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Formulation, Physicochemical Analysis, Sustainable Packaging-Storage Provision, Environment Friendly Drying Techniques and Energy Consumption Characteristics of Mango Leather Production: A Review

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Abstract: Mango leather is a dehydrated, flexible product prepared from ripe mango pulp having a sheet like structure and consumed as dessert or snack. It is prepared with different formulations along with mango pulp, sucrose, skim milk powder, gellan gum, coconut powder etc. Different formulations and physicochemical tests have been done by researchers to ascertain desirable composition and nutrient characteristics of mango leather. Drying techniques such as Sun drying, hot air drying, vacuum drying, microwave oven drying and infra-red drying have been employed by researchers to dry the mango pulp and the dehydration behaviour in different dryers had been studied. Mathematical modelling of the drying operation have been considered also. The energy consumption during these drying processes is studied to suggest an eco-friendly dehydration option for mango leather processing industry. The aim of the paper is to review the published papers on mango leather and to give a collective view on methods of preparation, effects of drying condition, and effects of packaging and storage for a sustainable ecosphere.

Key words: Mango leather, formulation, eco-friendly drying, energy consumption, sustainable packaging.

Introduction

The mango (*Mangifera indica* Linn.) belongs to the Anacardiaceae family and due to its flavour, taste and fragrance it is called the "King of fruits" (Nunes et al., 2007). Apart from sensory superiorities, mango have significant amount of bioactive compounds with antioxidant activity. Ripe mango contains high gallic acid and total polyphenols (Danalache et al., 2014). The significant amount of vitamin C, β carotene and minerals in ripe mango are helpful in prevention of cardiovascular disease and cancer (Alothman et al., 2010; Liu, 2003; Sanchez-Robles et al., 2009).

More than 1000 varieties of mango are being cultivated over the world occupying the second position as a tropical crop in terms of production and coverage area of cultivation (Solís-Fuentes and Durán-de-Bazúa, 2011; Muchiri et al., 2012). India produces 66% of total world mango production (Shafique et al., 2006) and holds the first position (Jahurul et al., 2015). Improper post-harvest management and processing causes more than 30% wastage (Carrillo-lopez et al., 2000; Rathore et al., 2007). As mango is a climacteric fruit, improper harvesting time, condition of ripening, and absence of suitable storage facilities affect the price and availability of mango. For the same reasons large portion of the

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produce is wasted (Lalel et al., 2003). Only about 2% of total mango produced is processed whereas 20-30% of total production is spoiled which costs about 480 million dollar (FAO, 2004).

Mango contains 81.7% of moisture; due to this high moisture content it is perishable in nature and consumed mostly as fresh (Hashmi et al., 2007). To obtain the taste and benefits of mangoes at off season a variety of processed mango products are produced like juice, mango bar, jam, jelly, mango powder, canned mango slices, mango purees and mango leather (Djantou et al., 2011; Ledeker et al., 2014, Liu et al., 2014, Sogi et al., 2015; Sriwimon and Boonsupthip et al., 2011; Hussain et al., 2003). Among all these mango products mango leather is most popular in India (Danalache et al., 2014).

Mango leather or mango bar can be produced by dehydration of fresh mango pulp or pulp accompanied by other ingredients (Raab and Oehler, 1976; Huang and Hsieh, 2005; Maskan et al., 2002; Diamante et al., 2014). Simultaneous moisture and heat transfer are the main characteristics of drying through which perishable ripe mango pulp can be transformed to mango leather and can be suitable for long term storage (FAO, 2004). Researchers formulate it with different components like sugar, soy flour, skim milk powder, coconut powder, pectin, acid, gum, preservatives etc. along with mango pulp to meet desired sensory and textural property. The evaporation of moisture from pulp along with other ingredients gives the cohesive leathery texture of mango leather (Vatthanakul et al., 2010).

To ascertain the desired quality of the processed mango leather, researchers have done various physicochemical analysis on it like proximate analysis, total ascorbic acid content, determination of colour, textural analysis, sensory analysis etc. Subject to the aim of research the researchers optimise their formulation based on the test results found.

Sun drying, being the most simplest and traditional drying method, is used from the ancient period of mankind. Though it gives natural colour and good texture of final product, the exposure to ambient environment and high time consumption are the problems associated with this kind of drying technique (Maskan et al., 2002). With progress in technology, more effective drying techniques are employed to produce mango leathers. The alternative drying methods are like hot air drying, microwave drying, vacuum drying, infra-red drying etc.

Most of the industries use convective type hot air oven for drying. Direct and indirect drying processes may cause crystallisation, shrinkage, puffing and desired or undesired biochemical reaction which ultimately affects the sensory, textural and nutritional qualities of mango leather (Diamante et al., 2014). Researchers have proposed different mathematical models for different kind of drying operations to predict the dehydration behaviour of the mango pulp.

Sun drying is free and renewable source of energy suitable for small scale industry but not for medium and large scale industry (Tiwari, 2016). Convection dryers are not economically viable for medium and small scale industries in developing countries like India (Ibrahim et al., 2009; Jayaraman and Gupta, 1995; Banout et al., 2010; Boughali et al., 2009). A substantial amount of thermal energy is lost in convective drying as well as inferior heat transfer quality is another disadvantage of hot air drying. Infra-red dryers provide rapid drying and low operational cost (Brooker et al., 1992; Strumillo, 1987; Nonhebel, 1973). Microwave drying is fastest mode of drying as electromagnetic energy converted directly to the kinetic energy during this process but cell damage is the constrain associated with whereas vacuum drying approach facilitates better quality of product (Krulis et al., 2005; Kompany, 1993; Jaya and Das, 2003; Zhang et al., 2006).

In this era of globalisation and competitive market packaging and storage of mango leather to expand its shelf life with respect to moisture content, water activity, microbial stability, texture and acceptability are the prime concern for industries (Irwandi et al., 1998).

The aim of this study is to consider the preparation method for mango leather, the effect of formulation on texture, sensory qualities, and the physicochemical tests to obtain the quality parameters. In this study the method of dehydration of mango pulp, the energy consumption behaviour of these dehydration techniques and packaging-storage conditions of mango leather are also reviewed.

Method of Preparation

In general after receiving of fresh ripe mango it is washed with potable water and then sorting is done. Thereafter peeling and cutting operations are involved. After extraction of pulp from ripe mangoes it may or may not be blanched, then mixed with other ingredients followed by heating which is an optional operation depending on the method used. Then drying of pulp is done followed by cutting, packing and labelling. The schematic flow chart of general mango leather production is shown in Figure 1.

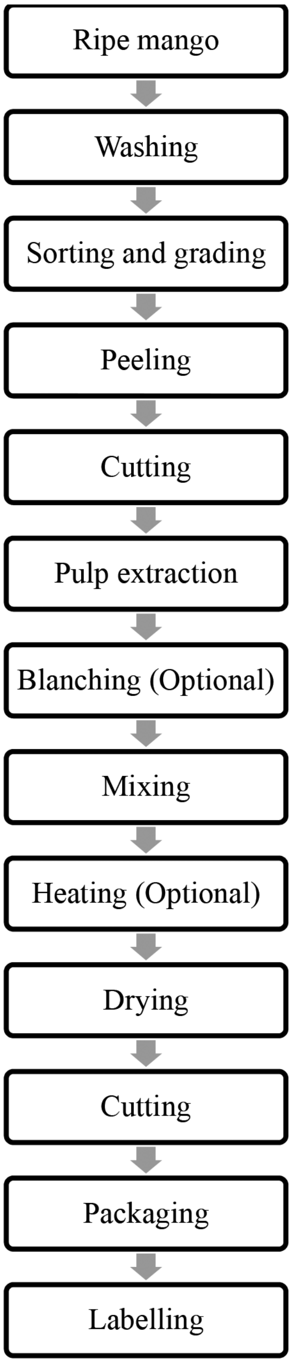

Figure 1: Flow chart of mango leather preparation.

Formulation of Mango Leather

Researchers have found different design to formulate mango leather in order to meet shortcomings from their point of view. Mir and Nath (1995) have prepared mango bar from mangoes of Langra cultivar. After washing, peeling and pulping it has been heated for 2 min at 91-93°C. They have increased the TSS to 30% by addition of powdered cane sugar, 0.6% of CA and 1734 ppm potassium metabisulphite (KMS) as preservative.

Gowda et al. (1995) have prepared mango fruit bar from Alphanso cultivar. 20% sugar, 0.2% CA and 700 ppm KMS are added to the pulp and dried to get good quality of mango bar. Similar kind of formulation is deliberated by Prasad and Nath (2002) where they use mangoes of Totapuri cultivar; after washing, peeling, pulping and it was heated for 2 min at 85°C. Total soluble solids of pulp was raised to 30% using powdered cane sugar, and 0.6% citric acid; whereas the preservative KMS is replaced by 1000 ppm SO_2 (Prasad and Nath, 2002).

In a recent study Effah-Manu et al. (2013) have prepared mango-sweet potato leather. They have used mango of Keitt variety. The sweet potatoes have been baked in an oven at 150-220°C for 2 h, 2.5 h and 3 h to convert the starch to dextrin. Then it is cooled at 30°C and the edible portion of sweet potatoes is homogenized in a blender; thereafter it is mixed with mango pulp in 30:70, 20:80 and 10:90 ratios respectively. 0.1% sodium benzoate and 0.2% citric acid are added to it. The final mixture is smeared on 7 mm × 7 mm aluminium trays coated with glycerol and dried. Though the overall acceptability of this leather is good but the amount of sweet potatoes incorporated is found insignificant by researchers (Effah-Manu et al., 2013).

The plain mango leather from mango pulp of cultivar Tommy Atkins is prepared by Azeredo et al. (2006) without addition of any preservative. The mango puree is passed through 1-mm sieve and the pulp is dried to obtain leather with moisture content 15-18% and optimise the time and temperature for production of the mango leather. The synergistic effect of pH and water activity inhibit microbial growth; thus, mango leathers with shelf-life for several months has been produced without the need of chemical preservatives.

A different kind of mango bar is formulated by Florina Danalache et al. (2014) where they have used mangoes of cultivar Palmer; after washing and cutting it is pureed at room temperature by blender. The pulp is heated at 88 ± 2°C in a water bath with addition of 1 gm of gellan powder per 100 gm of mango puree with continuous stirring at a rotation speed of 1640 G using a four-blade impeller. The mixture is poured in a rectangular silicone mould and kept at 22 ± 2°C temperature to set.

Gujral and Khanna (2002) prepared mango leather from Safaida variety, which is washed, peeled and pulped. The pulp with TSS 10.6% has been blanched at 80°C for 5 min, then cooled and 0.2% w/w of KMS has been added to it. The mango pulp has been mixed with soy protein concentrate (0%; 4.5%; 9%), skim milk powder (0%; 4.5%; 9%) and sucrose (0%; 4.5%; 9%). 250 g of this mixed pulp was poured on aluminium trays of dimension 25.5 cm × 13 cm × 2 cm. After drying it has been found that mango leather containing 4.5% skim milk powder and 4.5% sucrose is the most acceptable (Gujral and Khanna, 2002).

Mangoes of Langra cultivar have been washed, peeled and pulped by Gujral and Brar (2003). The pulp was blanched at 80°C temperature for 5 min, after cooling 0.2% of KMS has been added. 20% of sugar has been added to the pulp of total solid 14.3% to increase its sweetness and total solids. Then hydrocolloid has been incorporated to the mango pulp at concentrations of 1, 2, and 3% w/w respectively. 250 g of this mixture has been spread over 25.5 cm × 13 cm × 2 cm aluminum trays. After drying it is found that incorporation of hydrocolloid significantly modified the texture of mango leather. They also found that with redness (a) and yellowness (b) values of mango leather drop with increasing concentration of hydrocolloid whereas the concentration of hydrocolloid has been found insignificant in case of lightness value (L).

Gujral et al. (2013) produced mango leather by blanching of pulp at 80°C for 5 min to inactivate enzymes followed by addition of 1000 ppm of KMS as preservative, sucrose at concentration of 0, 5, and 10%, pectin at concentration of 0, 1, and 2%, maltodextrin in concentration of 0, 2.5 and 5% and has been kept overnight for hydration. Finally 300 g of this mixed pulp has been poured in aluminum trays measuring 0.3 m × 0.1 m × 0.03 m. They found that drying rate, drying rate constant and effective moisture diffusivity have been significantly affected by the additives like sucrose, pectin and maltodextrin.

G. Puspa et al. (2006) used Alphonso mango pulp with 16% TSS along with sugar (50 g), corn flour (5 g), and lime juice (2 g) at different specified level in mango leather preparation. Skim milk powder and roasted defatted soy flour with 51.8% of protein content is mixed together in the ratio of 1:1; this mixture has been finally mixed with mango pulp at concentration of 10, 15, 20 and 25%. After drying it has been found by the researchers that colour retention is higher for mango leather enriched with 20 and 25% soy flour. Whereas the mango leather enriched with 10 and 15% soy flour have significantly higher values of sensory attributes.

Mango bar has been prepared by Prasad (2009) from pulp of Totapuri cultivar. After washing, peeling and pulping it has been acidified to 0.3% CA and blanched at 85°C temperature for 5 min to inactivate enzymes. Powdered cane sugar has been added in different extent to this pulp to increase the TSS to 20, 25 and 30%. To this mixture, roasted Bengal Gram flour and skim milk powder has been added in concentration of 0, 5 and 10%. Citric acid has been added in order to maintain acidity at 0.3, 0.45 and 0.6%. The final mixture has been spread over stainless steel trays and dried. It has been found that 5% (w/w) roasted Bengal gram and 5% (w/w) skim milk powder at concentration gave superior sensory qualities.

Parekh et al. (2014) prepared mango bar from Kesar cultivar fortified with DCP (Desiccated coconut powder). After washing and pulping of mango the pulp has been passed through stainless steel sieve of 1 mm mesh. The pulp has been blanched to destroy enzyme at 91-93 °C for 2 min and cane sugar has been incorporated to increase the TSS at 30° Brix. KMS has been added to the pulp at level of 0 and 1734 ppm, DCP has been added to pulp at concentration of 0, 1, 2 and 3%. The final mixture has been spread over trays smeared with glycerine followed by drying. Investigators have found that the mango bar with 2% DCP and 1734 ppm of KMS has best sensory attributes, whereas interaction effect of the treatment recipes has been found insignificant.

Methods of Drying

Sun Drying

When mango pulp is spread over metal tray for drying an uneven surface is created. When Sun rays of shorter wavelength fall on this rough surface, a part of it is reflected back and the rest get absorbed by pulp. The Sun rays of long wavelength cannot be absorbed by pulp. The colour of mango pulp is the prime factor for absorption of radiation wavelength from sun rays (Nowak and Lewicki, 2004). Temperature can be expressed as the average energy of molecular motion according to the kinetic theory. Water molecules having kinetic energy more than the escape energy and by overcoming the cohesive force that binds the water molecules in mango pulp will escape from the surface of the pulp. The rate of evaporation is much lower as it takes time for heat to migrate into the pulp from the surrounding air.

The mango pulp mixture has been poured on aluminium tray smeared with oil and exposed to open air. Sun rays are directly incident on the pulp and evaporate the moisture present within it. Due to the reflection of the Sun rays on the shiny metal surface the drying temperature rise up and ultimately a leathery product can be obtained (Rameshwar, 1979).

Hot-air Drying

It is the conventional drying method where heat is transferred from the heated air to the pulp through the mechanism of conduction of heat. After the absorption of heat by the pulp the moisture diffuses from the pulp surface to the hot air as well as the moisture diffuses from the interior of pulp to the surface of the pulp. Both the diffusion processes continue simultaneously until the moisture content of pulp drops to a degree to achieve the drying purpose. The temperature difference is the driving force for the heat transfer while the driving force of mass transfer is the concentration difference of partial vapour pressure.

Mir and Nath (1995) produced mango leather in a cross-flow cabinet dryer at 63 ± 2°C for time 14-16 hours, where the tray load was 9.8 kg/m^2 to get final moisture content of 22.9, 20.5 and 19.5% for plain mango bar, mango-desiccated coconut powder (DCP) bar and mango-soy protein concentrate (SPC) bar respectively. The values of R^2 for the BET model are 0.9067 and 0.4898 for plain mango bar and mango-DCP respectively. In comparison to the Henderson model (R^2 values 0.8370-0.9800) and GAB model (R^2 values 0.8005-0.9325) for all the three types of mango bars it has been found that the Oswin model (R^2 values 0.9201-0.9731) and Smith model (R^2 values 0.9378-0.9493) were better. Therefore Oswin model is pertinent to drying all of the three types of mango bar whereas the GAB model fits to predict the sorption behaviour of plain mango bar only (Mohamad and Nath, 1995).

Hot air oven has been used by Gujral et al. (2013) at 103±2°C for 24 h to dry the mango pulp. The incorporation of sucrose and maltodextrin increases the drying as more water is bounded with increase of total soluble solid, whereas due to high water binding property drying time increases in case of pectin addition. Page's model describes the drying characteristics as well as the rate constant effectively with shape factor within the range of 0.799–0.996. The R^2 value has been found 0.86. The effective moisture diffusivity calculated by Fick's second law of diffusion has been found in the range of 1.65 to 4.03 × 10^{-7} m^2/sec. In regression analysis from the *p*-values it has been revealed that sucrose followed by pectin and maltodextrin affect the effective moisture diffusivity significantly (Gujral, 2013).

Cabinet dryer at temperature 60 ± 1°C and relative humidity of 15% has been used by Gujral and Brar (2003) to produce mango leather. The drying rate constant and shape factor have been investigated by them by using diffusion mechanism. The R^2 values lies in the range of 0.90-0.99. From the investigation it has been established that during early two hours of drying the rate of dehydration of mango leather is rapid; thereafter a significant drop in drying rate is observed. The incorporation of hydrocolloid significantly decreases the rate of drying for initial two hours whereas it has been found to have an insignificant effect on rate of dehydration for later period of drying.

Gujral and Khanna (2002) produced mango leather using hot air at a temperature of 60 ± 1°C and air velocity of 3.5 m/s in a cabinet dryer. From regression analysis, it has been found that increasing levels of sucrose lowered the drying time whereas drying time increases with increasing levels of skim milk powder and soy protein concentrate in mango pulp, because of water binding capacity of the protein molecules present in the skim milk powder and soy protein concentrate.

Azeredo et al. (2006) prepared mango leather using hot air oven to derive minimum drying time required to attain leather with moisture content of 15-18%. Drying temperature (60–80°C) and puree load (0.4–0.6 g/cm^2) have been selected as two independent variables to conduct drying in accordance with central composite design. Both the factors significantly affect the drying time. The minimum drying time to produce mango leather has been found 120 min at 80°C and with a puree load of 0.5 g/cm^2.

Prasad et al. (2002) studied the dehydration kinetics of mango leather which is dried at 70 ± 1°C for 26 hours with tray load 12.5 kg/m^2 in cross flow cabinet dryer. During the first eight hours of drying rate of dehydration was higher. The incorporation of roasted Bengal gram (RBF) in mango pulp slowed down the dehydration rate. Thereafter, less moisture loss was observed till 20 hours of drying time for both plain mango pulp and fortified mango pulp. Though after 14 hours and 16 hours of drying, the change in moisture content has been found insignificant for plain and fortified mango pulp respectively. Researchers found shape factors are 1.017 and 0.997 whereas drying constant (k) 0.318 and 0.255 for plain mango and mango-RBF leather respectively.

Parekha et al. (2014) conducted the quality evaluation of mango bar fortified with desiccated coconut powder using tray drier at 63 ± 2°C for 8-10 hours.

Microwave Drying

Microwave heating is one of the direct heating methods. Microwaves are basically a form of electromagnetic energy (300 MHz–300 GHz) which is generated by magnetrons due to the mutual force of electric and magnetic fields at right angle. The most common frequency used for drying of food material is 2450 MHz. When an oscillating electric field is incident on the polar molecules present in mango pulp (water), the permanently polarized dipolar molecules orient and reorient themselves according to the direction of the field at 2450 MHz, the orientation of the field changes 2450 million times per second. This consequences oscillatory migration of ions in the food and generates heat.

Pushpa et al. (2006) has produced mango leather through microwave drier of 750 W and 2450 MHz at power levels of 4, 8, 12, 16 and 20 W/g using 50 g of pulp with a power cycle of 30 s on and 30 s off respectively to achieve moisture content of 12-15%. Due to lower heat generation at lower power levels of microwave oven, the rate of drying is slow so the time required to dry the mango pulp is longer. They have found that increasing soy flour level from 15 to 25% is insignificant in variation of drying rates.

Infra-red Drying (IR Drying)

In IR drying without heating, radiation energy of the adjacent air is transferred from the heating element to the pulp surface. The radiation energy first impinges on the top-most surface of pulp, penetrates it and finally increases the sensible heat (Ginzburg, 1969). As thermal degradation of heat-labile phytochemical occurs at high temperature, the drying temperature should not be too high (Rieger and Šesták, 1993). During drying, as the moisture content decreases the transitivity and reflectivity increases while the absorptivity of the dried material decreases. The absorptivity, the skin depth and the transitivity are the functions of the density, wavelength of IR heating and properties of mango pulp. IR drying is preferred over hot air drying due to short drying time, high heat transfer coefficients and simple material temperature control system (Nowak and Lewicki, 2004). Because of these advantages IR drying in combination with convection or vacuum is more in practice in recent era (Mujumdar, 1995).

Effah-Manu et al. (2013) produced mango-sweet potato leather with 15.4% moisture content, through drying using flameless gas infrared catalytic heater at 45°C, 50°C and 55°C temperature. It has been found that the cabinet, oven and solar dried jackfruit leather had moisture contents of 18.85%, 14.79% and 18.5% respectively (Okilya et al., 2010). From these results of moisture content they concluded that in comparison with cabinet, oven and solar dryer infra-red dryer is more effective in producing mango leather.

Vacuum Drying

A vacuum dryer is an indirect type of heat dryer, that is, pulp is in contact with heated surface of dryer. Therefore drying is carried out by conduction mode. In this process materials are dried in a low pressure environment than normal atmospheric pressure and this results in a reduced temperature heating. Heated steam or hot water through hollow shelves is used as the heating medium. For the major part of the drying cycle, temperatures can be controlled with complete command and the mango pulp remains at the boiling point of water.

Jaya and Das (2003) have considered vacuum drying model for mango pulp. The ingredients (maltodextrin, glycerol monostearate, and tri calcium phosphate at an amount of 0.62, 0.015 and 0.015 kg/kg dry mango solid respectively) have been mixed with mango pulp. In the process of mixing a planetary mixer having its mixing arm operated at 75 m/min peripheral speed for 15 to 20 min has been used; thereafter the pulp has been spread on aluminum trays coated with teflon. This mixture has been spread to 2, 3 and 4 mm thickness and dried at temperatures 65, 70 and 75°C in a vacuum drier. The absolute pressure has been maintained in the vacuum dryer at 30–50 mmHg. They have found that the product was leathery but non-sticky. They have also found that during first 900 and 1000 s of drying, the reduction in moisture content is high. Mango pulp with thickness 0.004 m dried at 65°C shows maximum drying time of 10800 seconds and the pulp with thickness 0.002 m dried at 75°C shows minimum drying time of 3500 seconds. The value of R^2 for actual and predicted moisture content using predicted effective diffusivity lies in the range of 0.991 to 0.997.

Researchers consider different models to predict the product aspects which are listed in Table 1.

Energy Consumption Performance in Different Drying Techniques

Drying is the process for producing mango leather which is also the most energy intensive process in food preservation (Brooker et al., 1992). Comparative view of different drying methods employed during mango leather processing by researchers is shown in Table 2. The model for determining energy requirement during different drying techniques involved in mango leather production is as follows.

Energy Consumption of Hot Air Dryer

At different temperatures and air flow rates within the hot air oven the energy consumption is calculated by

Table 1: Mathematical models used by researchers

Method	*Model*	*Equation*
Florina Danalache (2015)	Generalised Maxwell model	$\sigma(t) = \varepsilon_0\left[E_1 \exp\left(-\frac{t}{\lambda_1}\right) + E_2 \exp\left(-\frac{t}{\lambda_2}\right) + \ldots\ldots + E_e\right]$
	Peleg model	$\sigma(t) = \sigma_e + \sigma_0\left(\frac{k_1/k_2}{k_1 + k_2.t}\right)$
Mir and Nath (1995)	BET	$m = \frac{m_{0,B} C_B a_w}{(1-a_w)(1-a_w + a_w C_B)}$
	GAB	$m = \frac{C_G K_G m_{0,G} a_w}{(1-K_G a_w)(1-K_G \mathrm{a_w} + C_G K_G a_w)}$
	Handerson	$(1-a_w) = e^{-K_H m^{n_H}}$
	Oswin	$m = C_0\left(\frac{a_w}{1-a_w}\right)^{n_0}$
	Smith	$m = \mathrm{A} - \mathrm{B} \ln(1 - a_\mathrm{w})$
K. Prasad (2002)	Diffusion mechanism	$\mathrm{MR} = \frac{M - M_e}{M_0 - M_e} = A \exp(-kt)$
Azeredo et al. (2006)	Central composite design	$Y = b_0 + \sum_{n=1}^{3} b_n X_n + \sum_{n=1}^{3} b_{nm} X_n^2 + \sum_{n<m}^{3} b_{nm} X_n X_m$
Gujral and Khanna (2002)	Central composite design	$Y = b_0 + \sum_{n=1}^{3} b_n X_n + \sum_{n=1}^{3} b_{nm} X_n^2 + \sum_{n<m}^{3} b_{nm} X_n X_m$
Gujral and Brar (2003)	Diffusion mechanism	$\mathrm{MR} = \frac{M - M_e}{M_0 - M_e} = A \exp(-kt)$
Gujral et al. (2013)	Central composite design	$Y = b_0 + \sum_{n=1}^{3} b_n X_n + \sum_{n=1}^{3} b_{nm} X_n^2 + \sum_{n<m}^{3} b_{nm} X_n X_m$
G. Pushpa et al. (2006)	Factorial randomized block design	$Y_{\mathrm{i,j}} = \mu + T_\mathrm{i} + B_\mathrm{j}$ + random error
Parekh et al. (2014)	Completely randomized design with factorial concept	$Y_{\mathrm{i,j}} = \mu + T_\mathrm{i}$ + random error

BET = Brunauer-Emmett-Teller; GAB = Guggenheim-Anderson-deBoer; C_B, C_G, C_O = Constants of BET, GAB and Oswin model respectively; K_G, K_H, K_O = Constants in GAB, Henderson and Oswin models, respectively; m = Moisture content; $m_{\mathrm{O,B}}$, $m_{\mathrm{O,G}}$ = Monolayer water content calculated by BET and GAB models respectively; n_H, n_O = Constants in Henderson and Oswin models, respectively; a_w = Water activity; Y = Dependent variable; b_0= Fixed response at the central point of the experiment; b_n, b_m, and b_nm= Linear, quadratic, and cross product coefficients respectively; $Y_{\mathrm{i,j}}$ = Dependent variable for which $X_1 = i$ and $X_2 = j$; X_1 = Primary factor; X_2 = Blocking factor; M = General location parameter; T_i = Effect for being in treatment i; B_j = Effect for being in block j; MR = Moisture ratio; M_O = Initial moisture content; M_e = Final moisture content; k = Drying constant; A = Shape factor; $\sigma(t)$ = Stress over time t; ε_0 = Initial strain; E_1, E_2 … = Elastic moduli; E_e = Equilibrium elastic moduli; λ_1, λ_2 = Relaxation time; t = compression holding time; σ_e= Residual stress; σ_0 = Initial relaxation stress; and k_1, k_2 = Constant.

Table 2: Comparison of different drying methods used in mango leather processing

Methods of drying	*Key features*	*Reference*
Sun drying	Energy extensive and most economical. Climate dependent and time consuming.	Rameshwar (1979)
Hot-air drying	Process parameter like drying temperature and air flow rate can be controlled. Very low residual moisture level cannot be achieved. A possibility of thermal damage is there for material with high initial moisture content.	Mir and Nath (1995) Gujral et al (2013) Gujral and khanna (2002) Azeredo et al (2006) Prasad et al (2002) Parekha et al (2014)
Microwave drying	Fastest drying process and high energy density. Rapid heat transfer along with inadequate homogeneity. A possibility of dark spot generation and plasma expulsion.	Puspa et al (2006)
Infra-red drying (IR drying)	Process parameters can easily be controlled. Uniform temperature distribution can be achieved. Depending on food commodity the wavelength of radiation is selected. In case of thin layer drying Far Infra-red radiation (3-1000 µm) is better whereas Near Infra-red radiation (0.78-1.4 µm) is efficient in drying of thick layers.	Effah-Manu L (2013)
Vacuum drying	Comparatively less energy consuming process and environment friendly process. Ideal for hygroscopic and heat sensitive material	Jaya and Das (2003)

using Eq. (1) (Motevali et al., 2011; Aghbashlo et al., 2008; Koyuncu et al., 2007):

$$E_{tH} = A \times v \times \rho_a \times \Delta T \times t \quad (1)$$

where E_{tH} is total energy consumed in each cycle of drying (kWh), A = container area (m^2), v = air flow rate (m/s), ρ_a = density of air (kg/m^3), t = time required for drying, ΔT = temperature difference (°C) and C_a = specific heat of air (kJ/kg °C).

As the specific heat of dry air is constant and it is 1.004 so C_a can be calculated from the Eq. (2) [63]

$$C_a = 1.004 + 1.88\, w \quad (2)$$

where w is relative humidity and can be determined from Eq. (3) (Aghabashlo et al., 2009)

$$w = 0.622 \times \frac{P_{vs}}{P - P_{vs}} \quad (3)$$

where P = air pressure (k Pa), P_{vs} = saturated vapour pressure (k Pa) and can be calculated from psychrometric chart.

Energy Consumption by Infra-red Dryer

The total energy consumption of infrared dryer (E_{tI}) is the sum of cumulative energy intake by the infra-red lamp (E_1) and the centrifugal blower (E_2) (Motevali et al., 2011; Sirvastava et al., 1993).

$$E_1 = K \times t \quad (4)$$

where K = power of IR lamp and t = time required for drying.

$$E_2 = \frac{V^3}{16600} \quad (5)$$

where V = velocity of air (m/s).

Therefore,

$$E_{tI} = E_1 + E_2 \quad (6)$$

Energy Consumption in Microwave Dryer

The energy consumption in microwave dryer (E_{tM}) can be determined by using Eq. (7) (Ozkan et al., 2007)

$$E_{tM} = G \times t \quad (7)$$

in which, G = output power of microwave (kW) and t = time required in drying.

Energy Consumption in Vacuum Dryer

The energy consumption of vacuum pump (E_1) is determined by using Eq. (8) (Ali et al., 2011).

$$E_1 = L \times t \quad (8)$$

where L = power of pump (kW) and t = drying time.

Energy consumption of heaters (E_2) can be calculated by using Eq. (9).

$$E_2 = Q \times I \cos \theta \times t \quad (9)$$

where Q = voltage (V), I = electrical current (amp), t = time required to drying, θ = phase angle between current and voltage sine wave. Therefore, the total energy consumption in vacuum drying (E_{tV}) is derived from Eq. (10):

$$E_{tV} = E_1 + E_2 \quad (10)$$

Physicochemical Analysis

A series of physicochemical analysis has been done by researchers to determine the effect of formulation and processing technology on quality of mango leather. The compositional view of mango leather found by researchers is listed in Table 3.

Equilibrium Relative Humidity (ERH) and Water Activity (a_w)

Five grams of accurately weighed mango bars are taken in pre-weighed, dried petri dishes and placed at desiccators, maintained at room temperature (25 ± 2 °C) (Prasad et al., 2002). The samples have been allowed to equilibrate to constant weights; thereafter the moisture content of samples at different relative humidity has been measured by vacuum oven method (Ranganna, 1986). a_w has been determined by using following equation:

$$a_w = \frac{ERH}{100}$$

Proximate Analysis

Researchers have analysed the moisture content, crude protein, fat, crude fibre, carbohydrate and ash content of mango leather according to AOAC methods (Effah-Manu, 2013; AOAC, 1990). The acidity, reducing and total sugars of samples have been analysed by Lane and Eynon method (Effah-Manu, 2013; Ranganna, 1986).

Determination of Total Soluble Solids (°Brix)

Effah-Manu et al. (2013) have determined the total soluble solids using the analogue hand-held refractometer. To calibrate the instrument distilled water and test solution of known sucrose concentration have been used. All the readings have been taken in duplicates and averaged before analysis of results.

Determination of Vitamin C (Total Ascorbic Acid) Content

Effah-Manu et al. (2013) have used the following procedure to determine the vitamin C in mango leather. 10 ml of sample extract was poured in a 100 ml volumetric flask and the volume made up by 0.4% oxalic acid solution. After filtration of this solution through Whatman No. 4 filter paper, 10 ml of the filtrate has been pipetted into a conical flask and 15 ml of 0.4% oxalic acid solution added to it. The solution has been titrated against 0.04% aqueous sodium dichlorophenolindophenol solution; end point has been detected on appearance of first pink shade. 0.01 N sodium thiosulfate along with potassium iodide (50%) and 1 N HCl has been used to standardize sodium dichlorophenolindophenol solution using starch as indicator. The amount of total ascorbic acid has been determined through the following equation (Sharma et al., 2016):

$$\text{Ascorbic Acid}\left(\frac{\text{mg}}{100\text{ g sample}}\right) = \frac{0.5\text{ mg}}{V_1} \times \frac{V_2}{15\text{ ml}} \times \frac{100\text{ ml}}{\text{weight of sample}} \times 100$$

Total Carotenes

Prasad (2009) underwent through the following method to estimate total carotenes in mango leather. 100 mg of leather has been added with 10 ml of 80% acetone and grinded well in mortar-pestle. After centrifugation of the mixture at 3000 rpm for 10 min the supernatant has been taken and the volume is made up to 10 ml. The optical density values have been studied at 480 nm in ultra violet spectra. The following equation has been used to calculate the amount of carotenoids in mango leather (Harbone, 1973).

Amount of carotenoids in 100 mg leather

$$= \frac{4 \times \text{optical density} \times \text{total volume of sample (10 ml)}}{\text{wright of leather (100 mg)}}$$

Texture Analysis

Florina Danalache et al. (2014) have carried out texture analysis of mango bar in order to mimic the human biting action. They employ method used by texture analyser equipped with 50N load cess (Mandala et al., 2007). By using an aluminium plunger with 60 mm diameter a double compression cycle test has been performed, with a time gap of 5 s between the two compression cycles. To avoid friction a thin layer of paraffin oil has been applied between plates and the testing sample in order to avoid friction. Hardness has

Table 3: Mango leather composition

TSS (°B)	*Moisture (%)*	*ERH (%)*	*Crude protein (%)*	*Crude fat (%)*	*Crude fibre (%)*	*Ash (%)*	*Carbohydrate (%)*	*Water activity*	*Vitamin C (mg/100 g)*	*Carotene (mg/100 g)*	*Reference*
	15.0 ± 1.60		2.25 ± 0.92	0.55 ± 0.03	2.82 ± 0.04	2.06 ± 0.25	77.32 ± 0.62	0.61 ± 3.8a	17.49 ± 2.11		Effah-Manu et al. (2013)
81.24							65.57		25.93		Parekha et al. (2014)
	15.21		2.0			2.0	65.94				Prasad et al. (2002)
	17.2							0.621			Azeredo et al. (2006)
	10.0										Gujral et al. (2002)
	10.0	45.16									Gujral and Brar (2003)
75-80	10.0-15.0							0.667-0.529			Pushpa et al. (2006)
	13.2		2.0	0.3		2.0	82.5			12.2	Prasad (2009)
	22.9	69					61.40-7150				Mir and Nath (1995)
	11.17 – 17.94							0.46 – 0.72			Dina et al. (2015)

been measured as the maximum force during the first compression cycle. Springiness is the ratio of the second and first compression distances. Cohesiveness has been defined as the ratio of the positive force area during the second and first cycle of compression.

Colour Measurement

The mango leather has been positioned underneath the optical sensor of Hunter Lab Calorimeter; the readings for mean value of *L*, *a* and *b* were considered from three measurements performed on each sample in terms of defining the colour of samples. Before initialization of experiment the colorimeter has been standardized by using standard white and black tiles (Effah-Manu et al., 2013; Pushpa et al., 2006). Table 4 represents the *L*, *a* and *b* values studied by researchers.

Sensory Analysis

Most of the researchers employ nine-point Hedonic scale to evaluate mango leather samples for flavour, colour and texture where the sensory panel consisted of 20 trained members. (Prasad et al., 2002; Effah-Manu et al., 2013; Azeredo et al., 2006; Gujral et al., 2013; Pushpa et al., 2006; Prasad, 2009; Dina et al., 2015).

A preference–ranking test (ISO 8587:2006) has been performed by Florina Danalache et al. (2014). As texture is the determining factor in developing food products like bars, they have been considered only one sensory parameter that is the overall texture and each panellist had been requested to assess that particular attribute of samples by preference. According to ISO 8587:2006 the sensory evaluation of mango bars has been carried out in a sensory room with six analysis boxes. The 63 panellists aged between 20-65 years old and regular consumers of mango fruit have been chosen. The five different mango bars have been presented to the panellists in random order and labelled with randomly generated code of three digits at room temperature (20-22°C). The panellists rank the five samples in order of their preference: (1) the least, (2) slightly, (3) moderately, (4) neither like nor dislike and (5) the most preferred texture (Meilgaard et al., 1999). The panellists have been asked to validate their choices and the justifications have been used to determine whether each sample was significantly preferred over the others.

Packaging and Storage

As mango leather is a ready to eat food so food containment can be achieved best by food packaging. This is the best way to control and protect the food against physical, chemical, biological and environmental deterioration. Therefore packaging and storage of mango leather is one of the prime factors with respect to food safety as well as for marketing.

Rectangular pieces of mango bars have been packed in polyethylene bags and stored at room temperature for six months. The chemical and organoleptic assessment of mango bars during the storage period of 0, 1, 2, 3, 4, 5 and 6 months show progressively decline of taste score with storage period (Parekha et al., 2014). Up to six months of time mango leathers are consumable. The similar kind of result is also found by other researchers (Narayana et al., 2003).

In some case Al foil rolled mango leather is packed in cellophane film (Effah-Manu et al., 2013). In some other cases polyethylene pouch as packaging material and at room temperature storage is used (Gujral and Khanna, 2002; Gujral et al., 2013; Gujral and Brar, 2003). The use of poly propylene (PP) pouches as packaging material and refrigerated storage at 11±1°C temperature is also found in some studies (Prasad, 2009).

The microbiological safety of mango leather on storage at 25°C for six months packaged in polypropylene buckets with lids has been studied by Azeredo et al. (2006). It has been found that mesophyllic aerobes remained less than 10 colony forming unit (CFU)/g, yeasts and mould count is less than 100 CFU/g throughout the storage period of six months. It has been concluded that the product is microbiologically safe for the storage period considered as there is no proof of presence of Salmonella and most probable numbers

Table 4: Colour values for mango leather

Cultivar	*L*	*a*	*b*	*Reference*
Keitt	59.01 ± 0.56	14.08 ± 0.10	47.77 ± 0.35	Effah-Manu et al. (2013)
Tommy Atkins	52.97	8.12	42.18	Azeredo et al. (2006)
Safaida	44.499	10.104	29.493	Gujral and Khanna (2002)
Langra	35.08	12.33	22.74	Gujral and Brar (2003)
Alphanso	52.487	9.849	20.947	Pushpa et al. (2006)

(MPN) of all coliforms (including *E. coli*) have been found to be lower than three organisms/gram.

Polyethylene pouch, wax paper and aluminium foil have also been used for packaging of mango bar purchased from market for two months of storage. During storage heavy load of Enterobacters and some other bacteria indicating spoilage have been found (Singh et al., 2003).

Conclusion

The "King of fruit" mango is not only superior with respect to sensory attributes but also has medicinal activity. But as it has high moisture content it is perishable in nature. Thus processing and preservation is required. Among the processed mango products mango leather is relished most. Texture and other sensory qualities of mango leather can vary with different formulations used and different drying techniques employed. These changes of qualities can be determined by a series of physicochemical analysis. The drying techniques used for mango leather preparation include sun drying, hot air drying, microwave drying, IR drying and vacuum drying. The total energy consumption of these dryers is investigated by researchers. There is lack of research in the field of process optimisation for mango leather production to get superior textural and nutritional quality. A vivid research is required in the area of packaging and storage of mango leather.

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