



## DRYING KINETICS, FOURIER-TRANSFORM INFRARED SPECTROSCOPY ANALYSIS AND SENSORY EVALUATION OF SUN, HOT-AIR, MICROWAVE AND FREEZE DRIED MANGO LEATHER

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### ABSTRACT

Mango leather produced from dried mango pulp is a traditional fruit product in India. Traditionally it is processed through natural convective drying or sun drying of ripe mango pulp. Mango leather was produced through sun, convective (hot air), freeze, and microwave drying. Drying kinetics was studied with the help of nine empirical models used extensively in food industries. Root mean square error (RMSE), correlation coefficient ( $R^2$ ), and the sum of square errors (SSE) these four statistical measures were examined for nine different models to learn the best-fitted model. The Fourier-transform infrared spectroscopy study was conducted for compositional analysis of differently dried samples in the wavelength range of 400-4000  $\text{cm}^{-1}$  at ambient temperature. For sensory analysis, the test panel was constructed as per ISO 8586-1, ISO 4120:2004, ISO 5496:2005, ISO 10399:2004 standards were maintained for selecting panel members. Quantitative descriptive analysis of different mango leather was estimated as per the protocols defined in ISO 11035:1994.

**Keywords:** Snack food, Model fitting, Food analysis, Quantitative descriptive analysis

### INTRODUCTION

Mango leather is cherished as a snack food in India, for its consummate organoleptic properties (Sarkar *et al.*, 2018). Being a tropical country, sun drying is a widely practiced method for mango leather preparation, though it is a climate-dependent process. Due to uniform drying characteristics, hot air oven drying is adopted by different food industries (Fernando *et al.*, 2016). Freeze drying is not generally employed to produce mango leather, however, it is assumed as a superior method to maintain the nutritional quality of the product (Acar *et al.*, 2014). Being a rapid and controllable process microwave drying is considered as an energy-saving method as well as cost-effective (Zarein *et al.*, 2013). To design mango leather processing for industrial applications, mathematical modeling is indispensable. Several studies have been available for drying kinetics of mango slices dried under tunnel dryer (Goyal *et al.*, 2006), convective dryer (Dissa *et al.*, 2014), Osmo-dehydrated mango (Kumar *et al.*, 2014), solar drying (Dissa *et al.*, 2009), though an inadequate number of studies have been found for drying kinetics of mango leather processing concluded by drying of mango pulp in different drying techniques. It is the first approach to study the sun drying (traditional approach) and freeze drying kinetics of mango leather processing.

Fourier-transform infrared spectroscopy (FTIR) progressively gains popularity in the field of food analysis due to its fast and non-destructive fingerprint modus operandi (Erwanto *et al.*, 2016, Ojha *et al.*, 2018). Few research works have been reported for FTIR analysis of mango. Duarte *et al.*, 2002 estimated sugar content of mango juice in different stages of ripening, Jha *et al.*, 2010 quantified the sugar content of commercially available mango juice on market, Olale *et al.*, 2017 also determined sugar content of two mango varieties of Kenya, Leizi *et al.*, 2017 predicted maturity stage of mango by FTIR analysis. Though as per our knowledge, it is the first approach to study the FTIR spectrum for differently dried mango.

Sensory perception of consumer and product characteristics like colour, texture, and flavour profile can be correlated with quantitative descriptive analysis (QDA) of concerned food material. Though various studies are available in the field of sensory science (Lestringant *et al.*, 2019), inadequate results are there in the zone of QDA study for ethnic food like mango leather, as per our literature survey this is the first QDA study for mango leather.

The aim of this study is to determine the drying kinetics for mango leather processing under sun, hot, microwave and freeze drying; FTIR spectroscopic characteristics of different mango leathers and QDA sensory estimation of the final product.

### MATERIALS AND METHODS

Sun drying (30±5 °C), hot air oven (70 °C) (Concepts International, Kolkata, India), microwave (200 W) (Samsung, Combi CE1031LAT, Mumbai, India) and freeze drying (-40 °C, 0.1 mBar pressure) (FDU 1200, EYELA, Japan) was adapted as described in Sarkar *et al.*, 2020. Puree load was 0.5  $\text{g}/\text{cm}^2$ . The total soluble solid of the pulp was maintained at 25 °B with addition of sugar.

In order to describe the most effective model for mango leather (Langra variety) processing thin layer drying models of various types were taken into consideration (Table 1). In calculating the Moisture Ratio (MR) during drying of mango pulp an equation stated below is used-

$$MR = \frac{M - M_{eq}}{M_{in} - M_{eq}} \quad (1)$$

Where, M = moisture content of mango leather at a different time interval (t) (kg moisture/kg dry leather),  $M_{in}$  = moisture present in mango pulp initially (kg moisture/kg dry leather),  $M_{eq}$  = moisture in mango leather at equilibrium (kg moisture/kg dry leather) (Arslan *et al.*, 2010). In determining the best fitting model parameters like Root Mean Square Error (RMSE), Correlation Coefficient ( $R^2$ ), and Sum of Square Errors (SSE) have been taken into account.

$$R^2 = 1 - \frac{\sum(MR_p - MR_e)^2}{\sum_{i=1}^N (MR_m - MR_e)^2} \tag{2}$$

$$RMSE = \sqrt{\left[ \frac{1}{N} \sum_{i=1}^N (MR_e - MR_p)^2 \right]} \tag{3}$$

$$SS_e = \sum (MR_t - MR_m)^2 \tag{4}$$

Where,  $MR_e$ - MR from experiments,  $MR_p$ - model predicted MR, N- observation number,  $MR_t$ - moisture ratio at time t,  $MR_m$ - mean moisture ratio (Acar et al., 2014). Fick’s law of diffusion defines the drying behaviour of food material during falling rate period. Throughout the process it was assumed that effective moisture diffusivity and temperature remained constant, hence shrinkage was negligible and change in moisture content was only due to diffusion, the equation for unsteady-state moisture diffusion of an infinite slab (Demiray et al., 2017) can be represented as follows-

$$MR = \frac{8}{\pi^2} \sum_{n=1}^{\infty} \frac{1}{(2Z-1)^2} e^{-\left(\frac{(2Z-1)^2 \pi^2 D_e t}{4L^2}\right)} \tag{5}$$

Where  $D_e$  - effective moisture diffusivity ( $m^2/s$ ) and L - (sample thickness)/2 (3mm).

The logarithmic form of the first portion of the equation (5) can be expressed as:

$$\ln(MR) = \ln \frac{8}{\pi^2} - \left(\frac{\pi^2 D_e t}{4L^2}\right) \tag{6}$$

$D_e$  was estimated from  $\ln(MR)$  versus t plot, considering the following equation:

$$D_e = - \frac{Slope \cdot 4L^2}{\pi^2} \tag{7}$$

Bruker Fourier-transform infrared spectroscopy (FTIR) spectrophotometer (Bruker Tensor 27, Bruker Corp, Massachusetts, USA) was used in recording the FTIR spectra in duplicate at a temperature of 25°C, the wavelength range was 400-4000  $cm^{-1}$  and sixteen scans were taken at 2  $cm^{-1}$  resolution. Analysis of spectral data was carried out with the help of BRUKER software version 7.5 (1991) (Origin Lab Corporation, Northampton, MA, USA).

Four male and same number of female participants in the age bracket of 25-40 years were considered to construct the panel, as per ISO 8586-1 (1993) for sensory analysis. ISO 4120:2004 was the standard considered for triangular discrimination; ISO 5496:2005 was the standard for odour and taste identification proficiencies. ISO 10399:2004 was the standard used for ability of discrimination between two food materials with respect to sensory qualities. The sensory attributes of mango leather prepared under traditional (SD) and contemporary (HAD, MWD, and FD) dehydration techniques was estimated according to ISO 11035:1994. The evaluations of panelists and panel have been carried out through Panel Check software (Norwegian Food Research Institute and the Technical University of Denmark) version V1.4.2.

**Table 1** The drying models considered for freeze dried, hot air dried, microwave dried and microwave convective dried mango leather processing.

Sl No.	Name of Model	Equation	Reference
1	Page	$MR=e^{-kt^n}$	(Page et al., 1949)
2	Modified Page	$MR=e^{(-kt)^n}$	(White et al., 1981)
3	Logarithmic	$MR=a e^{-kt^n}+c$	(Yaldiz et al., 2001)
4	Lewis	$MR=e^{-kt}$	(Lewis et al., 1921)
5	Henderson	$MR=a e^{-kt}$	(Henderson et al., 1961)
6	Two term exponential	$MR=a e^{-kt} + (1 - a) e^{-kbt}$	(Yaldiz et al., 2001)
7	Wang and Singh	$MR= 1 + at + bt^2$	(Wang et al., 1978)
8	Fernando and Amarasinghe	$MR= (1 + at + bt^2)/(1 + ct)$	(Fernando et al., 2016)
9	Midilli	$MR=a e^{-kt^n} + bt$	(Midilli et al., 2018)

**Table 2** The model parameters for freeze dried, hot air dried, microwave dried and microwave convective dried mango leather with statistical measures of each model

Process	Model	Model Coefficients	R <sup>2</sup>	RMSE	SS <sub>e</sub>
Sun drying	[1] $[MR=e^{-kt^n}]$	k = 0.000309 n = 1.1647	0.996842	0.035846	0.03983
	[2] $[MR=e^{(-kt)^n}]$	k = 0.000964 n = 1.0000	0.996873	0.015390	0.00734
	[3] $[MR=a e^{-kt^n}+c]$	a = 1.1481 k = 0.000817 c = - 0.1202	0.998147	0.011847	0.00435
	[4] $[MR=e^{-kt}]$	k = 0.000964	0.996873	0.015390	0.00734
	[5] $[MR=a e^{-kt}]$	a = 1.0510 k = 0.00102	0.995685	0.018077	0.01013
	[6] $[MR=a e^{-kt} + (1 - a) e^{-kbt}]$	a = 1.5292 k = 0.000739 b = 0.5951	0.998220	0.011611	0.00418
	[7] $[MR= 1 + at + bt^2]$	a = - 0.00079 b = $1.79 \times 10^{-7}$	0.999258	0.007495	0.00174
	[8] $[MR= (1 + at + bt^2)/(1 + ct)]$	a = - 0.00089 b = $2.201 \times 10^{-7}$ c = - 0.00013	0.999331	0.007118	0.00157
	[9] $[MR=a e^{-kt^n} + bt]$	a = 0.9976 k = 0.000260 n = 1.1938 b = $8.711 \times 10^{-6}$	0.999479	0.006283	0.00122
Hot air drying	[1] $[MR=e^{-kt^n}]$	k = 0.00371 n = 1.0081	0.996745	0.016077	0.00491
	[2] $[MR=e^{(-kt)^n}]$	k = 0.00389 n = 1.000	0.996742	0.016083	0.00491
	[3] $[MR=a e^{-kt^n}+c]$	a = 0.9853 k = 0.00435 c = 0.0391	0.997843	0.013088	0.00325
	[4] $[MR=e^{-kt}]$	k = 0.00389	0.996742	0.016083	0.00491
	[5] $[MR=a e^{-kt}]$	a = 1.0113 k = 0.00394	0.996966	0.015520	0.00458

	[6] $[MR=a e^{-kt} + (1-a) e^{-kbt}]$	a = 0.2882 k = 0.00412 b = 0.8967	0.996383	0.016946	0.00546
	[7] $[MR= 1 + at + bt^2]$	a = 0.00329 b = $3.135 \times 10^{-6}$	0.997379	0.014426	0.00395
	[8] $[MR= (1 + at + bt^2)/(1 + ct)]$	a = - 0.00287 b = $2.558 \times 10^{-6}$ c = 0.000765	0.999075	0.008568	0.00139
	[9] $[MR=a e^{-kt^n} + bt]$	a = 0.9967 k = 0.00191 n = 1.1511 b = 0.000132	0.999567	0.005867	0.0006539
Microwave drying	[1] $[MR=e^{-kt^n}]$	k = 0.0237 n = 0.9977	0.999987	0.001031	0.0000159
	[2] $[MR=e^{(-kt)^n}]$	k = 0.0235 n = 1.000	0.999986	0.001054	0.0000167
	[3] $[MR=a e^{-kt^n} + c]$	a = 0.9971 k = 0.0237 c = 0.0034	0.999991	0.000879	0.0000116
	[4] $[MR=e^{-kt}]$	k = 0.0235	0.999986	0.001054	0.0000167
	[5] $[MR=a e^{-kt}]$	a = 0.9996 k = 0.0235	0.999986	0.001076	0.0000174
	[6] $[MR=a e^{-kt} + (1-a) e^{-kbt}]$	a = 0.1396 k = 0.0202 b = 1.1951	0.999988	0.000978	0.0000143
	[7] $[MR= 1 + at + bt^2]$	a = - 0.0131 b = 0.00011	0.996587	0.016679	0.00417
	[8] $[MR= (1 + at + bt^2)/(1 + ct)]$	a = - 0.0131 b = 0.000052 c = 0.0107	0.999994	0.00071	0.0000008
	[9] $[MR=a e^{-kt^n} + bt]$	a = 0.997 k = 0.0233 n = 1.0045 b = 0.000045	0.999998	0.000425	0.000003
Freeze Drying	[1] $[MR=e^{-kt^n}]$	k = 0.00044 n = 1.208	0.992878	0.02535	0.0135
	[2] $[MR=e^{(-kt)^n}]$	k = 0.00168 n = 1.0000	0.988043	0.032846	0.02266
	[3] $[MR=a e^{-kt^n} + c]$	a = 1.0962 k = 0.00163 c = - 0.0438	0.988103	0.032705	0.02254
	[4] $[MR=e^{-kt}]$	k = 0.00168	0.988043	0.032846	0.02266
	[5] $[MR=a e^{-kt}]$	a = 1.064 k = 0.00179	0.987369	0.03376	0.02393
	[6] $[MR=a e^{-kt} + (1-a) e^{-kbt}]$	a = 1.2756 k = 0.00128 b = 0.3725	0.986915	0.034362	0.0248
	[7] $[MR= 1 + at + bt^2]$	a = - 0.00139 b = $5.485 \times 10^{-7}$	0.995677	0.019751	0.00819
	[8] $[MR= (1 + at + bt^2)/(1 + ct)]$	a = - 0.00156 b = $6.647 \times 10^{-7}$ c = - 0.0003	0.997105	0.016163	0.00549
	[9] $[MR=a e^{-kt^n} + bt]$	a = 0.9736 k = 0.000076 n = 1.5095 b = 0.000082	0.99877	0.010534	0.00233

RESULTS AND DISCUSSION

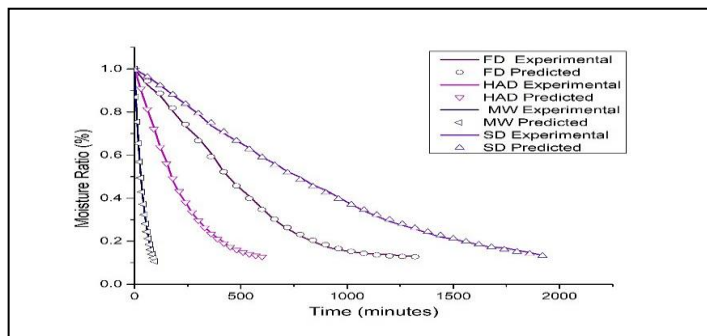


Figure 1 Drying kinetics of freeze dried, hot air dried, microwave dried and microwave convective dried mango leather

Considering the thin layer drying models and assuming an even distribution of temperature and moisture within mango pulp during the different drying processes, the endured parameters were modeled and thereafter fitted to all the nine equations (Table 1). Model convolutions can be ascribed by the constants considered for each model, though the best-fitted model is described by various statistical measures and not by the constants that exist within the model (Onwude et al., 2016). The experimental results fitted well with the entire models (Table 2). It was observed that the Midilli model (Midilli et al., 2002) fitted best with the R<sup>2</sup> of 0.999479, 0.999567, 0.999998, 0.99877 along with lowest RMSE and SSE value of 0.006283, 0.005867, 0.000425, 0.010534 and 0.00122, 0.0006539, 0.000003, 0.00233 for sun, hot air, microwave and freeze drying respectively. The plots for drying kinetics of all the four drying processes predicted best by the Midilli model are presented in Fig. 1. Midilli model predicted sun drying better for Bitter leaves, Crain-crain leaves and the fever leaves drying (Alara et al., 2018 ; Philip et al., 2007), hot air drying better for broccoli stalk, mushroom slice drying (Salim et al., 2017 ; Dinani et al., 2014) , microwave drying better for apple slice and onion slice drying (Sufer et al., 2017) , freeze drying better for Kiwi slice and kefir drying (Izli et al., 2016 ; Isleroglu et al., 2019) in prior studies.



From initial moisture content of 5.45 kg moisture/kg dry leather to attain the final moisture content of 0.163 kg moisture/kg dry leather, irrespective of drying methods used moisture amputation of mango pulp was transpired mainly in the falling rate period and the constant rate period was not observed for any of the drying methods. During the thin layer drying of mango pulp, the temperature distribution was assumed to be uniform, as the thickness of the layer was uniform (Onwude *et al.*, 2016). In the initial phase of drying due to the fast diffusion of water molecules the rate of drying was fast as cell wall pathway and transmembrane transport way define the moisture movement in this phase, while the moisture vapour diffusion became dominant in the later phase of drying through the symplastic transport mechanism, which ensued in a slowdown in the drying rate. Effective moisture diffusivity ( $D_e$ ) is the key parameter to describe the falling rate period. The range for  $D_e$  gained from  $26.37 \times 10^{-7} \text{ m}^2/\text{s}$  (sun drying) to  $2363 \times 10^{-7} \text{ m}^2/\text{s}$  for microwave drying. Whereas, intermediate  $D_e$  value of  $193.7 \times 10^{-7} \text{ m}^2/\text{s}$  and  $44.63 \times 10^{-7} \text{ m}^2/\text{s}$  were observed for convective drying (hot air oven) and freeze drying respectively. These large deviations in diffusivities during different modes of drying procedures can be explicated by considering the diversified approach of energy transmission to the mango pulp. Similar results were reported for germinated corn by Bualuang *et al.*, 2017 and for grape by Maskan *et al.*, 2002. The amount of moisture present within the mango pulp responsible chiefly for its dielectric characteristics. The electromotive energy absorbs by the polar components of mango pulp, mainly the water molecules, fasten the rate of evaporation, therefore the absorption of electromotive energy absorption is directly proportional to leftover moisture. In contrast to the sun and hot drying, microwave can infiltrate the outermost inert dry layer and produce an outward flux of vapour from the inner side of the mango leather (Wang *et al.*, 2007). An extended falling rate was observed for SD. Similar result was observed for sun drying of tomato slices by Rajkumar *et al.*, 2007. Due to the sluggish rate of heat transfer, sun drying was the leisureliest drying process with drying time 32 hours followed by freeze drying with a drying time of 22 hours and hot air drying with drying time of 10 hours, where convective heat transfer was responsible for moisture removal. During freeze drying, due to sublimation, moisture reaches to surface of mango leather through the capillary action. As the partial vapour pressure of mango pulp was higher than that of lyophilizer condenser, the moisture at the surface front got dried out (Acar *et al.*, 2014).

#### FOURIER-TURNFORM INFRARED SPECTROSCOPY ANALYSIS (FTIR)

Each spectrum containing more or less fifteen to sixteen peaks of ranges lies in between  $448\text{--}3557 \text{ cm}^{-1}$  (Fig. 2). Carboxylic groups ( $-\text{COO}$ ) of pectin shows symmetric stretching at peak value  $1336 \text{ cm}^{-1}$  (SD). On the other hand, two bands appearing at  $1422\text{--}1425 \text{ cm}^{-1}$  (SD, HAD, MWD, FD) and  $1638\text{--}1642 \text{ cm}^{-1}$  (HAD, SD, MWD) (Ajila *et al.*, 2010) represent the asymmetric and symmetric stretching frequency of ionic carboxylic group. Conjugation of the carbonyl group ( $\text{C}=\text{O}$ ) with  $\text{C}=\text{C}$  and  $\text{C}=\text{O}$  stretch can be represented by the peaks appear close to  $1638 \text{ cm}^{-1}$ . In the case of primary and secondary amides, the amide ( $\text{N}-\text{H}$ ) bending may be related to the peak at  $1642 \text{ cm}^{-1}$  (MWD) (Leopold *et al.*, 2011). Partial overlapping of the absorption band is noticed for carboxyl ( $\text{C}=\text{O}$ ) and amide ( $\text{N}-\text{H}$ ), at peak value  $1680\text{--}1630 \text{ cm}^{-1}$  and  $1640\text{--}1620 \text{ cm}^{-1}$  respectively.  $\text{C}-\text{O}$  bond shows stretching vibration at  $2123\text{--}2126 \text{ cm}^{-1}$  because of the non-ionic carboxylic group or their ester acid ( $-\text{COOH}$ ,  $-\text{COOCH}_3$ ) (Rambla *et al.*, 1998). Symmetric stretching frequency of  $-\text{CH}_2$  lie at the peak value of  $2931 \text{ cm}^{-1}$  (HAD) whereas either of symmetric or asymmetric  $\text{C}-\text{H}$  stretching frequency of aliphatic acids is represented by a peak at  $2932 \text{ cm}^{-1}$  (SD, HAD, MWD, and FD). Absorption frequency of hydroxylation lies in the region of  $3700$  to  $3000 \text{ cm}^{-1}$ . It has been observed that stretching frequency of  $-\text{OH}$  mostly retains at  $3377 \text{ cm}^{-1}$  (SD) (Ajila *et al.*, 2010). Amide ( $\text{N}-\text{H}$ ) stretching frequency is observed in the range of  $3500\text{--}3000 \text{ cm}^{-1}$ . From the study, it can be noted that this stretching frequency is noticed for all products dried under four different methods (SD, HAD, MWD, and FD). Stretching frequency of hydroxyl ( $\text{O}-\text{H}$ ) group in alcohols, phenols, carboxylic acid available in pectin, lignin, cellulose (Adina *et al.*, 2010) shows a broad peak at  $3557$  (MWD) and  $3353 \text{ cm}^{-1}$  (HAD). This can be explained by the phenomena of having intra and intermolecular  $-\text{H}$  bonds of such compounds.

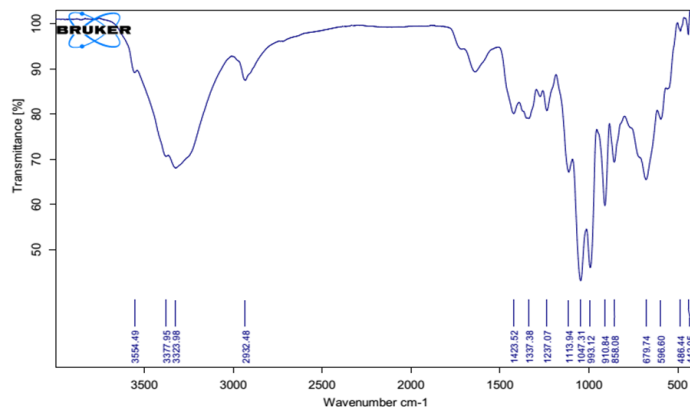


Figure 2 FTIR spectra of Freeze dried mango leather



(a)



(b)



(c)



Fig. 3. Different types of Mango leather - (a) Hot Air Oven dried mango leather. (b) Microwave dried mango leather; (c). Freeze dried mango leather; (d) Sun dried mango leather.

**SENSORY EVALUATION**

The panelists and panel performance was evaluated towards the sample attributes. Panelists significantly perceive the variance within samples (Fig. 3a, 3b, 3c, 3d), with respect to orange-yellow colour, rigidity, surface finish, chewiness, and aftertaste. The panelists attained a low p-value as well as low MSE values for all the sensory attributes, by the development of constellation adjacent the lower-left portion of the plot, inferring the samples are categorically dissimilar from each other.

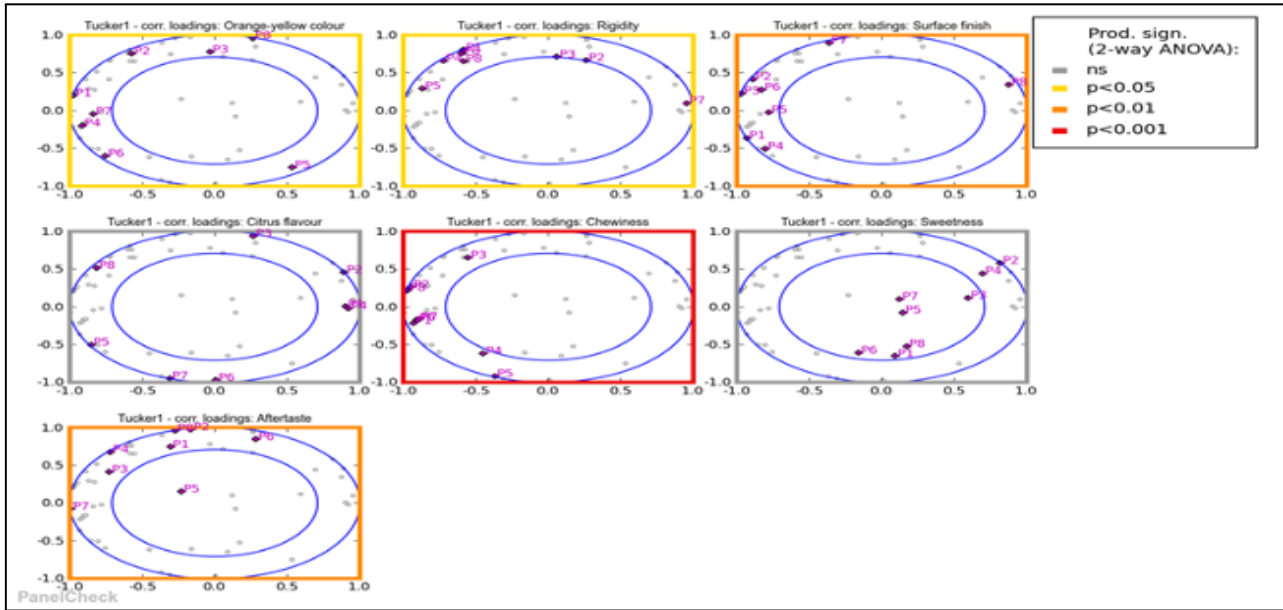


Figure 4 Tucker 1 plot for each sensory attribute. The borders exterior the outer eclipse represents the statistical significance in different p-value

The multivariate approach of analysis produces the Tucker-1 plot (Fig.4.), where specific incongruity was observed for statistically significant ( $p < 0.5$ ) attribute aftertaste (P5) and insignificant ( $p > 0.5$ ) attribute sweetness (P1, P3, P5, P6, P7, and P8). For all the other attributes no such discrepancies have been observed. Regardless of these disagreements, most of the panelists were accommodated in the outer eclipse, recommending 100% of explained variance for each attribute. It was also found that the explained variances accommodated themselves within the first two principal components (PC), by predicting the pronounced systematic variation of analyzed data set proposing the panel is well-trained and static. Instead of a panel, samples are considered during consensus analysis of the data set. The standardized PCA Bi-plot (Fig.5) describe that mutually axis 1 and 2 showed a very high correlation (70.6% and 26.3%) among all sensory attributes. The attributes like citrus flavour and sweetness reside on the positive side of the PC1, while orange-yellow colour, chewiness, surface finish, rigidity, and aftertaste belong to the negative side of PC1. On a similar fashion, sweetness, rigidity, and aftertaste were observed at the positive coordinate of PC 2, though four other attributes namely orange-yellow colour, surface finish, citrus flavour, and chewiness observed at the negative side of PC 2.

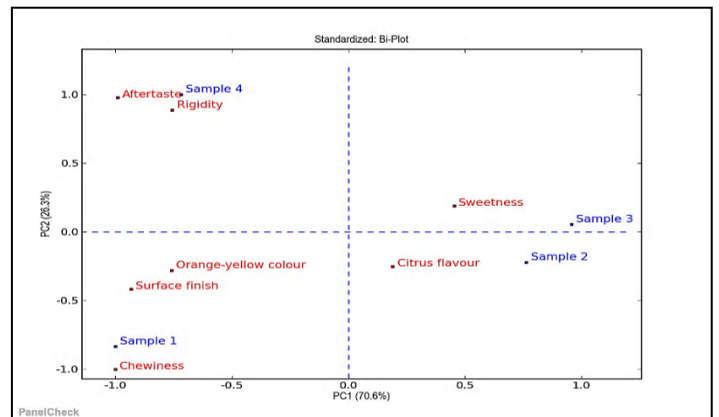


Figure 5 PCA Bi-plot for Sun dried (Sample 1), Hot air dried (Sample 2), Microwave dried (Sample 3) and Freeze dried (Sample 4) mango leather.

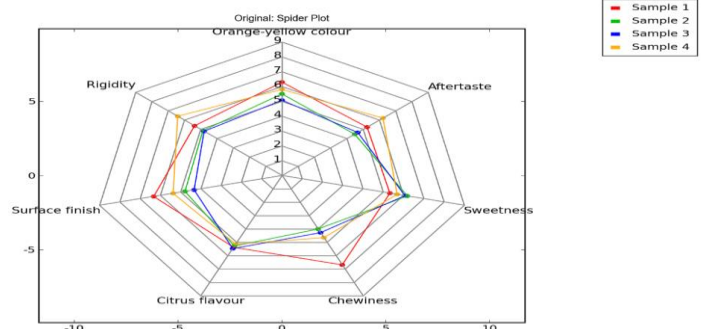


Figure 6 Spider for Sun dried (Sample 1), Hot air dried (Sample 2), Microwave dried (Sample 3) and Freeze dried (Sample 4) mango leatherThe SD (sample 1)

was more correlated with orange-yellow colour, surface finish and chewiness, HAD (sample 2) and MWD (sample 3) were found to be more correlated with citrus flavour and sweetness respectively. FD (sample 4) was found to be correlated with sensory attributes like rigidity and aftertaste. SD was appeared to be preeminent regarding orange-yellow colour, surface finish, and chewiness, whereas HAD and MWD found to be superlative with respect to sweetness and citrus flavour respectively, while the attributes like rigidity and aftertaste found to be superior for FD. Spider plot (Fig. 6) showed the overall representation of the sensory attributes which was in accordance with information acquired Fig. 5. Surface finish, orange yellow colour, and chewiness were the attributes where SD (sample 1) showed its superiority. While FD (sample 4) showed the maximum score in terms of rigidity and aftertaste. MWD (sample 3) showed the highest citrus flavour development. HAD (sample 2) was scored maximum in terms of sweetness.

## CONCLUSION

Thin-layer drying models were studied for mango leather and Midilli model was fitted best with the maximum value for  $R^2$  of 0.999479, 0.999567, 0.999998, 0.99877 along with minimum RMSE and SSE value of 0.006283, 0.005867, 0.000425, 0.010534 and 0.00122, 0.0006539, 0.000003, 0.00233 for sun, hot air, microwave and freeze drying respectively. The effective diffusivity was found maximum for MWD ( $2363 \times 10^{-7} \text{ m}^2/\text{s}$ ) followed by HAD ( $193.7 \times 10^{-7} \text{ m}^2/\text{s}$ ), FD ( $44.63 \times 10^{-7} \text{ m}^2/\text{s}$ ) and sun drying ( $26.37 \times 10^{-7} \text{ m}^2/\text{s}$ ). SD was the lengthiest (32 hours) process, while MWD being the shortest (96 minutes) method for mango leather production. The FTIR analysis implied that different drying methods insignificantly affect the carbohydrate composition. SD was found better with respect to its distinguished orange-yellow appearance, smoothness of the surface, and chewability, however, HAD and MWD were exceptional with compared to sweetness and characteristics citrus flavour of mango leather respectively, whereas, in terms of rigidity and aftertaste FD was preferred most.

## Compliance with ethical standards

**Conflict of interest:** Authors declare no conflict of interest.

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