh fruits that are preserved in fruit bars, it is plausible that their uptake consumption have a positive effect in reducing the risk of many diseases.

Keywords Fruit bars, fruit snacks, production techniques, antioxidants, quality

INTRODUCTION

Fruits are a natural source of energy, vitamins, minerals, and dietary fiber. Typically contains between 10% and 25% carbohydrates, less than 1.0% of proteins, and a very small amount (less than 0.5%) of fat. Important fruit minerals include Ca, Mg, Na, K, P, Cl, and S and, in microquantities, Fe, Cu, Co, Mn, Zn, I, and Mo. Potassium is the most abundant mineral in fruits followed by calcium (Kader and Barret, 1996).

The Dietary Approaches to Stop Hypertension diet estimates that fruit and juices consumption contribute an average of 5.8%, 17.3%, 33.0%, and 6.6% to the intakes of calcium, magnesium, potassium, and zinc, respectively (Lin et al., 2003).

Low intake of fruits and vegetables is estimated to cause about a total worldwide mortality more than 2 million deaths per year (Lock et al., 2005). Increasing individual fruit and vegetable consumption to up to 600 g per day could reduce the burden of ischemic heart disease, ischemic stroke, stomach, lung, and colorectal cancer by 31%, 19%, 20%, 12%, and 2%, respectively (Lock et al., 2005). The minerals, vitamins, antioxidants, and dietary fiber content in fruits and vegetables might confer these health protective benefits, that is, preventing free radicals from damaging proteins, DNA, and lipids (Scalbert et al., 2005; Isabelle et al., 2010).

Healthy eating has become one of the most important factors in food choice among governments and cultured consumers. They were conscious that more frequent consumption of fruit and vegetables should be a part of a healthy diet (Margetts et al., 1997). One of the barriers in increasing fruit and vegetables consumption is time required to prepare them. Thus, it is not surprising that if it comes to fruit, consumers require product available in many outlets most of the year, suitable for many uses, with long shelf-life and not messy (Jesionowska et al., 2008). Overall, fruit bars have a far greater nutritional value (e.g., especially in terms of energy, minerals, antioxidants, and fiber) than the fresh fruits because all nutrients are concentrated. Because of the growing consumer demand for healthy, natural,

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and convenient foods, snack bars are becoming a popular and convenient food and, therefore, would be an ideal food format to benefit from the abovementioned remarkable health benefits of fruits (Sun-Waterhouse et al., 2010).

A possible constraint for the success of a processed product like fruit snack bars is the negative perception of some consumers that fruit processing decreases product quality.

For the European fruit market, with the exception made for freshly squeezed juice, processed fruit products, canned or bottled juices, and canned fruit, are typically not considered to be equivalent to fresh fruit. In addition, processed fruit products are not considered to have the same health effects as fresh fruit and there was an overall lack of confidence in their components (Briz et al., 2008). Similar results were reported by a comparable study for Europe in which participants from northern countries accepted the sensory characteristics of processed fruit better, and evaluated their healthiness and quality to be higher. It seems that processed product consumption fitted the eating habits of North European consumers more closely, whereas South European consumers were solely fresh fruit oriented (Kraszewska et al., 2009). In contrast, for the US market, freeze-dried fruits and fruit chips were considered the hottest trend in the snack business in 2008 with fruit chips posted growth of 98% over the previous year (Sloan, 2008).

European perception may be the consequence of recommendations of public campaigns that are probably interpreted only in relation to fresh fruit, and may, therefore, miss their impact when it comes down to the consumption of prepared and especially processed fruit (Briz et al., 2008). However, processed fruit products can be more convenient for the consumer once their health properties of these foods have been demonstrated. This kind of fruit-based snacks can help to increase the availability and wider consumption of fruit especially by the young and it is necessary to develop a knowledge base on the uptake of such products (Briz et al., 2008).

With that motivation in mind, this review covers some general aspects of the conventional and innovative overall procedures and key steps reported for the manufacture of such fruit bars and representative examples of these processes. Moreover, the nutritional characteristics of fruit bars, focused on their antioxidant content and antioxidant activity are also discussed. Finally, an attempt is made to describe some of the general quality parameters and assays that are currently used to characterize fruit bars.

CONVENTIONAL METHODS OF PRODUCTION OF FRUIT BARS

In this work, fruit bar refers to a variable content fruit component (fruit pieces, fruit puree, or fruit powder) food bar in a single-serving size of any tridimensional form including traditional rectangular shape. Fruit bars are products consumed since ancient times in some Asian countries. In India, the best known are those manufactured with a mixture of mango pulp and sugarcane juice that was wore on bamboo to be dried in the sun. The product obtained by this traditional and unhygienic process is called "mango leather" (Gujral and Brar, 2003). Improved, standardized methods for mango leather production have been reported elsewhere (Rao and Roy, 1980; Jagtiani et al., 1988). An industrialized method for the manufacture of these snacks uses basically the same sequence of processing of fruit pulp mixed with sugar paste to form sheets that are dehydrated in a tray dryer (50–60°C, 18—24 h) thereby obtaining a food microbiological attributes, color, and flavor acceptable (Abdelhaq and Labuza, 1987). Fruit bars fabricated with these procedures are called fruit leathers because they have a texture resembling leather. In contrast, fruit cheeses are pulps that are boiled until they have a final sugar content of 75–85%. When they cool, they set as a solid block and can be cut into bars or cubes. Fruit leathers/cheeses can be eaten out of hand as confectionery items or incorporated into baked canned and frozen foods. They fall into the category of intermediate moisture foods, having water activity around 0.6 and moisture value between 8% and 15%. There are many variations on their basic formulation and process. The formulation may include a mixture of pulps, fresh or dried fruit, sugar (i.e., sucrose, maltodextrin, and juice concentrates), binders (typically pectin), and a variety of minor ingredients (e.g., colors, flavors, and acids). Small amounts of oil and lecithin may also be added to reduce stickiness as fruit leathers have fructose, and are prone to absorb water and to become sticky (Torley et al., 2006). The regular steps for the conventional manufacture of fruit bars (leathers and chesses) are shown in Table 1.

Variety of fruits like apple, durian (CheMan et al., 1997), gold kiwifruit (Vatthanakul et al., 2010), grape (Maskan et al., 2002), guava (Vijayanand et al., 2000), jackfruit (CheMan and Taufik, 1995), kiwi (Lodge, 1981), longan (Jaturonglumlert and Kiatsiriroat, 2010), mango (Gujral and Brar, 2003), pear (Huang and Hsieh, 2005), peach (McHugh and Huxsoll, 1999), and tomato (Ahmad et al., 2005) have been used in the preparation of fruit bars. As mentioned before, mango fruit bar is traditionally prepared by adding cane sugar to ripe mango puree, spreading the puree on bamboo mats and drying the pulp in the sun (Gujral and Brar, 2003). Fruit bars prepared like this from fruit purees such as banana and guava, however, resulted in hard textures thereby rendering the bars unacceptable. To overcome this problem, there are suggested enzymatic treatments and the blend of suitable additives such as maltodextrin, pectin, soluble starch, and wheat flour (Vijayanand et al., 2000). Comparative analysis of some fruit-based bars is presented in Table 2.

Several studies have been made to analyze alternative steps, reduce operational costs, and/or improve overall quality attributes of different types of fruit bars. Thus, it makes sense to examine the innovative options reported for the manufacture of these products. This will be done in the following sections.

DRYING TECHNIQUES IN FRUIT BAR PRODUCTION

Drying or dehydration is one of the oldest methods of food preservation for later use and can be defined as a simultaneous

Table 1 Stages for conventional manufacture of fruit bars

Stage in process		
Essential	*Optional*	Notes
Washing		Fruits are washed and sanitized in chlorinated water (100 ppm)
Peeling	No peeling in some cases	By hand using knives or peelers, or using peeling machines
	Treatment with sulfur dioxide	This is optional to reduce browning. Applications of SO_2 have been restricted in many countries because the health risk of sulfite residues.
Pulping		Pulper, steamers, or pulper finishers are used for extraction of pulps
	Homogenizing	To mix different pulps. Ratios according to different formulations
	Heating or blanching	80°C for 5–10 min
	Deacidification	The high acidity of some fruits reduces their quality and limits their use in food bars
	Enzyme treatment	Blends of macerating enzymes consisting of pectinases in combination with other carbohydrate degrading enzymes can result in higher extraction of the soluble solids and soften final products
Addition of sugar or edulcorant		Sugar is added to the pulp to increase its sweetness and total solids
	Adding other additives	Citric acid, hydrocolloids (Pectin, starch, alginate, etc.)
	Concentrating or syruping	Fruit puree is boiled up to having >68°Brix
Spreading		Spreading in trays containing oil coating film
	Drying	Usually solar/convective drying process
Packing and labeling		The fruit bar is sealed for moisture-proof, airtight plastic bags
Storing		In a cool dry place away from sunlight

heat- and mass-transfer operation in which water activity of a material is lowered by the removal of water. Drying occurs by vaporization of the liquid by supplying heat to the wet feedstock. Dehydration of fruit leather is a process which involves simultaneous heat and mass transfer. The heat-transfer rate is a function of external heat-transfer coefficient and the thermal conductivity of the material, while mass-transfer rate generally depends on mass-transfer coefficient and mass diffusivity of water in the material (Sakai and Hanzawa, 1994). Heat may be supplied by conduction (contact or indirect dryers), by convection (direct dryers), by radiation, or volumetrically by placing the wet material in a microwave or radio frequency electromagnetic field. Over 85% of industrial dryers are of convective type with hot air or direct combustion gases as the drying medium (Mujumdar, 2007). Drying process may cause changes in the physicochemical properties that could influence the final quality of the product. These modifications are changes in optical properties (color and appearance), sensory properties (odor, taste, and flavor), structural properties (density, porosity, and specific volume), textural properties, rehydration properties (rehydration rate and rehydration capacity), and nutritional characteristics (vitamins and proteins). Dehydration step could enhance some quality indices (flavor, digestibility, etc.) as it could diminish others (vitamins, aroma, etc.).

The traditional conditions used in open sun drying (i.e., environmental contaminations and uncontrolled circumstances like unexpected rain, overdrying, insufficient drying, and discoloring by ultraviolet) do not fulfill the international quality standards. Thus, open sun drying has been replaced by enhanced solar dryers. Conventional drying with high air temperature and longer drying time may also cause serious damage to the quality attributes of the product such as flavor, color, nutrients, and reduction in bulk density and rehydration capacity of the dried product (Vadivambal and Jayas, 2007). So, different dehydration processing schemes have been proposed for the production of fruit bars including single-type dehydration or combined methods of drying. Some of them are: convective drying, convective-solar drying (Maskan et al., 2002), air-infrared radiation (IR) heating (Nowak and Lewicki, 2004; Timoumi et al., 2007), vacuum drying (Jaya and Das, 2003), vacuum-microwave (Vadivambal and Jaya, 2007; Cui et al., 2008), and freeze drying (Nussinovitch et al., 2004; Cui et al., 2008).

Table 2 Typical physical properties and composition of fruit bars

Fruit bar	a_w	Moisture content (%)	Sugar content (%)	pH	Reference
Commercial fruit leathers	0.42–0.53	7.4–17.4	31.9–62.0	3.6–3.9	(Torley et al., 2006)
Mango and banana fruit bars		11.9–13.2	61.9		(Prasad, 2009)
Papaya and tomato fruit bar		20.9–22.1	78.1–79.8	4.3–4.6	(Ahmad et al., 2005)
Restructured pineapple	0.85–0.92	20.0	21.0		(Grizotto et al., 2007)
Restructured peach	0.55–0.77	18.9–31.0	0–60.0		(McHugh and Huxsoll, 1999)
Pear fruit leather	0.36–0.48	4.0–8.0			(Huang and Hsieh, 2005)
Apple bar		15.56	71.0		(Agrahari et al., 2004)
Apple snack bar	0.46–0.48	10.7–11.7			(Sun-Waterhouse et al., 2010)
Guava and mango bars	0.45	11.0–14.0			(Vijayanand et al., 2000)

Solar Drying

The heat from the sun, coupled with the wind, has been used to dry and preserve fruits and food crops are still practiced largely unchanged from ancient times. Three basic designs of solar dryers are direct, indirect, and specialized solar dryers. In direct solar dryers, the product is heated by sun and the material to be dried is placed in an enclosure, with a transparent cover on it. In the indirect or convection dryer, the product is exposed to warm air which is heated by means of a solar absorber, or heat exchanger. Specialized dryers are normally designed with a specific product in mind and may include dryers combining the principles of the above 2, where the product is exposed to the sun and a stream of preheated air simultaneously, or hybrid systems where other forms of energy are also used (Sharma et al., 2009).

For sun and solar drying of fruits and fruit bars, there exist many investigations as these by Pande and Thanvi (1991) who designed, developed, and tested a solar dryer cum water heater for dehydrating fruit and vegetables or heating water exclusively. Two important features of this equipment were the possibility of continue the drying process in the night, and its capacity (it can save 418 kWh of electricity as a water heater or dehydrate 500 kg of fruits or vegetables/year) (Pande and Thanvi, 1991). Sharma et al. (1993) studied different solar dryers for fruits and vegetables and suggested maximum allowable temperatures and typical ranges for initial and final moisture content for safe dehydration and storing of some crops. Mahmutoğlu et al. (1996) analyzed the effects of pretreatment solutions and dryer types (solar vs. sun) for sultana grapes. A comparative study of natural and solar drying for preservation of fruits and vegetables is given by (Gallali et al., 2000). Similar evaluation for hot air drying and sun drying of pestil, a well-known fruit leather in Turkey, was made by Maskan et al. (2002). Sreekumar et al. (2008) developed and tested a new type of solar dryer, particularly meant for drying vegetables and fruit, with 2 compartments: one for collecting solar radiation and producing thermal energy and the other for spreading the product to be dried (Sreekumar et al., 2008).

Mathematical modeling of fruit sun drying has also been studied for apricot, peach, fig, plum, and grape (Tŏgrul and Pehlivan, 2004), and mulberry fruit (Doymaz, 2004). In the first study, 12 mathematical models were tested to fit the drying rates of the fruits. Among them, the approximation of the diffusion model for apricots and figs, the modified Henderson and Pabis (1969) model for apricot, grape, and plum, and the model given by Verma et al. (1985) for peach were found to best explain 1-layer open sun drying behavior of the fruits.

Doymaz (2004) conducted experiments of sun drying of both treated with ethyl oleate solution and untreated mulberries. Comparing the correlation coefficients and κ^2 values of 2 models, he concluded that the exponential model represents better the thin-layer drying characteristics of mulberries better than the empirical Page model (Page, 1949)

Infrared Drying Process

One of the ways to shorten the drying time is to supply heat by IR. IR has some advantages over convective heating. Heat-transfer coefficients are high, the process time is short and the cost of energy is low. Since dry air is substantially transparent to IR (N_2 and O_2 do not absorb IR), the process can be done at ambient air temperature (Nowak and Lewicki, 2004). When using IR is applied as supplemental heat to conventional convective drying, high heat and mass transfer rates at the surface will result in fast heating, overheating, or overdrying of the material, which would lead to quality problems without major increase in the drying rates. Those risks can be overcome with compact and automated equipment with high degree of control of process parameters (Sakai and Hanzawa, 1994; Nowak and Lewicki, 2004). This method of heating is especially suitable to dry thin layers like apple slices (Nowak and Lewicki, 2004; Timoumi et al., 2007) and fruit leather (Jaturonglumlert and Kiatsiriroat, 2010). Mathematical modeling of fruit convective-infrared drying has been studied for apple pomace (Sun et al., 2007) and longan fruit leather (Jaturonglumlert and Kiatsiriroat, 2010). Logarithmic model and Page model were most adequate in describing thin-layer drying for apple products. For longan fruit leather, the authors proposed a set of modified correlations for predicting ratio of heat- and mass-transfer coefficients and the heat-transfer coefficient in term of heat-transfer Nusselt number.

Freeze Drying

There are several drying techniques for production of dehydrated foods such as convective hot air drying, vacuum, freeze, and spray drying; among them, freeze drying is the most suitable to preserve nutritional and antioxidant content of fresh fruits (Orrego et al., 2009). Freeze drying is a drying process for the long term preservation of heat-sensitive food and other biological materials based on the phenomena of sublimation. The product is first frozen solid. It is then exposed to a controlled temperature and reduced pressure ($<$300 Pa) environment. A successful freeze-drying process preserves most of the initial raw material properties or attributes such as shape, dimensions, appearance, taste, color, flavor, texture, and biological activity. The product, in the dry state, is usually highly porous, brittle, hygroscopic, and with excellent rehydration capacity (Orrego, 2008). The use of freeze drying in the production of fruit-like texture products for incorporation into food products such as yogurt was reported since 1976 (Luh et al., 1976). Freeze-dried texturized fruits can be produced by freeze-dehydrating gels consisting of fruit concentrate or puree. The products were dry and crunchy with a high content of fruit ingredients (Nussinovitch et al., 2004).

Microwave heating provides a possibility of shortening the freeze drying time because of the volumetric dissipation of microwave energy and promoting heat and mass transport. However, the different combinations will lead to dissimilar drying characteristics and results. Cui et al. (2008) made a comparison between freeze drying and microwave vacuum of apple chips. The samples prepared by the latter method exhibited very close rehydration capacity, color retention, and texture with those of the freeze-dried ones but with a little higher shrinkage.

In the dehydration of sliced bananas and mashed bananas, which are foamed by blending with a foaming agent, drying rates could be increased by a factor of 16 using microwave energy instead of hot air alone (Drouzos and Schubert, 1996).

Effects of Drying on Quality

In terms of quality, an optimized food-processing operation must minimize the losses of nutritional value, keeping the product acceptability and safety. In the particular case of food drying, this means the reduction of loss of volatiles and flavors and changes in color and texture, preserving most of the original nutritional value for the dried product. The consequences of drying procedure on physicochemical and nutrimental properties of fruit bars are rather scarce. Conversely, the effects of dehydration on dried fruit and vegetables have been discussed in some depth elsewhere (Nijhuis et al., 1998; Nicoli et al., 1999; Vadivambal and Jayas, 2007). Nevertheless, most of the general conclusions applied for drying fruits and vegetables could be followed for the identification of a suitable drying method and conditions that minimize the quality loss in fruit bars dehydration.

As mentioned before, mass production of dried foods and fruit bars is often made in convective dryers. Case hardening and shrinkage are the main problems. In latest years, improvement of quality retention by dried products by altering process conditions and/or pretreatments, has been a foremost research target in convection drying (Nijhuis et al., 1998; Doymaz, 2004).

Among drying techniques, freeze drying is the most suitable to preserve nutritional and antioxidant content of fresh fruits (Asami et al., 2003; Orrego et al., 2009). Comparison between vacuum-microwave drying and freeze-drying resulted in similar retention of anthocyanins and antioxidant activity, which were both relatively higher than that recovered from cranberries dried by hot air drying (Leusink et al., 2010). Lin et al. (1998) studied the textural characteristics of vacuum-microwave-dried, air-dried, and freeze-dried carrot slices. The puncture force required to break vacuum-microwave-dried and air-dried carrot slices was 11.0 and 18.1 N, respectively, indicating that less case hardening occurred with vacuum-microwave-dried carrot slices. Freeze-dried carrot slices required the least puncture force. However, freeze-drying is far more expensive than convective drying, and is used for the production of a minor amount of high-value added fruit products.

Yongsawatdigul and Gunasekaran (1996) evaluated the quality attributes of microwave-vacuum-dried cranberries by testing the color and they conclude that microwave-vacuum-dried cranberries had better color than the air-dried product. Funebo and Ohlsson (1998) studied dehydration of apple and the L, a, and b values were similar for hot air and microwave-dried apples. Maskan (2001) studied the rehydration characteristics of kiwi Microwave-dried kiwi fruit slices exhibited lower rehydration capacity and faster water absorption rate than the air dried samples.

Heat treatment associated with fruit bar manufacture operations often reduces the number of original volatile flavor compounds of fruits, while introducing additional volatile flavor compounds through the autoxidation of unsaturated fatty acids and thermal decomposition, and initiation of Maillard reactions. The products of these reactions (mainly hydroxymethylfurfural) are characterized by raised antioxidant potential. For instance in dried plums hydroxymethylfurfural is present at levels averaging 22 mg/100 g fresh weight (Donovan et al., 1998). The newly formed Maillard products, besides increasing the antioxidant capacity, can reduce polyphenol oxidation by inhibition of polyphenol oxidase (Tan and Harris, 1995; Tarko et al., 2009). However, the reported effects of Maillard products on human health are quite contradictory. Depending on food composition and processing conditions, they have been found to have mutagenic or antimutagenic activity (closely related to their antioxidant activity) (Nicoli et al., 1999).

There is a lack of studies on the effect of thermal processing on the changes of fiber and protein in fruit bars. However, for fruits and vegetable fried products, it had been observed losses of protein content. Vattem and Shetty (2003) found that the protein content decreased by almost 75% for cranberry and oregano treated slices after frying. They proposed that the thermal treatment associated to frying promotes makes the starch more available for Maillard reactions. (Vattem and Shetty, 2003).

Regarding to changes in fiber derived from thermal treatments of vegetables and fruits, Khaunum et al. (2000) observed a significant increase in the content of soluble fiber (i.e., in carrots, potatoes, and plantains) compared with the decrease in the content of insoluble fiber. They suggest that some of the insoluble dietary fiber was converted to digestible carbohydrates and, therefore, not recovered as soluble dietary fiber and other part the nondigestible fibers were transformed to short length chains or units which might not be precipitated. Similar effect of increasing of solubilization of fiber components for extrusion of wheat, resulting from the reduction in cellulose and lignin, the major components of insoluble fiber, presumably due to dextrinization or other types of thermal decomposition. (Khanum et al., 2000).

STRUCTURED FRUIT PRODUCTS

Research in structured fruits began in the middle of 20th century when Peschardt patented a process for produce restructured cherries using cherry puree and alginate gelled into a bath of calcium salt (Peschardt, 1946). Structured fruit products made of fruit pulp, a wide range of hydrocolloid gels, and other traditional food additives, have been the subject of numerous patents and commercial applications (Szczesniak, A., 1968;

Tolstoguzov, 1971; Lugai et al., 1992). These products are, in most cases, composite materials in which fruit ingredients are embedded in a polymeric gel matrix.

Nussinovitch has performed several studies on the formation and properties of structured fruits. In the first study, he included highly acidic fruit pulps and juices (apple pulp and reconstituted grape fruit juice) to calcium alginate gels (Kaletunc et al., 1990). In a further work, raspberry pulp was combined to calcium alginate gels, with and without the addition of agar to increase brittleness and stiffness (Nussinovitch and Peleg, 1990). Nussinovitch et al. (1991) also studied the combined effect of fruit pulp (orange, banana, and apricot), sugar, and gum on texturized fruit products. Sugar addition strengthened gels up to a maximum point after which this property was reduced. Conversely, fruit pulp weakened gel strength down to a minimum point after the gel system regained strength. He also conducted other studies to produce hydrocolloid-based, texturized fruit products (Weiner and Nussinovitch, 1994), and multilayered texturized fruits (Ben-Zion and Nussinovitch, 1996). A plausible explanation of the gel texture improvements of sucrose addition, when its concentration is between 300 and 400 g/kg, is that sugar is capable of reducing solvent–polymer interaction and thus increases polymer–polymer attraction, but seems to cause a decrease in gel homogeneity at high concentrations (Nussinovitch et al., 1991; Mouquet et al., 1997).

Other structured fruit systems have also been investigated. A pectic gel could be formed by dehydrating a formulation of fruit puree added with sucrose and an organic acid, by the mechanism of sugar–acid–high methoxyl pectin gelation. As the drying proceeds, the well-hydrated dispersion of sugar and pectin forms a network that is produced by junctions between pectin molecules entrapping a concentrated sugar-fruit solids solution. These gels are not thermoreversible. By means of this procedure, using a drying time of 6.67 h at 60°C, an apple sheet was produced with high acceptability by a panel of consumers (Díaz et al., 2009). Owen et al. (1991) reported a process for dehydrated restructured fruit bar which involves gelling of apple puree by adding low methoxyl pectin and calcium monohydrogen phosphate. Texture and thermostability of structured mango formed with 90% fruit pulp were evaluated in a study of Mouquet et al. (1992). In this study, firmness of restructured fruits was achieved without the common step of previous neutralization of the acid pulp with a NaOH.

A mixture of alginate and pectin, that also forms thermoreversible gels, showed advantages over the pure hydrocolloids. The nature of the interactions between pectin and alginates in mixed gels is not well known, but appears to be a heterogeneous association between specific chain sequences of 2 polymers: alginate poly-L-guluronate "blocks" and pectin poly-D-galacturonate sequences of low charge density (Thakur et al., 1997). In a study of fruit-alginate-pectin interactions, the gels formed, even at low pH, were firm, support cutting, and can be obtained without the addition of calcium, required for structuring with pure alginate (Mancini and McHugh, 2000). In another work, dried natural fruit chips were produced using fruit ingredient (in a particulate, comminuted or concentrate form) and an analogous fruit cheese manufacturing procedure with final chips drying (McGuirre et al., 2001). Based on the reported effect of glycerol in food systems as remover of immobilizing free water and so a_w suppressor (Boyle et al., 1993), a Brazilian research group investigated how different concentrations of alginate, low methoxy pectin, and glycerol could be used to obtain restructured concentrated pineapple pulp, with the aid of response surface methodology. Their results showed that changes in pectin and alginate levels have statistically significant effects on the firmness of restructured pineapple fruit, and glycerol, used at the concentration of 100 g/kg, reduced the water activity of the restructured product to an intermediate moisture level (0.880) (Grizotto et al., 2007).

SPONGES OR CELULAR SOLIDS

Drying either gels or texturized hydrocolloid fruit products produces sponges or cellular materials with a characteristic porous structure. Sponges may be defined as dispersions of gas in a solid matrix. There has been considerable recent interest in the use of sponges or scaffolds derived from synthetic and natural materials within the pharmaceutical and biomedical area, particularly as matrices for controlled drug delivery, as wound dressings and as matrices for cell growth within the tissue engineering field. Other hydrocolloid-based cellular solids are sponges produced by fermentation of immobilized yeasts (Nussinovitch et al., 1994; Nussinovitch and Gershon, 1997); cellular solids produced from oil-containing gels by freeze dehydration (Nussinovitch and Gershon, 1997); enzymatically produced hydrocolloid sponges (Nussinovitch et al., 1998), hydrocolloid cellular solids as carriers for vitamins (Reifen et al., 1998), and cryogelled supports for enzyme immobilization (Orrego and Valencia, 2009; Orrego et al., 2010). These kinds of dried gels or hydrocolloid-texturized fruit gels could serve as a basis for potential novel fruit bars or other food snacks like artificial fruit (Luh et al., 1976), intermediate moisture orange product (Blake, 1980), and fruit sponge (Thai et al., 2007).

EXTRUSION

Extruded fruit bars made from sugar, soybean oil, soy protein, cellulose, gum, and natural and artificial colors are available commercially.

Extrusion processing plays an important role in food processing as it provides versatility in handling wide range of raw materials and creating novel products. Extrusion combines a number of unit operations, that is, mixing, cooking, shearing, puffing, final shaping, and drying in 1 energy efficient rapid continues process (Yağci and Göğüs, 2008). The high-temperature short-time conditions in extrusion processing can avoid lengthy processing and dehydration procedures and minimize thermal degradation. Extrusion also has minor effects or improve the natural colors and flavors of foods while inactivating undesirable enzymes, lowering antinutritional factors, and sterilizing the product (Reifsteck and Jeon, 2000; Gamlath, 2008).

Despite the increased use of extrusion processing on cereals, legumes, confectioneries, and extruded crisp breads, a small amount of studies have investigated extrusion as a means of forming restructured fruit products. Nevertheless, it is accepted that extruders are especially useful for processing products with high fruit contents such as fruit leathers and fruit jelly bars (Reifsteck and Jeon, 2000).

While extruded bars formed by coextrusion with rice flour with dried fruits and fruit juice concentrates exhibited similar sensory properties compared to extrudate made exclusively from rice, in the coextrusion assays the juices performed better than the dried fruit in regards to expansion (Maga and Kim, 1989). The potential of extrusion technology to restructured peach and peach/starch gels was studied by McHugh and Huxsoll (1999). They could obtain up to 100% peach gels using twin screw extrusion technologies. Using starch and sugar solutions, they claimed to be able to modify physical properties such as water activity, color, and texture. Finally, they proposed apply their findings to the manufacture of fruit products from other commodities such as strawberries, apricots, pears, and apples and they patented a general procedure for restructuring bulk processed fruits and vegetables utilizing drum drying and extrusion, and products made by such methods.

The result of different ripening stages of banana during extrusion processing in combination with rice flour on the physical, nutritional, and sensory properties of the extruded snack products was investigated by Gamlath (2008). The effects of extrusion processing variables on antioxidant activity, total phenolic content, and β-glucan content of extrudates of barley flour, barley flour–tomato pomace, and barley flour–grape pomace blends was studied by Altan et al. (2009).

Table 3 provides a summary of the new unit operations that have been reported for the production of fruit bars.

NUTRITIONAL ASPECTS

Antioxidants in Fruit and Fruit Bars

Fruits and vegetables contain different antioxidant compounds, such as vitamin C, vitamin E, and carotenoids and polyphenol compounds, such as flavonoids (García-Alonso et al., 2004). Polyphenolics are widely distributed in nature as secondary metabolites from plants. More than 8000 natural phenolics are currently known to occur in plant sources (Dae-Ok and Chang, 2004). Fruits and vegetables are also high in flavonoid content. There are over 4000 naturally occurring flavonoids (Einbond et al., 2004). Flavanols, flavonols, and anthocyanins are included in flavonoids. Between flavanols, the most common in fruits are of the catechin and gallocatechin types and they can exist in the monomer form or can polymerize, giving rise to condensed tannins or proanthocyanidins (García-Alonso et al., 2004). The anthocyanins, a subclass of flavonoids, are important flower and fruit pigments.

Total phenolic content is commonly determined in raw materials and fruit bars by the Folin–Ciocalteau method with or without modifications. The results are expressed as ferulic acid equivalents [mg ferulic acid/g sample (db) using a calibration curve with ferulic acid (Altan et al., 2009)]. Alternatively,

Table 3 Trends in new unit operations for processing fruit bars

Stage in Process	Notes
Drying	
Infrared drying	Advantages of IR over convective heating are higher heat- and mass-transfer coefficients and shorter time in drying process.
Freeze drying	Used individually for drying fruit slices. Freeze drying is the most suitable dehydration method to preserve nutritional and antioxidant content. The product is flavored, highly porous, brittle, hygroscopic, and with excellent rehydration capacity. However, this method is a slow and expensive process.
Microwave-freeze drying	Drying rates can be increased by as much as an order of magnitude. A major drawback is the nonuniformity of the energy within the chamber. Products have with very close rehydration capacity, color retention, and texture compared with those produced by freeze drying.
Gel structured matrix	
Calcium alginate gel	The alginate gels along with fruit pulps can form a gel with adequate solid characteristics to be suitable as a fruit bar. Besides the alginate concentration, the formation of the gel and its textural properties are influenced by the presence of calcium ion and sequestering agents, pH, temperature, and rate of solubility.
Pectin gel	Non thermoreversible pectin gels, formed by dehydrating formulations of fruit puree added with sucrose and an organic acid, forms good acceptance fruit leathers.
Mixtures of alginate and pectin gels	Many articles and patents discuss the use of a combination of alginates with other hydrocolloids, such as pectin, agar, and carrageenan, together with fruit pulp and other traditional food additives like purees, sugar, and acids, to create simulated fruit products.
Sponge/texturized matrix	Drying by convection, freeze dehydration, or freeze/thaw either gels or texturized hydrocolloid fruit products produces sponges or cellular solids that could be used as matrices for fruit bar production.
Extrusion	There are offered extruded fruit bars made from sugar, soybean oil, soy protein, cellulose, gum, and natural and artificial colors. The high-temperature short-time conditions in extrusion processing can avoid lengthy processing and dehydration procedures and minimize thermal degradation.

phenolic content of snack bar could be expressed as catechin equivalents (Sun-Waterhouse et al., 2010).

The most popular and widespread approach for carotenoid quantification is based on reversed-phase high-performance liquid chromatography (RP-HPLC) using C_{18} or C_{30} columns coupled to diode-array detection. RP-HPLC allows the separation and quantification of all individual carotenoid compounds including the provitamin A carotenoids that have dietary vitamin A activity. Alternative methods include spectrophotometry in the visible range to determine the total carotenoids content. Recently, it has been proposed a new visible and near-infrared reflectance spectroscopy analysis that has good potential for the high-throughput screening of carotenoid contents and in particular for the total carotenoid contents of lyophilized *Musa* fruit samples (Davey et al., 2009).

Antioxidant Activity

A wide range of methods has been described in the literature for assessing antioxidant activity. These include radical scavenging assays, ferric reducing assay, or inhibition of the oxidation of oils, emulsions, low-density lipoproteins, or liposomes (Roberts and Gordon, 2003). The antioxidant potential of fruits, vegetables, and chemicals usually has been described as Trolox (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid) equivalent antioxidant capacity (TEAC) in molar units. Commonly known methods, besides TEAC assay, are the ferric reducing ability of plasma (FRAP), the total radical-trapping antioxidant parameter (TRAP), 1,1-diphenyl-2-picrylhydrazyl ($DPPH\cdot^{+}$) assay (based on free radical scavenging activity in organic phase) and oxygen radical absorbance capacity (ORAC) assay, which also use Trolox for the expression of antioxidant capacity. According to Kim and Lee (2004), the description of antioxidant potential of various chemicals or dietary foods using vitamin C-ascorbic acid-equivalent antioxidant capacity (AEAC) is preferable to that used by the TEAC, TRAP, or ORAC assays (Dae-Ok and Chang, 2004).

Relationships Between Antioxidants Content and Antioxidant Activity

Several relationships between chemical structure and antioxidant activity of phenolic compounds have been encountered. Specifically, the antioxidant potential of phenolics depends on the number and arrangement of the hydroxyl groups and the contribution of the 3-OH group in flavonoids (Fernandez-Panchon et al., 2008).

Phenolics content has been well correlated to antioxidant capacity in fresh, pureed, and dried fruits. Twenty-two freeze dried fruits examined by Isiwata et al. (2004) showed highly correlated polyphenol content and radical-scavenging activity (Ishiwata et al., 2004). Similar results were found for antioxidant activities (ORAC assay) of strawberry, peach, and apple, fresh, sliced, and pureed and their total phenolics contents (Rababah et al., 2005). In a different work designed to determine the amount and quality of phenol antioxidants in dried fruits (apricots, cranberries, dates, figs, raisins, and dried plums), and compare them with the corresponding fresh fruits (apricots, cranberries, dates, figs, grapes, and plums), dried fruits showed a greater nutrient density, greater fiber content, increased shelf life, and significantly greater phenol antioxidant content compared to fresh fruits. The quality of the antioxidants in the processed dried fruit was the same as in the corresponding fresh fruit (Vinson et al., 2005). Dehydration generated the same expected rise in total phenolics, total anthocyanins, and ORAC levels for dried apples, blueberries, peaches, and strawberries in comparison with their respective values for fresh fruit. Again, there was found a strong correlation among total phenolics, total anthocyanins, and ORAC in the dried fruit (Threlfall et al., 2007).

Up to now, vitamin C, a barely stable antioxidant of nutritional interest has been commonly assessed as indicator of processing damage. That is the main reason because processed fruits have been long considered to have lower nutritional value than fresh fruits due to the decline in vitamin C during thermal processing. Unexpectedly, vitamin C content in apples and berries weakly contributes to total antioxidant activity, indicating most of the activity comes from the natural combination of phytochemicals, mostly phenolics (Eberhardt et al., 2002; Kalt, 2005). Based on those evidences, it had been suggested that, in some commodities, heat treatment might retain their total phenolics, flavonoids, and total antioxidant activity despite the loss of vitamin C. That was the situation in a study in which there were no changes in total phenolics and total flavonoids content in tomatoes with thermal treatment at 88°C (Dewanto et al., 2002). In the evaluation of the antioxidant properties and storage life of a plain and a formulated soy enriched apple bars, Agrahari et al. (2004) noticed no significant changes in phenolic contents during dehydration or storage in either apple bar, irrespective of storage conditions. In contrast, ascorbic acid was easily oxidized during processing and storage. Antioxidant activity resulting from the presence of phenolic compounds in the bars was also established. Some published data in relation to phenolics content and antioxidant activity for fruits, dried fruits, and fruit bars are shown in Table 4.

ADDITIONAL QUALITY ASPECTS

Consumer Preferences

Consumers from different countries prefer fruit bars that are more tasted followed by proper textural features. Thai consumers wanted kiwi fruit leathers more fruit flavored, with a lower hardness (Vatthanakul et al., 2010). For cereal bar snack food, the majority of Scotland consumers also ranked taste as the most important characteristic influencing their purchase intent, followed by textural features, price, and appearance. The healthy image aspect was relatively less important. Analysis of the relationship between the sensory measures

Table 4 Total phenolics (as gallic acid equivalent, GAE), antioxidant activity (AA), and AA assays of various fresh and dried fruits and fruit bars

Fruit	Total phenolics (mg GAE/g)	AA	AA method and units
Apple	1.86[e]–3.41[f]	4754[h]	DPPH (AEAC) (mg/100g dry weight)
		2.18[i]	ORAC (μmol/g)
Plain apple bar	0.98–1.06[c]	5077–5200	FRAP (μmol/g)
Soy-enriched apple bar	1.69–1.72[c]	8173–8520	FRAP (μmol/g)
Apricot	7.31[h]	8.47–11.38[g]	$TEAC_{FOLIN}$(μmol/g)
Sun-dried apricot	16.22[h] (28.1% water content)	28.38–43.33[g]	$TEAC_{FOLIN}$ (μmol/g)
Banana	1.38[e]–2.31[f]	2.21[a,i]	ORAC (μmol/g)
Blueberry	41.80[b]–7-95[f]	26.4–62.3[a]	ORAC (μmol/g)
Cantaloupe	0.26[e]–1.24[f]		
Cherry	0.73[a]-3.16[e]	6529[h] (79% water content)	DPPH (AEAC) (mg/100g dry weight)
		1010[h] (30% water content)	
Cranberry	1.71[a]-6.78[e]	13.4–39.8[a]	ORAC (μmol/g)
Fig	10.98 [h] (11% water content)	2524[h] (79% water content)	DPPH (AEAC) (mg/100g dry weight)
		1087[h] (21% water content)	
Grapefruit	0.22[e]–2.14[f]	4.83[i]	ORAC (μmol/g)
Grape (white)	1.94[e]	4.46[i]	ORAC (μmol/g)
Grape (red)	3.70[e]–1.75[f]	1.24–7.39[a]	ORAC (μmol/g)
Guava	2.47[f]	9.9–16.7[f]	ORAC (μmol/g)
Kiwi fruit	2.78[f]	1.08–6.02[a]	ORAC (μmol/g)
Lemon	0.41[e]		
Lychee	0.29[f]	5.4[f]	ORAC (μmol/g)
Mango	0.56[f]	0.49[a]	ORAC (μmol/g)
		1.5–2.2[f]	
Melon	0.38[e]	2195[h] (20% water content)	DPPH (AEAC) (mg/100g dry weight)
		440[h] (87% water content)	
		0.97[i]	ORAC (μmol/g)
Nectarines, 80% flesh, 20% peel	13.6[d]-102.4[d]	46–1447[d]	DPPH (AEAC) (mg/kg)
	1.07[f]		
Orange	0.41[e]–3.37[f]	1.97–7.5[a]	ORAC (μmol/g)
Papaya	0.58[f]–3.89[h]	950 [h] (87% water content)	DPPH (AEAC) (mg/100g dry weight)
		325 [h] (27% water content)	
		2.6–5.3[f]	ORAC (μmol/g)
Peach	0.70[e]	146–1789[d]	DPPH (AEAC) (mg/kg)
	0.228–1.042[d]		
Pear	1.90[e]	0.46[a]–1.34[i]	ORAC (μmol/g)
Pineapple	0.66[e]–0.67[a]	798[h] (79% water content)	DPPH (AEAC) (mg/100g dry weight)
		321[h] (33% water content)	
Plum	2.26[e]	9.49[a]	ORAC (μmol/g)
Plums, flesh tissue	0.22–0.77[d]	205[d]	DPPH (AEAC) (mg/kg)
Plums, peel	1.63–3.32[d]	1314[d]	DPPH (AEAC) (mg/kg)
Raspberry	1.21[a]–5.40[f]	21.4[a]	ORAC (μmol/g)
Starfruit	1.26[a]–2.10[f]	12.9[f]	ORAC (μmol/g)
Strawberry	1.33[e]–3.68[f]	12.8–20.6[a]	ORAC (μmol/g)
	2.57–2.88[a]	15.36[i]	
Tomato	0.80[f]	1.89[i]	ORAC (μmol/g)

[a](Fernandez-Panchon et al., 2008).
[b](Velioglu et al., 1998).
[c](Agrahari et al., 2004).
[d](Gil et al., 2002).
[e](Vinson et al., 2001).
[f](Mahattanatawee et al., 2006).
[g](Güçlü et al., 2006).
[h](Ishiwata et al., 2004).
[i](Wang et al., 1996).

and degree of like confirmed the above segregation of preference, with sensory aromas and flavors having most influence on consumer living (Bower and Whitten, 2000). Moreover, in a Chinese study, it appears that shiny surface, sweet and tart tastes, and fruit aroma were important sensory characteristics of fruit leather, which could provoke the consumers purchasing desire. No considerable preference difference was observed between either sex or age groups (Huang and Hsieh, 2005).

The color of mango leather can be described as yellowish orange and is a very important parameter with respect to consumer preference (Gujral and Brar, 2003).

Some Ingredient Effects

Ingredients could affect considerably the flavor of fruit bars. In the production of *Limonia acidissima* fruit bar, high methoxylated pectin induced an undesirable modification of typical flavor and intensity of flavor and taste, whereas low methoxylated pectin induced few alterations (Vidhya and Narain, 2010), while from the study of guava bar fabrication organoleptic quality (i.e., color, flavor, taste, texture, and overall acceptability) of leather decreased gradually with increase in the quantity of sugar added (Jain and Nema, 2007). Sugars were found also responsible of some color characteristics of fruit bars. The reducing sugars from honey or other ingredients like greater ripeness fruits would lead to the nonenzymatic Maillard browning reaction and caramelization at an elevated temperature, which explains the variations in color detected in the fruit bar base (Gamlath, 2008; Sun–Waterhouse et al., 2010).

In a study of pear fruit leathers prepared by drying a mixture of pear juice concentrate, pectin, corn syrup, and water, Huang and Hsieh (2005) found that pectin was the most significant independent ingredient (followed by moisture and corn syrup content) that affected texture, color, microbial growth, moisture content, water activity, glass transition temperature, and sensory attributes. Glass transition temperature was correlated with instrumental and sensory hardness and chewiness and instrumental hardness, chewiness, and cohesiveness could be used to predict their corresponding sensory attributes (Huang and Hsieh, 2005).

Similar importance of pectin and syrup on some fruit bar properties were reported by Vatthanakul et al. (2010) in the development of gold kiwifruit leather product development using pectin, sugar, salt, citric acid, water, and glucose syrup. They found that tensile strength increased considerably with increasing pectin and glucose syrup content. For moisture content, it was found that the percentage of pectin and glucose syrup used were significant factors. The optimum quantity of gold kiwifruit leather added glucose syrup 15 g and pectin 2 g per 100 g of gold kiwifruit puree (Vatthanakul et al., 2010).

Optical Properties

The color of food is important for its acceptability and in consumer studies product quality is related to color. Generally, thermal treatments promote color changes on food products surface which follow zero and first order kinetics (Avila and Silva, 1999). The most commonly used systems for measurement of color are Hunter lab, Commission Internationale d'Eclairage (CIE) L*a*b, CIE L*C*h, CIE XYZ, and CIE Yxy, which are bases on the fact that the human eye has 3 types of color sensors which are sensitive to the colors red, green, and blue and that all colors are seen as a mixture of these 3 colors (Olivas and Barbosa-Cánovas, 2005). The L*a*b*, or CIELab, color space is an international standard for color measurements, adopted by the CIE in 1976. L* is the luminance or lightness component, which ranges from 0 to 100, and parameters a* (from green to red) and *b** (from blue to yellow) are the 2 chromatic components, which range from −120 to 120 (Jaya and Das, 2003). The L*C*h color system uses the same principle as the same principle as the L*a*b* system but employs cylindrical coordinates. Comparison of color differences can be achieved by calculation the ΔE^*ab when using CIE L*a*b* color space, or the ΔH^* when using the CIE L*C*h scale. Although ΔE^*ab defines the absolute amount of color difference, it does not define what way the colors are different. On the other hand, the hue difference (ΔH^*) not only represents an absolute color difference, but also shows if the change of color leads towards more light, pale, dark, or deep colors.

Various reported values of CIE L*a*b* coordinates for fruit bars are presented in Table 5.

Textural Properties

Texture is one of the important characteristics indicating product quality. Both sensory evaluation techniques and instrumental measurements are used in food research to assess texture parameters. Among instrumental analysis of texture, tests that

Table 5 CIELAB color coordinates of different fruit bars

Fruit bar	*L**	*a**	*b**	Reference
Nine formulations of Gold Kiwifruit leather	36.60–38.98	10.6–12.8	24.86–28.44	(Vatthanakul et al., 2010)
Extended white commercial cereals				(Camire et al., 2007)
Blueberry	70.90	5.82	6.99	
Concord grape	76.05	3.65	10.13	
Cranberry	73.86	6.55	10.48	
Red raspberry	73.21	7.45	10.10	
Extruded peach/starch gels	49.00–52.00	13.0	17.00–21.00	(McHugh and Huxsoll, 1999)
Mango leathers				(Gujral and Brar, 2003)
Control	35.08	12.33	22.74	
Treated with Guar gum	33.73–35.19	10.25–11.44	21.64–22.23	
Sodium alginate	33.12–34.88	8.19–10.11	18.26–18.96	
Carboxymethyl Cellulose	33.29–38.05	9.90–11.61	20.65–24.04	
Acacia gum	34.65–35.31	9.65–9.90	21.32–21.91	
Pectin	35.30–36.23	8.92–9.52	20.94–22.58	

attempt to imitate the action of the jaw like texture profile analysis (TPA), become the most popular. In TPA test, the sample is compressed twice. Several textural characteristics like fracturability, hardness, cohesiveness, adhesiveness, springiness, gumminess, and chewiness are measured by this single test and the parameters obtained from it correlate well with various sensory ratings (Olivas and Barbosa-Cánovas, 2005). TPA was first developed for the General Foods Texturometer (Szczesniak et al., 1963) and later adapted to the Instron Universal Testing Machune (Bourne et al., 1966), and computer-assisted texturometers such as the TA-XT2 (Stable Micro Systems, UK) or the QTS (Stevens, UK).

The most widespread parameters derived from the TPA curve are the maximum load during the first compression cycle is defined as hardness (Newtons). Fracturability or brittleness (Newtons) is defined as the force at the first significant break in the curve during the first compression cycle. Cohesiveness (N × mm) is the ratio of the areas under the curve for the second compression to that under the curve for the first compression portion. Adhesiveness is the work (N × mm) necessary to pull the plunger away from the sample. The length to which the sample recovers in height during the time that elapses between the end of the first compression cycle and the start of the second compression cycle is defined as springiness (mm). Gumminess (Newtons) is defined as the product of hardness times cohesiveness, and chewiness (N × mm) is defined as the mathematical product of hardness, cohesiveness, and springiness (Meullenet et al., 1998; Mochizuki, 2001).

Meullenet et al. (1998) studied both sensory and instrumental TPA techniques to evaluate a wide variety of commercial foods (21 samples including hard candy, gelatin, fruit chew, tootsie roll, and almond). They founded high linear correlations between sensory and instrumental TPA parameters for hardness ($r = 0.76$) and springiness ($r = 0.83$), but no significant correlations between sensory and instrumental TPA parameters for cohesiveness and chewiness. Similar observation were made for hardness and springiness in a study concerned with sensory aspects of cereal bar snacks (Bower and Whitten, 2000).

A limited number of researchers have been carried out instrumental textural evaluations of fruit bars such as jackfruit leather (CheMan and Taufik, 1995), mango and guava bars (Vijayanand et al., 2000; Gujral and Brar, 2003), papaya and tomato fruit bar (Ahmad et al., 2005), and pear fruit leathers (Huang and Hsieh, 2005). Guava and mango bars had similar textural characteristics initially with hardness values of 86.32 N and 79.95 N, respectively, which marginally reduced to 80.44 N and 78.20 N after 3 months of storage at ambient (Vijayanand et al., 2000). Fruit leather made from papaya and tomato showed hardness values between 1.86 and 14 N in fresh and negative peak area (adhesive force) in the 0.97–8.03 N (Ahmad et al., 2005). For textural studies of pear fruit leathers prepared by drying a mixture of pear juice concentrate, pectin, corn syrup, and water, pectin was found to be the most important factor that rendered the fruit leather higher in hardness, springiness, cohesiveness, and chewiness. The addition of corn syrup softened the fruit leathers and it also decreased springiness and increased the adhesiveness significantly. Water increased the cohesiveness and decreased the springiness (Huang and Hsieh, 2005). These observations were similar to the results of the jackfruit leather by CheMan and Taufik (1995). Pear fruit leather presented the following textural properties ranges: hardness (N) 45.37–129.36, adhesiveness (N × mm) (0.407–1.735), cohesiveness 0.739–0.879, springiness (mm), 0.781–0.910, and chewiness (N × mm) 25.088–102.90 (Huang and Hsieh, 2005).

CONCLUDING REMARKS

The following observations arise from this review.

It is widely accepted in scientific circles the health-promoting properties of fruits and vegetables. These benefits are due to the presence of some vitamins, minerals, dietary fiber, and nonessential phytochemicals like polyphenols.

Because of the growing cultured consumer demand for healthy, natural and convenient foods, fruit snack bars are becoming a popular and, therefore, would be an ideal food format to deliver the fruit derived minerals, vitamins, antioxidants, and dietary fiber. In contrast, acceptance of regular consumers is mainly determined by the fruity flavor and the proper texture of the fruit bar and its healthy properties is considered relatively less important. Additionally, another people have the negative perception that a processed fruit product has poor quality (in comparison with fresh fruits).

Fruit bar production includes many variations on their basic formulation and process. The preparations may include a mixture of pulps, fresh or dried fruit, sugar (i.e., sucrose, maltodextrine, and juice concentrates), binders (typically pectin), and a variety of minor ingredients (e.g., colors, flavors, and acids).

In addition to the conventional steps of manufacturing (pulping, homogenizing, heating, concentrating, and drying), there have been proposed the use of gelled fruit matrices, dried gels or sponges, and extruders for processing fruit bars. In general, heat treatments associated with fruit bar manufacture operations often reduce original flavor and introduce additional volatile flavor compounds. Different single-type dehydration or combined methods include convective drying, convective-solar drying, air-infrared, vacuum and vacuum-microwave drying, and freeze drying are also suggested as alternative to solar/convective usual drying stage. Solar and conventional air drying may cause unfavorable damage to the quality attributes of the product while proper infrared, microwave, and freeze drying preserve them at different levels.

Most of fruit bars fall into the category of intermediate moisture foods, having water activity around 0.6 and moisture value between 8% and 15%. When using the restructured fruit techniques for their manufacture, these 2 quality parameters rise to values of about 0.7–0.9% and 20–30%, respectively.

Phenolics content has been well correlated to antioxidant capacity in fresh, pureed, dried fruits, and fruit bars. In contrast with ascorbic acid that is easily oxidized during processing and storage, the presence of phenolic compounds in the bars is well established.

Pectin and moisture are the most significant independent ingredients that affected texture, color, microbial growth, water activity, and sensory attributes of fruit bars. Protein supplementation of fruit bars is technically feasible and the consumer acceptance seems to be not adversely affected. Sugars from different ingredients affect of some color characteristics of fruit bars as they lead to the nonenzymatic Maillard browning reaction and caramelization in operations that require elevated processing temperature.

In the literature, there are many reports focusing on the effect of processing on the nutritional components of fruits. However, the consequences of ingredients and manufacture operations on physicochemical and nutrimental properties of fruit bars are rather scarce. To maximize beneficial effects and increase the consumption of fruit bars, future studies should emphasize in overcome the possible uncertainties about their healthy image and, consequently, develop and document a knowledge base on the uptake of such products.

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