Moisture sorption characteristics of ready-to-eat snack food enriched with purslane leaves

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Abstract Green leafy vegetables are important part of our regular diet that provides us with essential nutrients necessary to support human life and health. Since these are produced in surplus and have limited shelf-life, preservation of vegetables can help to prevent wastage and increase nutrient availability in the diet during off-season. Purslane leaves, rich in micronutrients were dried using tray dryer at 60 ± 2 °C for 7 h. and incorporated at 20% level in *khakhra*. Organoleptic and physico-chemical properties of the product were evaluated. Further, the sorption properties of *khakhra*, were studied at 27 ± 2 °C over a range of water activity of 0.10–0.92. Several models were chosen to fit sorption behavior, but the Peleg model showed the best fit. The present study in fact provides a platform to understand the rationalities behind the physico-chemical changes in the product, which, in turn, helps in predicting the best suitable packaging material for storage in addition to the stability of the product.

Keywords Purslane leaves mixture · ERH · *khakhra* · Ready-to-use snack food

Introduction

Since last decade a substantial progress has been evidenced in standard of living of the people across the world. It is predominantly due to the widespread industrialization and technology advancement in all the sectors. The fast food market has also proliferated in a very short time due to the fast-paced life style, where consumers majorly consider convenience and easy access to nutritious and appetizing food. Therefore, the demand of ready-to-eat foods, like extruded snack food drastically increased worldwide. According to a study published in USDA (USDA 2010), approximately 97% of the Americans are receiving an average of 24% of their calories from snack foods. On the other hand, variety of junk foods has also been seen holding a major part of the diet due to the benefits it holds in place. These are processed foods that constitute high calories, principally derived from starch and fat but lack of adequate amount of fiber. Based on epidemiological research, many gastrointestinal and cardiovascular diseases are often witnessed in the consumers who rely majorly on the diet that lacks fiber in it (Kumari and Grewal 2007). Fruits and vegetables include a distinct variety of plant foods that supply not only energy and nutrients but also significant amount of fiber. India is the second largest producer of fruits and vegetables in the world, after China (National Horticulture Database published by National Horticulture Board (Oxford University Press 2016).

Despite of abundant production, most sections of modern societies tend to limit their diet to a variety of vegetables and avoiding certain green leafy vegetables like purslane leaves that provides excellent nutrition aspects than major cultivatable vegetables. It is known to have high alpha-linolenic acid and other fatty acids than any other vegetables (Palaniswamy et al. 2001). Moreover, purslane

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is considered as “power food” because of its exceptional nutritional properties, which makes it suitable for incorporation into varied snack foods. It would provide extra nutrient in the diet that contributes to our health maintenance and well-being (McDonald and Nicholson 2006).

Dietary supplement is a designed formulation that enhances the nutrient profile of the regular diet by incorporating the micro and macronutrients essential for human health. Traditionally, people have used herbal medicines to get rid of various problems like illness, fever, wounds and infection, CVD, constipation, weight management, immune-modulators and memory loss etc. Purslane is characterized as wild plant, hence underutilized despite its high antioxidant, mineral and omega-3 fatty acid content in it (Palaniswamy et al. 2001). Therefore, utilization of natural resources in the direction of health care system is becoming challenging every day. Further, requirement of nutraceuticals has been found to increase with the consumer's awareness in connection with the diet and health. So, it is essential to integrate these active ingredients with the current food formulations to facilitate enhanced nourishment with an added advantage to the consumers in relation to health.

The consumers' perspective has changed significantly ever since last decades in the field of food production and consumption. Consumers are more aware that the food contributes significantly to their health and wellbeing (Mollet and Rowland 2002; Young 2000). Now-a-days consumers are not only consuming foods to only fulfill their hunger need but also to obtain essential nutrients, to avoid nutrition-related problems and to get better physical and mental well-being (Menrad 2003; Roberfroid 2000b). Many countries, including India, are known to have traditional foods which are nutritionally better than common junk foods (Pathania et al. 2017). The functional foods can play an excellent role to alleviate the lifestyle diseases. These foods gained much popularity and attention because of increasing expenditure on healthcare, increase of life span and desire of people for improved quality of their later years (Kotilainen et al. 2006; Roberfroid 2000a, b, 2002).

Indian cuisine surrounded a broad variety of regional cuisines. These cuisines are significantly different from each other due to a wide range of diversity in soil type, climate and occupations. Among these cuisines, the snack food product, *khakhra*, a very thin cracker is chosen for the study that is originated from the state of Gujarat. The *khakhras* are uniquely hand-made and baked products, usually served during the breakfast. There are different varieties of *khakhra* available in the market but most of them do not have additional health benefits. The incorporation of purslane in *khakhra* may fulfill the requirement as it is rich in various micronutrients.

The moisture content of the purslane *khakhra* is an important parameter that demonstrates the hygroscopic nature of the product majorly contributing to fatty acid oxidation that yields strong influence on quality of product. A moisture sorption isotherm describes the correlation between the water activity (a_w) and the equilibrium moisture content (EMC) for a food product at a constant pressure and temperature. The knowledge of sorption characteristics of the product is essential to determine the packaging requirements, stability and quality of the product during storage. It also helps in designing and optimization of processing parameters, like drying, packaging, modelling moisture changes during storage and predicting ingredient formulation etc. Therefore, the aim of the present study was to investigate the moisture sorption characteristics of ready-to-eat snack food, *khakhra* enriched with purslane leaves using sorption data to determine the best fit sorption model among various models tested.

Materials and methods

The fresh purslane, wheat flour, turmeric and other spices were procured from local market of Mysore, India. All the chemicals used in the study were of analytical grade (AR) and procured from Sisco Research Laboratories, Mumbai. The entire experiments in the present investigation were conducted in triplicates.

Preparation of purslane powder

Fresh and undamaged leaves were plucked and washed to remove foreign matter, such as dirt and mud using under running tap water. After washing the leaves were subjected to drying in a try dryer for 7 h at 60 ± 2 °C (AOAC 1990). The dry matter was ground into a fine powder in an electric mixer-cum-grinder and packed in an air tight container for subsequent use.

Preparation of *khakhra*

khakhra, a native of Gujarati traditional food was made of wheat flour, turmeric and salt and considered as control, whereas purslane powder (in the ratio of 20%) was added for sample preparation. The complete ingredients were mixed with water to form dough and rolled evenly using roller pin to form a very thin circular shaped raw *khakhra*. The raw *khakhra* was half-baked using pre-heated pan on medium flame and kept aside for 15 min. The half-baked *khakhra* was baked again on a pre-heated pan by pressing it with a wooden piston to avoid formation of air bubbles. The pressure is continued on low flame till its texture becomes hard and crispy. The baked *khakhra* was removed

from the pan and allowed to cool at room temperature for 5 min. The samples were packed in polyethylene bags for further analysis.

Analysis of chemical properties of the *khakhra*

The prepared baked *khakhra* samples were examined for proximate analysis, including moisture content, fat, protein and total ash content according to AOAC (1990) methods.

Texture measurement of *khakhra*

The texture is one of the important quality characteristics of the snack food product. The hardness of *khakhra* was measured using texture analyser (TA HDi, Stable Micro Systems Ltd., U.K.). Hardness was measured in terms of breaking force i.e., the force required to break *khakhra* using a load cell of 50 kg. The *khakhra* sample was mounted on a 3-point bend rig support and hardness was measured. The punch diameter and the cross-head speed used were 2 mm and 50 mm/min, respectively (Debnath et al. 2003).

Colour measurement of *khakhra*

The colour parameters for purslane enriched *khakhra* was determined using colour flux Hunter colour Lab scale (Konica Minolta, CM 6500). The instrument was calibrated with white and black ceramic cover and 10° view angle was used to capture the color values. The results were recorded in terms of color parameters i.e., L^* , a^* , b^* and ΔE . The L^* represents the lightness of the sample, where positive value indicates whiteness and zero indicates black. The positive a^* value (above zero) represents product redness whereas the negative values represents green shade. The b^* values above zero signifies yellow hue while blue hue for below zero. ΔE value demonstrates the overall color difference between the *khakhra* samples with and without purslane incorporation. Color parameters were determined for each sample at multiple locations to ascertain the average color values of the product (Ranganna 1997).

Fatty acid composition of *khakhra*

The fatty acid composition of FAME prepared from *khakhra* sample was carried out as per the method followed by Shanker and Debnath (2015). Baked *khakhra* samples were ground into a fine powder and hexane was used for the extraction of oil. After 12 h, the extracted oil was recovered by evaporating the solvent (hexane) using Rota evaporator (BUCHI, Rotavapor R-215, Switzerland). About 180–200 mg of oil sample was used for KOH–

MeOH methylation experiment. Approximately, 40 μ L of oil was taken in a 10 mL centrifugal tube and further added with 3 mL of KOH–MeOH solution (0.5 M). The mixture in the tube was heated at 60 °C for 15 min followed by cooling at room temperature. The cooled solution was further mixed carefully by adding 3 mL of n-hexane and 2 mL of distilled water. Consequently, 2 mL of hexane was added along with Na_2CO_3 to remove any moisture traces in the samples. The solution in the mixture tube was evidenced with phase separation. The top layer was collected for GC analysis.

Sorption studies of *khakhra*

A sorption isotherm of *khakhra* is desired at different humidity. The same is obtained using saturated aqueous salt solutions in contact with an excess of the solid (salt) phases. Various saturated salt solutions like LiCl, $\text{C}_2\text{H}_3\text{KO}_2$, MgCl_2 , K_2CO_3 , NaBr, NaNO_2 , NaCl, K_2CrO_4 and KNO_3 were used to maintain the water activity (a_w) value of 0.11, 0.22, 0.33, 0.44, 0.54, 0.64, 0.72, 0.86 and 0.92, respectively (Labuza et al. 1985). Different desiccators were used to keep these saturated solutions. In sorption experiments, the *khakhra* samples were conditioned to 65% RH at 27 ± 2 °C before transferring it to the desiccator. Each desiccator was loaded with 10 g sample and weighed periodically until it reached constant moisture content ($\sim 5\%$). The experiment was continued up to 3 months.

Sorption model fitting

The water sorption isotherms of agricultural products are reported in many studies. In the present study GAB (Jena and Das 2012), Peleg (Maroulis et al. 1988; Kumar et al. 2018), Caurie (Caurie 1970), Hasley, Smith and Oswin (Chirife and Iglesias 1978; Jain et al. 2010) models were used for fitting the sorption data. Further, these five models were employed to analyze their suitability for predicting moisture sorption behaviour of *khakhra*. The linear forms of the models were adopted to analyse the sorption data in determining the corresponding constants. The goodness of fit of each model was computed in terms of coefficient of determination (R^2) from the plot of experiment and root mean square error (RMSE) values, calculated as follows:

$$\text{RMSE} = \left\{ \left[(\text{M}_{\text{exp}} - \text{M}_{\text{pre}}) / \text{M}_{\text{exp}} \right]^2 / N \right\}^{0.5} \times 100$$

where, M_{exp} = moisture content experimental (% db), M_{pre} = moisture content predicted (% db), N = number of observations.

Sensory evaluation of *khakhra*

The 9-point hedonic scale is the widely used sensory evaluation technique for measuring food acceptability in the field of Food science since many years (Meligarrd et al. 1999). This technique originally uses “words only” 9-point hedonic scale as scale of liking. And the products are assessed with the verbal responses linked along with the assigned numbers 1 (dislike extremely)–9 (like extremely) facilitating an ordinal measure of preference (Meligarrd et al. 1999; Labuza et al. 1985; Kumar et al. 2017). A 20 membered panel of judges were recruited for evaluating the *khakhra* samples with (20%) and without purslane. The nominated panel primarily comprised of staff, student and faculty at the Central Food Technological Research Institute (CFTRI), as well as panelists extended over wide range of age and education.

The *khakhra* samples were prepared and evaluated in a sensory evaluation room, comprised of several cubicles equipped with white light and air conditioning to maintain the room temperature ($27 \pm 2^\circ\text{C}$). Each panelist in a cubicle were provided with freshly made *khakhra* samples placed in white plastic plates labelled three-digit random codes. They were also provided with distilled water and plain, unsalted *khakhra* to rinse their oral cavity in the middle of samples. The panelists were randomly provided with samples and asked to rate their assessment for product acceptability in terms of appearance, texture, taste, flavor and overall acceptability on a 9-point hedonic scale. The panelist were also presented with additional questions about product acceptability across wider range of age groups, be of interest in consuming the product if available in market and recommending to their family and friends.

Statistical analysis

All experiments were done in triplicate. The data were expressed as mean values $\pm$ standard deviation derived from triplicate determinations. All the data were collected, compiled and analyzed statistically using SPSS software (version 22.0) with defined statistical significance of $P < 0.05$.

Results and discussion

Changes in physico-chemical composition of purslane *khakhra*

The moisture is an important parameter of any food product. The water activity plays crucial role for determining the shelf-life of the food products. The purslane leaves contain 80–90% of moisture in general. The

moisture content of the product is responsible for development of proper texture and crispiness of the *khakhra*. Proximate composition of *khakhra* incorporated with dried purslane leaves are given in Table 1. Results showed that the crude protein, crude fibre and total ash of the product were found to increase slightly. It might be due to the replacement of other ingredients with dried purslane leaves.

The fatty acid profile of *khakhra* showed variety of fatty acids present in the product. The palmitic acid, linoleic acid, lauric acids were found higher in the product in comparison to the control (Table 1). Omega-3 fatty acid is also present in small amount in leaves incorporated *khakhra* which makes the *khakhra* nutritionally beneficial for health. These fatty acids have been associated for reduction of increased risk of coronary heart disease and some tumours. This was made in absence of oil and by using whole wheat flour making the product a healthier option for snacking.

Change in colour and texture of purslane *khakhra*

The major factor that influences the quality index and acceptability of food is its colour. Now-a-days, food

Table 1 Physico-chemical characteristics of *khakhra*

Parameters	Control	Sample (product)
Moisture (%)	4.56 ± 0.5^a	6.47 ± 0.7^a
Fat (%)	5.06 ± 0.3^a	6.43 ± 0.6^a
Protein (%)	1.84 ± 0.6^a	2.07 ± 0.4^a
Ash (%)	0.3 ± 0.01^a	0.41 ± 0.01^a
Crude fibre (%)	1.4 ± 0.2^a	1.9 ± 0.3^a
Colour		
L*	60.2 ± 0.4^a	69.3 ± 0.1^b
a*	3.1 ± 0.24^a	3.7 ± 0.1^a
b*	18.6 ± 0.1^a	19.1 ± 0.2^a
ΔE	34.0 ± 0.5^a	41.5 ± 0.04^b
Breaking force (N)	13.34 ± 0.4^a	10.95 ± 0.6^a
Fatty acids (% relative area)		
Caprylic acid	0.22 ± 0.4^a	0.43 ± 0.3^a
Lauric acid	1.98 ± 0.1^a	2.18 ± 0.3^a
Palmitic acid	39.76 ± 1.6^a	31.40 ± 1.9^b
Stearic acid	1.84 ± 0.3^a	2.39 ± 0.4^a
Oleic acid	14.54 ± 0.9^a	13.63 ± 1.4^a
Linoleic acid	35.78 ± 2.4^a	44.29 ± 1.7^b
Linolenic acid	3.29 ± 0.6^a	5.08 ± 0.4^a

Values are expressed as mean $\pm$ standard deviation; values presented above are means of 3 replicates

a and b indicate that means with different letter are significantly different ($P < 0.05$)

market is in the favor of natural colorants so that application of artificial colorants can be minimized. Some excellent sources of natural colorants are fruits and vegetables. Purslane is liable to impart a great range of hues by its incorporation in *khakhra* majorly during the processing and storage. Therefore, it is imperative to determine the color characteristics of *khakhra*. Usually, the parameters, such as L^* , a^* , b^* and ΔE values are used to measure the colour quality of the food product. As showed in Table 1, the overall color difference, ΔE of *khakhra* were found to change significantly ($P < 0.05$) with the addition of purslane leaves. The results also showed a significant increase ($P < 0.05$) in lightness, L^* values ranged from 60.2 to 69.34. While the a^* values also increases in the range of 3.1 to 3.7, but it exhibits an insignificant change ($P > 0.05$) in redness of the product (Table 1). The b^* values also follow the same trend as a^* values, yielded no significant change in yellowness hue of the product. The colour characteristics of the *khakhra* were found to shift, as substantiated by ΔE , from white (control) to greenish in the purslane *khakhra* containing 20% purslane leaves. These results were supported with those obtained by El-Saies et al. (2011).

The breaking force is taken as an indicator of the quality of texture. Results in Table 1 showed that the incorporation of purslane leaves significantly decreased the breaking force of the resultant sample (product) as compared to the control. Chauhan and Bains (1988) reported that, incorporation of different leaves concentration with rice flour increased the crispness and decreasing breaking force of the extruded products.

Sorption isotherm of purslane *khakhra* and predictive models

The *khakhra* is a dry snack product with low moisture content. Therefore, this product is susceptible to absorb moisture from the surrounding atmosphere. In this experiment, the *khakhra* is considered as a moisture sensitive food, thus the package is used to function as a moisture barrier (Brennan 1989). The *khakhra* was kept under different relative humidity. The weight loss or gain with time was observed. The moisture sorption isotherm of *khakhra* was estimated at the temperature of 27 ± 2 °C with in the relative humidity of 11–92%. Sorption isotherms were plotted between equilibrium moisture content of *khakhra* and water activities at constant temperature. The resultant isotherms (experimental and predicted) of different models are presented in Fig. 1. Various models such as, GAB, Peleg, Curie, Smith and Oswin were tested to predict the sorption data and to establish the sorption behavior of *khakhra* (Table 2). The results of the fitting of five mathematical equations on experimental moisture sorption data

yielded are shown in Table 3. Adsorption isotherms of *khakhra* at 27 °C are shown in Fig. 2. An isotherm is characteristic of high carbohydrate foods (Rakshit et al. 2014). At a definite temperature the sorption isotherms show a symmetry between raise in moisture content with raise in water activity (a_w). This can be explained as an increase in the vapor pressure of water within the foods with any increase in the surrounding vapor pressure (Sharma et al. 2009). At higher a_w , sorption behavior is found to significantly get affected by the starch component of the product and resulted an increase in equilibrium water uptake at the experimental temperatures. Related studies were recorded by Sharma et al. (2009) for basundi mix, Rakshit et al. (2014) for legume based *wadi* and McMinn et al. (2007) for oat based products. All the results showed a decline in the hygroscopic character of purslane *khakhra*. The moisture sorption data of *khakhra* fitted to a two-parameter model (Smith, Caurie, Oswin), a GAB model with three-parameter and Peleg model with four-parameter are shown in Table 3. For sorption model R^2 values are indicative, as it indicates good fit for the data obtained. Value of R^2 is close to 1 is most suitable. Equation obtained by Smith model showed that holds good for the range from 0.1 to 0.9 and the constant Ma ranged from -0.68 to 0.38 and Mb from 1.08 to 2.18. The purslane *khakhra* showed a higher RMSE value of 0.12. Goodness of fit for a_w varied from 0.1 to 0.9. The Caurie model also held good for this range. The Caurie constants varied from -0.68 to -1.07 and from 2.18 to 2.36, respectively.

For linear regression analysis, the linear form of the Oswin model was used to solve experimental data. An acceptable correlation and the constants equation were obtained which varied from 1.15 to 1.54 and “n” varied from 0.41 to 0.39 (Table 3). The most successful models are the Peleg and GAB for the full range of water activity (0.1–0.9). The Peleg and GAB models appeared to be the most suitable to describe the sorption relationship of *khakhra*. For sorption studies of foods mostly these models have been extensively applied. The lower RMSE values were observed from GAB (0.03 to 0.05) and Peleg (0.01 to 0.02) models. The Peleg equation has been successfully used to explain the sorption activities of foods (Maroulis et al. 1988). The Peleg equation has been found to represent satisfactorily for experimental data in the whole series of a_w 0.1–0.9. It can be noted (Table 3) that Peleg model showed relatively good fit at 27 ± 2 °C as regression coefficient (R^2) and RSME obtained as 0.99 and 0.01, respectively. This indicated the Peleg equation is the best fit for sorption data for *khakhra* containing dry purslane.

Fig. 1 Comparison of experimental (S) and predicted (C) moisture sorption isotherms of *khakhra* by various models

Sensory evaluation

Consumer panel sensory score showed incorporation of dried purslane leaves to *khakhra* (up to 20%) was fairly accepted. Though the panel acceptance was slightly inclined towards control in terms of appearance, color, taste and overall acceptability, however, control and product showed no significant differences ($P > 0.05$). With the incorporation of purslane, the crispiness score decreased slightly but did not influence the palatability

(Fig. 3). The lower score can be substantiated with the texture data on breaking strength represented in Table 1. With almost similar after taste, color, taste and superior nutritional profile and the sensory panelists revealed their willingness to purchase and consume *khakhra* with 20% purslane leaves over control sample with no purslane added (Fig. 3).

Table 2 Selected isotherm equations for experimental data fitting

Sl. no.	Model	Equation	Linearized equation	Constant
1	GAB	$\frac{M}{M_0} = \frac{Gka_w}{(1-Kaw)(1-Kaw+GKaw)}$	$M = \frac{a_w}{(A \times a_w^2) + (B \times a_w + C)}$ $A = \frac{K}{M_0[(\frac{1}{G}) - 1]}$ $B = \frac{1}{M_0[(1 - \frac{2}{G})]}$ $C = \frac{1}{M_0 G K}$	M ₀ , G, K
2	Smith	$M = Mb - Ma \times (aw)$	$M = Mb - Ma \ln \times (1 - aw)$	M _a , M _b
3	Caurie	$\ln M = a + b \times a_w$	$\ln M = a + b \times aw$	a, b
4	Oswin	$M = a \left[\frac{a_w}{(1-aw)} \right]^n$	$\ln M = \ln a + n \times \ln \left(\frac{aw}{1-aw} \right)$	a, n
5	Peleg	$x_n = a(aw)^b + (a_w)^d$	$x_n = a(aw)^b + (a_w)^d$	a, b, c, d

Table 3 Model parameters, coefficient of determination (R²) and % RMSE for sorption isotherms of *khakhra*

Sorption model	Model parameters					R ²	% RMSE
GAB	M	G	K				
Control	0.65	37.15	0.87			0.99	0.03
Sample	0.89	36.11	0.84			0.99	0.05
Peleg	k1	k2	n1	n2			
Control	2.92	4.28	1.11	0.29		0.99	0.02
Sample	3.52	3.61	1.32	0.21		0.99	0.01
Curie	a	b					
Control	− 1.07	2.36				0.99	0.11
Sample	− 0.68	2.18				0.99	0.12
Smith	a	b					
Control	0.38	1.08				0.99	0.05
Sample	− 0.68	2.18				0.99	0.12
Oswin	a	b					
Control	1.15	0.41				0.99	0.07
Sample	1.54	0.39				0.99	0.01

Fig. 2 Moisture sorption isotherms for control and sample (20% purslane powder) of *khakhra* at working temperature of 27 °C **Fig. 3** Comparative sensory evaluation of *khakhra* using 9-point hedonic scale

Conclusion

It can be concluded from the present investigation that the purslane leaves can be used for the preparation of value-added products that are rich in micronutrients. In this study an attempt was made to incorporate purslane leave powder in *khakhra* to enrich it with active ingredients. It demonstrated a substantial consumer acceptance in terms of palatability, physico-chemical characteristics, sensory attributes and nutritional quality. Moreover, sorption studies were also conducted in order to understand the sorption characteristics of *khakhra* at a temperature of 27 ± 2 °C at a_w range of 0.1–0.9. Peleg model was found to be successfully fit the sorption data and facilitated in understanding the changes occurring in *khakhra* at various humidity conditions. This study can serve as the explanation for the onset of various physico-chemical and microbiological events in *khakhra* that may lead to its spoilage. Moreover, it also provides a platform for optimization of processes and ingredients for predicting the suitable packaging materials for enhancing the shelf life.

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