LWT - Food Science and Technology 146 (2021) 111441

Contents lists available at ScienceDirect

LWT

journal homepage: www.elsevier.com/locate/lwt

# Optimization of process parameters for the production of jaggery infused osmo-dehydrated coconut chips

M. Pravitha [a,*], M.R. Manikantan [b,**], V. Ajesh Kumar [c], Shameena Beegum [b], R. Pandiselvam [b]

[a] Agro Produce Processing Division, ICAR- Central Institute of Agricultural Engineering, Nabibagh, Berasia Road, Bhopal, India
[b] Physiology, Biochemistry and Post-Harvest Technology Division, ICAR- Central Plantation Crops Research Institute (CPCRI), Kudlu.P.O, Kasaragod, India
[c] Centre of Excellence for Soybean Processing and Utilization, ICAR-Central Institute of Agricultural Engineering, Nabibagh, Berasia Road, Bhopal, India

A R T I C L E I N F O

*Keywords:*
Coconut chips
Jaggery
Osmo-dehydration
Mineral analysis
Texture

A B S T R A C T

Coconut slices were converted into healthy coconut chips by replacing conventional osmotic agent with jaggery to counteract the health deteriorating effect of refined sugar. The optimal processing condition to yield the desired product was determined by employing a Box-Behnken design based on independent variables: drying temperature (50–70 °C), jaggery solution concentration (45–55 °Brix), and slice thickness (0.50–1.00 mm). The simultaneous optimization of these processing parameters was done based on the responses: final moisture content, drying rate, rehydration ratio, crispness, appearance, taste and overall acceptability. Further, the sample prepared at the optimized condition (drying temperature - 66.22 °C, slice thickness - 0.55 mm and jaggery solution concentration - 46.18 °Brix) was characterized and compared with traditional refined sugar osmosed coconut chips. Proximate and mineral analysis of the optimized sample suggested that incorporating a new osmotic agent, jaggery, has improved the nutritional quality of the chips with higher consumer acceptability.

## 1. Introduction

Coconut (*Cocos nucifera* L.) also known as "life tree'', is considered as the most important and potential tropical palm due to its versatile uses (Hebbar et al., 2020). Globally it is cultivated in more than 97 countries with an annual production of 63.76 million tonnes. In 2019, the leading producing countries of coconut were Indonesia (16.65 million tonnes), Philippines (14.15 million tonnes), India (10.34 million tonnes), Brazil (2.46 million tonnes), and Sri Lanka (2.09 million tonnes) (FAO, 2019). However, the coconut farming sector around the world facing multiple challenges such as pest and disease, escalation of input cost, price fluctuation and fragmented landholdings. All these obstacles ultimately make coconut farming least profitable enterprise. The development and popularization of distinct value-added products from coconut can tackle these constraints to a greater extent.

Conventionally known value-added products from coconut include coconut oil, virgin coconut oil, coconut milk from the mature coconut and coconut water from the tender coconut etc, (Madhavan et al., 2010). The potential use of coconut as snack food was also exploited by introducing products like coconut based chips originated from coconut kernel. Coconut kernel or endosperm is usually considered as a nutrient-rich part of coconut due to the presence of carbohydrate, fat, salt, and vitamins A, $B_1$, $B_2$, $B_5$ and C (da Silva et al., 2014), hence its utilization for value-added product development is much desirable. In general, fruits and vegetable-based crunchy and crispy snacks available in the market are oil fried. But present-day consumers are more concerned about health; this forced the snack food industries to prepare low-fat products with a similar taste and mouthfeel of conventional fried snacks (Khubber et al., 2020). The existing coconut chips production method is relevant in this aspect because convective drying has been employed to evaporate the water from fresh coconut slices which yields a healthy product compared to the traditional method of frying used for chips preparation (da Silva et al., 2013).

Till date, coconut chips available in the market were produced by refined sugar assisted osmotic dehydration. This refined sugar contains 99.9% sucrose, which is having very low nutritional value and rich in empty calories. Besides these adverse effects of refined sugar, its intake has also been related to a higher chance of the occurrence of dental problems in occidental societies (Seguí et al., 2015). Before the introduction of refined sugar, jaggery (non-centrifugal sugar) was the

* Corresponding author. Agro Produce Processing Division, ICAR- Central Institute of Agricultural Engineering, Nabibagh, Berasia Road, Bhopal, India.
** Corresponding author. Physiology, Biochemistry and Post-Harvest Technology Division, ICAR- Central Plantation Crops Research Institute (CPCRI), Kudlu.P.O, Kasaragod, India.
*E-mail addresses:* pravitha.m@icar.gov.in (M. Pravitha), manikantan.mr@icar.gov.in (M.R. Manikantan).

https://doi.org/10.1016/j.lwt.2021.111441
Received 6 January 2021; Received in revised form 27 March 2021; Accepted 1 April 2021
Available online 5 April 2021

dominant form of sugarcane product used for sweetening purposes. Jaggery is a better sweetening agent than refined sugar in nutritional point of view, as it is a rich source of minerals (calcium-40-100 mg, magnesium-70-90 mg, potassium-1056 mg, phosphorus-20-90 mg, sodium-19-30 mg, iron-10-13 mg, manganese-0.2–0.5 mg, zinc-0.2–0.4 mg, copper-0.1–0.9 mg, and chlorine-5.3 mg per 100 g), vitamins (vitamin A-3.8 mg, vitamin $B_1$-0.01 mg, vitamin $B_2$-0.06 mg, vitamin $B_5$-0.01 mg, vitamin $B_6$-0.01 mg, vitamin C-7.00 mg, vitamin $D_2$-6.50 mg, vitamin E-111.30 mg, vitamin PP-7.00 mg per 100g jaggery), and protein (280 mg per 100 g jaggery). With the presence of all these minerals and vitamins of sugarcane juice, jaggery is known as the healthiest sugar in the world (Singh et al., 2013). Jaggery is a part of many of the traditional medicines used to treat health issues such as infections, bronchitis, cough, anaemia, constipation, jaundice, general debility and heart or blood conditions (Kadam et al., 2008)

To the best of our knowledge, no research has been undertaken on the use of jaggery as an effective osmotic agent to yield a healthy snack. Hence, the present investigation aims to develop jaggery infused coconut chips. Determination of optimum levels of solute concentration, drying temperature and slice thickness is, however, important as an increase or decrease of these parameters may have an undesirable effect on the overall quality of the final product. Therefore objectives of this study were finalized to optimize the process parameter for the development of jaggery infused coconut chips with the aid of Response Surface Methodology (RSM) and also to characterise and compare the final product with traditionally available coconut chips.

## 2. Materials and methods

### 2.1. Sample preparation

Coconut (*Cocos nucifera* L; West Coast Tall cultivar) with 11–12 months maturity were harvested from the ICAR-Central Plantation Crops Research Institute (ICAR-CPCRI) farm. These fresh matured coconuts were subjected to dehusking (power dehusker: capacity of 350 coconuts/h and 2 hp power requirement), deshelling (desheller: capacity of 150 coconuts/h and 0.5 hp power requirement) and testa removal operation (testa removal machine: capacity of 100 coconuts/h and 0.5 hp power requirement) mechanically by using the machines developed in ICAR-CPCRI. White coloured kernel obtained after testa removal further cut into triangular pieces of three-inch size to make it convenient for hold during slicing operation. Slicing was done with a multi-commodity slicer (capacity of 60 coconuts/h and 0.5 hp power requirement) developed by ICAR-CPCRI. Slices were directed into a water-filled tray provided at the outlet end of the slicer to avoid contamination. For the experiment, three different slice thicknesses such as 0.50 mm, 0.75 mm, and 1.00 mm were used, which was achieved by adjusting the clearance of the cutting blade and further confirmed with a vernier calliper. These thickness levels were finalized based on preliminary experiments carried out by referring to the method given by Manikantan et al. (2016). In the initial trials, it has been observed that lower thickness value causing more breakage in chips during handling and packaging, conversely thicker slices resulted in a product with an undesirable leathery texture. Slicing was succeeded by water blanching at 90–95 °C for 2 min. This facilitates the removal of some amount of oil and arrests the enzymatic activity so that the final product will have more crispness and taste (Elfnesh et al., 2011).

### 2.2. Osmotic dehydration

After blanching, slices were subjected to osmotic dehydration with an aqueous solution of jaggery having different concentrations as per the design (Table .1). Concentration ranges (45–55 °Brix) were finalized by initial trials; concentration below 45 °Brix resulted in a product with less sweetness and concentration beyond 55 °Brix yielded a product having more hygroscopic behaviour because of the hygroscopic nature of jaggery (Verma et al., 2019). This dehydration process was carried out in a rotary shaker water bath with agitation at 40 °C to maintain uniform temperature and make the process effective. Ingredients were mixed in a proportion as described by Manikantan et al. (2016); one kg slices were immersed in 1 L osmotic solution with 10 g common salt and 20 ml vanilla essence (Vanilla No.1, IFF, Chennai, India). The dewatering operation was performed for 30 min (Garcia-Noguera et al., 2010). After the osmotic dehydration, solution was drained and the slices were gently blotted with tissue paper to remove excess jaggery solution from their surface and weighed.

### 2.3. Convective drying

Jaggery osmosed slices were convectively dried at selected temperatures by using tray dryer at an air velocity of 2 m/s. The weight of the sample was noted at each 15 min time interval and the drying operation was continued till the difference between successive sample weights becomes less than 0.01 g, which corresponds to its equilibrium moisture content (Chandra et al., 2020). This total time required to reach equilibrium moisture content was considered as drying time, which varies based on the experimental condition. The dried samples were cooled for 5 min in a desiccator containing silica gel and then stored in 100 μm thick aluminium foil laminated with LDPE film pouches till further analysis.

### 2.4. Experimental design

An experimental plan and further statistical analysis of data with regression model fitting for each response were carried out by using Design Expert® Software version 10 (Statease Inc., Minneapolis, MN). Based on the literature reviews independent variables for this study were selected as slice thickness, drying temperature and concentration of osmotic solution, which were found to influence the quality of the final product appreciably (Alam et al., 2019; da Silva et al., 2014; Madamba, 2003). A three-factor three level Box-Behnken design model with five replicates at the central point, which gives 17 experiments was selected to study the influence of processing parameters on the drying characteristics and sensory attributes (Table 1). The levels of processing parameters were chosen as independent variables: 1.) slice thickness (ST: 0.50–1.00 mm), 2.) jaggery solution concentration (SC: 45–55 °Brix), and 3.) drying temperature (DT: 50–70 °C); whereby each of these variables was tested at three different coded levels: low (−1), medium (0), and high (+1). Results of preliminary trials were assisted in fixing the range of these independent parameters. The responses considered attaining optimum condition were final moisture content (FMC), drying rate (DR), rehydration ratio (RR) and sensory attributes such as crispness (CR), appearance (AP), taste (TA) and overall acceptability (OA).

Response values were analyzed by fitting the data in a second-order polynomial model. The generalized second-order polynomial model proposed for predicting response variables is given as:

$$Y=B_0+B_1X_1+B_2X_2+B_3X_3+B_{12}X_1X_2+B_{13}X_1X_3+B_{23}X_2X_3+B_1^2X_1^2+B_2^2X_2^2+B_3^2X_3^2 \tag{1}$$

In this equation, Y represents the dependent variable (the estimated response) and $X_i$ (i = 1–3, 1-DT, 2-ST, 3-SC) represent the independent variables. Coefficients of the polynomial were represented by $B_0$ (constant term), $B_1$, $B_2$, and $B_3$ (linear coefficients for DT ST, and SC respectively), $B_1^2$, $B_2^2$, and $B_3^2$ (quadratic coefficients), and $B_{12}$, $B_{13}$, and $B_{23}$ (interactive coefficients).

Model adequacy was confirmed by scrutinizing the ANOVA table. The fitness of the models was further affirmed based on statistical parameters such as coefficient of determination ($R^2$), F test value and lack of fit. Interaction effects of independent variables were pictorially represented by 3-D response surface graphs for better depiction of results.

### 2.5. Characteristics of coconut chips

#### 2.5.1. Moisture content

The moisture content of samples before and after drying was determined by following the standard procedure of the hot air oven method at a temperature of 105 °C with a heating time of 24 h (AOAC, 1975). Measurements were taken in triplicate and average values were used in RSM. These moisture content values were calculated by using Eq. (2) and Eq. (3). Initial and final moisture content values on dry basis were used for the determination of the drying rate.

$$\text{Moisture content on wet basis (m wb \%)} = \frac{\text{Weight of water removed (g)}}{\text{Weight of sample taken (g)}} \times 100 \tag{2}$$

$$\text{Moisture content on dry basis (M db \%)} = \frac{\text{Weight of water removed (g)}}{\text{Weight of dry matter in sample (g)}} \times 100 \tag{3}$$

#### 2.5.2. Drying rate

The drying rate (DR) is expressed as the amount of moisture evaporated over time. The drying rate of samples was calculated using Eq. (4) (Guo et al., 2020).

$$DR = \frac{D_{t1} - D_{t2}}{t2 - t1} \tag{4}$$

Where DR is the drying rate (kg water/kg dry matter $min^{-1}$), $D_{t1}$ and $D_{t2}$ are moisture content at time $t_1$ and $t_2$ in kg water/kg of dry matter and t (min) is the drying time.

#### 2.5.3. Rehydration ratio

The rehydration ability of dried samples was evaluated by following the method given by Zhou et al. (2020) with a slight modification. About 5 g of dried chips were immersed in a beaker containing 250 ml of distilled water for a period of 3 h. Then the samples were drained, blotted with tissue paper, and weighed. The rehydration ratio (RR) was calculated as follows:

$$\text{Rehydration Ratio} = \frac{W_r}{W_d} \tag{5}$$

Where $W_r$ is the drained weight (g) of the rehydrated sample, $W_d$ is the weight (g) of the dry sample used for rehydration.

#### 2.5.4. Sensory evaluation

The sensory attributes of developed osmo-dried coconut chips were evaluated by an untrained panel formed by 30 panellists to assess the consumer acceptability. A specially designed sensory score sheet comprises 4 sensory attributes namely taste (TA), appearance (AP), crispness (CR), and overall acceptability (OA) was distributed to each judge. The definition of each sensory attribute was described to the panellists before starting the evaluation. In which crispness was instructed to score by evaluating altogether amount and quality of the sound produced, deformability and brittleness of the product during mastication (Salvador et al., 2009). Samples were distributed randomly by keeping in separate plastic plates, which were given with three-digit numbers for further identification. Panellists were instructed to clean their mouths by drinking water before proceeding to the next sample. A structured 9 point hedonic scale (1 = dislike extremely, 5 = neither like nor dislike, 9 = like extremely) was used to numerically describe the sensory attributes of the samples (Mishra Pandey & Mishra, 2015). The average score for each attribute was used as response input in the RSM.

### 2.6. Model optimization and validation

Optimization of independent variables was performed by multi-criteria methodology with the analysis of Derringer function or desirability function (Bezerra et al., 2008). In this technique, the individual desirability function will generate for each response by transforming the responses into a dimensionless desirability scale ($d_i$) ranging from 0 (completely undesirable) to 1(fully desirable). Desirability index calculation steps involve the setting of goal for each response like

**Table 1**
Outline of the experimental design matrix and observed values of response variables.

| Independent variables | | | Responses | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Temperature (°C) | Thickness (mm) | Concentration (° Brix) | FMC | DR | RR | TA | AP | CR | OA |
| 60 | 0.75 | 50 | 2.83 | 0.008784 | 1.52 | 7.60 | 7.40 | 6.8 | 7.50 |
| 60 | 0.5 | 55 | 2.36 | 0.006259 | 1.54 | 8.28 | 7.85 | 8.52 | 8.11 |
| 50 | 0.5 | 50 | 3.02 | 0.006874 | 1.53 | 8.33 | 8.10 | 7.51 | 8.03 |
| 60 | 0.75 | 50 | 2.70 | 0.009524 | 1.52 | 7.40 | 7.60 | 6.62 | 7.40 |
| 70 | 0.50 | 50 | 1.69 | 0.011770 | 1.49 | 8.22 | 7.77 | 8.22 | 8.57 |
| 60 | 0.75 | 50 | 2.90 | 0.008588 | 1.52 | 7.35 | 7.71 | 6.42 | 7.01 |
| 60 | 1.00 | 45 | 2.60 | 0.005847 | 1.57 | 5.42 | 7.03 | 4.71 | 5.50 |
| 60 | 0.75 | 50 | 2.89 | 0.008648 | 1.53 | 7.31 | 7.72 | 6.6 | 7.50 |
| 50 | 0.75 | 55 | 2.90 | 0.005220 | 1.49 | 7.35 | 7.71 | 7.02 | 7.20 |
| 60 | 1.00 | 55 | 3.67 | 0.001040 | 1.51 | 7.35 | 7.14 | 5.42 | 5.20 |
| 60 | 0.75 | 50 | 2.81 | 0.008901 | 1.51 | 7.42 | 7..81 | 7.21 | 7.30 |
| 70 | 0.75 | 45 | 1.71 | 0.010480 | 1.54 | 7.77 | 7.44 | 7.88 | 8.04 |
| 50 | 1.00 | 50 | 3.50 | 0.003454 | 1.43 | 5.42 | 7.02 | 5.14 | 5.58 |
| 60 | 0.50 | 45 | 2.04 | 0.006259 | 1.59 | 8.71 | 8.00 | 8.57 | 8.42 |
| 70 | 1.00 | 50 | 2.90 | 0.008940 | 1.49 | 6.22 | 7.55 | 5.55 | 6.05 |
| 70 | 0.75 | 55 | 2.01 | 0.006054 | 1.56 | 8.00 | 8.05 | 8.44 | 8.01 |
| 50 | 0.75 | 45 | 3.00 | 0.006367 | 1.56 | 7.85 | 8.10 | 7.14 | 7.64 |

FMC, Final moisture content (% wb); DR, Drying rate (kg water/kg dry matter $min^{-1}$); RR, Rehydration ratio; TA, Taste; CR, Crispness; AP, Appearance; OA, Overall acceptability.

maximizing the parameters DR, RR, TA, AP, CR and OA and minimize FMC by keeping independent variables in range by assigning the highest importance to all the responses. Then, the program will evaluate the overall desirability value from the geometric mean of individual desirability values. Values of independent variables at maximum desirability were selected as the optimized condition. Further validation of the optimization was performed by comparing predicted and experimental value. The deviation between these two can be assessed by calculating absolute error by using Eq. (6)

$$Absolute\ error\ (\%) = \left| \frac{Experimental\ value - Predicted\ value}{Predicted\ value} \right| \times 100 \tag{6}$$

### 2.7. Characterization and comparison of optimized sample with refined sugar osmosed sample

The optimized sample processed at 0.60 mm ST, 46 °Brix SC, and 66 °C DT was characterized in terms of proximate, mineral composition, water loss, solid gain, texture and colour and which was then compared with refined sugar osmosed sample prepared at the same condition.

#### 2.7.1. Proximate, mineral and water activity analysis

Proximate analysis was carried out as follows: crude protein (N × 6.25) was determined by the micro-Kjeldahl method (AOAC, 2000). Fat, moisture and ash contents were determined using standard AOAC, 2012 methods 991.36, 953.07 and 923.03 respectively. The phenol-sulphuric acid calorimetric assay method was followed for the determination of total carbohydrate by using glucose as the standard solution (DuBois et al., 1956). Mineral contents such as iron (Fe), copper (Cu), zinc (Zn) and manganese (Mn) were estimated using iCE 3000 series Atomic Absorption Spectrophotometer (Thermo Fisher Scientific, Hemel Hempstead, Hertfordshire, UK). The adjustment in cathode lamp suitable for each element and background correction using deuterium lamp during the measurements were done with the help of in-built software. Determination of potassium (K) and sodium (Na) content was carried out by flame photometer (Elico Flame Photometer CL 378). Water activity was detemined with a LabMaster AW NEO (Novasina®, Lachen, Germany) instrument.

#### 2.7.2. Water loss and solid gain

The water loss (WL) and solid gain (SG) in osmotically treated coconut slices in jaggery and refined sugar was calculated by the following equations (Shi et al., 1995):

$$WL = \frac{M_0 X_{w0} - M_t X_{wt}}{M_0} \tag{7}$$

$$SG = \frac{M_t X_{st} - M_{t0} X_{so}}{M_0} \tag{8}$$

Where $M_0$ and $M_t$ are the initial and final sample mass (g), respectively; $X_{w0}$ and $X_{wt}$ are the initial and final sample moisture content (g water/100 g), respectively; and $X_{s0}$ and $X_{st}$ are the initial and final sample total soluble solids content (g solid/100 g), respectively. All experiments were conducted in triplicate, and the average values were reported.

#### 2.7.3. Texture analysis

The fracturability (g) of the optimized chips samples was determined by using TA.XT Plus Texture Analyser (Stable Micro Systems, UK) equipped with a Crisp Fracture Rig (HDP/CFS) and a 25 kg load cell for comparing and evaluating the crispness with sugar osmosed coconut chips. In which randomly selected sample placed centrally on the sample holder penetrated with a 6.325 mm ball probe (pre-load speed 2.00 mm/s, test speed 1.00 mm/s, post-load speed 5.00 mm/s, and distance 5.0 mm) as per the method described by Maetens et al. (2017). The force required to break the sample was recorded as fracturability. Test results were obtained from 6 replicate samples.

#### 2.7.4. Colour analysis

The colour measurement of chips was carried by using a colorimeter (Model: LabScan XE HunterLab), which gives CIELab values (L* = 0 to 100, a = red-green, b = yellow-blue). The chroma (C*) and hue angle (h°) values were calculated using Eqs. (9) and (10).

$$C^* = \sqrt{a^{*2} + b^{*2}} \tag{9}$$

$$h^0 = \tan^{-1}(b^* / a^*) \tag{10}$$

### 2.8. Statistical analysis

All experiments for optimization were done in duplicate, and average values were used in RSM. Other data analysis was done by SAS (SAS 9.3, USA), and expressed as mean value ± standard deviation (n = 3 for proximate and mineral composition, water activity, solid gain and water loss, n = 5 for colour, n = 6 for texture). The confidence level for statistical significance was set at a probability value of 0.05.

## 3. Results and discussion

The response variables of jaggery infused coconut chips for different processing condition as per the experimental design given by RSM are shown in Table .1. The significant terms of the response variable were determined by ANOVA and given in Table .2. An insight into ANOVA summary statistics revealed that the fitted model corresponding to each response was statistically significant with no significant lack of fit and high $R^2$ value.

### 3.1. Effect of factors on the final moisture content of coconut chips

Moisture content is an important parameter for any food product that will determine its storage stability. The FMC values for coconut chips developed at different processing condition were ranging from 1.69 to 3.67% (wb). A Second-order polynomial regression equation was fitted to explain the relationship between FMC and independent variables, and this equation could be able to describe at least 95% of total variations. It was observed that FMC was significantly influenced by variation in ST and DT ($p < 0.01$), while the levels of SC found to be influential as well ($p < 0.05$), but less dramatically than the other two independent variables. From Table .3, levels of ST and SC were in positive correlation with FMC in both linear and interaction terms. Conversely, temperature exhibited a negative relationship with FMC.

The increasing trend of FMC with ST could be due to the case hardening effect that occurred during the drying process which is usually predominant in thicker sliced samples. This ultimately causes a hindrance to water removal and results in higher FMC (Kingcam et al., 2008). Similarly, hypertonic solution immersed samples resulted in a product with higher FMC than those osmosed at a lower concentration at a constant level of ST and DT (2.01% and 1.71% respectively at DT: 70 °C and ST: 0.75 mm). This effect could be because of the formation of an impervious layer by the deposition of jaggery solutes on the slice surface, which eventually causes a restriction in water removal during the drying process (Kaur et al., 2020). Similar behaviour also observed by other researchers like Ramolla and Mascheroni (2005) in pineapple and Bchir et al. (2009) in pomegranate. However, from Fig. 1.a, high temperature processed samples resulted in a low FMC product. This diminishing nature of FMC with DT could due to the activation of the water molecule to the higher energy level at elevated temperature condition which makes them break away from their sorption sites. In addition to that higher temperature accelerates moisture migration in heat-sensitive biomaterials by creating a larger heat transfer gradient (Marey & Shoughy, 2016).

**Table 2**
ANOVA of the second order polynomial models of the various responses.

| ANOVA | FMC | DR | RR | TA | AP | CR | OA |
|---|---|---|---|---|---|---|---|
| **Mean** | 2.66 | 0.00731 | 1.52 | 7.42 | 7.61 | 6.93 | 7.24 |
| **SD** | 0.20 | 0.00092 | 0.011 | 0.31 | 0.16 | 0.38 | 0.19 |
| **PRESS** | 3.07 | 0.000062 | 0.011 | 7.33 | 1.46 | 10.30 | 1.05 |
| **$R^2$** | 0.9574 | 0.9593 | 0.9703 | 0.9652 | 0.9232 | 0.9697 | 0.9882 |
| **Adj- $R^2$** | 0.8807 | 0.8860 | 0.9167 | 0.9024 | 0.7850 | 0.9150 | 0.9670 |
| **Adeq precision** | 11.733 | 13.462 | 16.724 | 13.707 | 8.375 | 12.500 | 19.906 |
| **Model F value** | 12.48 | 13.09 | 18.12 | 15.39 | 6.68 | 17.75 | 46.58 |
| **P value** | 0.0063 | 0.0056 | 0.0026 | 0.0039 | 0.025 | 0.0028 | 0.0003 |
| **Lack of fit** | 0.1438 | 0.1650 | 0.0015 | 0.1056 | 0.5060 | 0.0014 | 0.8776 |
| **CV %** | 7.71 | 13.2 | 0.75 | 4.21 | 2.16 | 5.42 | 2.66 |

FMC, Final moisture content (% wb); DR, Drying rate (kg water/kg dry matter $min^{-1}$); RR, Rehydration ratio; TA, Taste; CR, Crispness; AP, Appearance; OA, Overall acceptability.

**Table 3**
Regression coefficients of the quadratic polynomial for osmo-convective dehydration of jaggery treated coconut slices during optimization.

| Coefficients | FMC | DR | RR | TA | AP | CR | OA |
|---|---|---|---|---|---|---|---|
| $B_O$ | 2.81** | 0.00896** | 1.52** | 7.45** | 7.57* | 6.61** | 7.3** |
| $B_1$ | −0.51** | 0.00191** | 0.010* | 0.16 $^{NS}$ | 0.00575 $^{NS}$ | 0.41* | 0.28** |
| $B_2$ | 0.45** | −0.0015** | −0.018** | −1.14** | −0.37** | −1.50** | −1.29** |
| $B_3$ | 0.20* | −0.00129* | −0.020** | 0.15 $^{NS}$ | 0.033 $^{NS}$ | 0.14$^{NS}$ | −0.056$^{NS}$ |
| $B_{12}$ | 0.18$^{NS}$ | 0.00014 $^{NS}$ | 0.027** | 0.23 $^{NS}$ | 0.20 $^{NS}$ | −0.078 $^{NS}$ | −0.022$^{NS}$ |
| $B_{13}$ | 0.100$^{NS}$ | −0.00082 $^{NS}$ | 0.024** | 0.18 $^{NS}$ | 0.21* | 0.17 $^{NS}$ | 0.11 $^{NS}$ |
| $B_{23}$ | 0.19* | −0.0012* | −0.00325 $^{NS}$ | 0.59* | 0.072 $^{NS}$ | 0.18 $^{NS}$ | 0.15 $^{NS}$ |
| $B_1^2$ | −0.15$^{NS}$ | 0.000486 $^{NS}$ | −0.025** | −0.050 $^{NS}$ | 0.15 $^{NS}$ | 0.39 $^{NS}$ | 0.27* |
| $B_2^2$ | 0.11* | −0.000169* | −0.00082 $^{NS}$ | −0.35 $^{NS}$ | −0.14 $^{NS}$ | −0.40 $^{NS}$ | −0.52** |
| $B_3^2$ | −0.26** | −0.00024** | 0.042** | 0.34 $^{NS}$ | 0.067 $^{NS}$ | 0.61* | 0.14 $^{NS}$ |

Note:** significant at 1%, *significant at 5%, $^{NS}$ not significant,1,2,3 are temperature, slice thickness, concentration.
FMC, Final moisture content (% wb); DR, Drying rate (kg water/kg dry matter min-1); RR, Rehydration ratio; TA, Taste; CR, Crispness; AP, Appearance; OA, Overall acceptability.

### 3.2. Effect of factors on drying rate

The DR is the term that quantifies the amount of moisture removed per unit time per unit weight of dry matter. In the present study, based on processing condition, DR value is varying from 0.0010 to 0.0117 kg water/kg dry matter $min^{-1}$. All three linear terms, interaction and quadratic terms of SC and ST showed a significant ($p < 0.01$) influence in the model prediction of DR ($R^2 = 0.959$). Among these significant model terms, only the linear term corresponds to DT exhibited a positive effect on DR.

From the RSM plot (Fig. 1b), DR is dropping with the increase of ST. This could be because moisture present in the thicker slices needs to travel more distance during drying. Moreover, the exposed surface area for a given volume of product is less in thicker sliced samples; this consequently makes the DR lower (Doymaz & Özdemir, 2014; Sadin et al., 2014). The effect of SC on DR also follows the same trend as that of ST. This detrimental effect of SC on DR can be illustrated by the binding effect of the osmotic agent that has diffused into the kernel during osmosis, creating water removal to be more difficult during drying (Tan et al., 2001). Unlike ST and SC, DT positively correlates with DR. This is more likely because the increased moisture diffusion occurs at the higher temperature of drying (Marey & Shoughy, 2016).

### 3.3. Effect of factors on rehydration capacity of coconut chips

Rehydration capacity is the most important quality deciding factor for dried food products. The extent of physical changes occurring in a product due to pre-treatment and processing condition has a dominant influence on its value. In the present study, it could be seen (Table .3) that all model terms of RR were significant except ST × SC interaction term and ST quadratic term. Among linear terms, ST and SC model terms were more significant ($p < 0.001$) and correlate negatively with RR. However, interaction factors were positive suggesting that the increase of ST and SC in combination with higher temperature had a beneficial effect on RR. Additionally, a positive coefficient term of DT shows this RR can also be improved by increasing DT.

Variation in RR with ST is pictorially represented in Fig. 1.c. Lower thickness was desirable to achieve a higher RR value than thicker sliced samples. This is because, during the drying process, the thicker slices were exposed to drying air for a longer duration. This effectively causes the increased cell rupture which ultimately leads to lower RR values (Mewa et al., 2018). Likewise, SC also imparts a negative effect on RR. The reason for this negative effect might be attributed to the blockage of the porous structure by solute at a higher concentration level (Md. Shafiq Alam et al., 2010). In addition, hypertonic solution immersion can interrupt the cellular structure in biomaterial due to the development of osmotic stress, which further results in the lowering of RR (Rastogi et al., 2004). At the same time, the increase of DT resulted in a product with high RR. This result was probably because of the tissue collapse and cell damage effect caused by high temperature drying, which enhances water retention of the product by occupying water molecules in the spaces created by damaged cell (Srikanth et al., 2019; Vega-Gálvez et al., 2008). Similar result was also obtained for Aral and Beşe (2016), in which they have reported that the RR of samples dried at 70 °C was higher than those dried at 50 °C. According to them, this positive correlation of DT with RR is attributed to the creation of porous structure in high temperature dried products, which allows higher water migration into the product.

### 3.4. Effect of factors on sensory attributes of coconut chips

The sensory attributes for osmo-convective dehydrated coconut slices were evaluated based on TA, AP, CR and OA. Second-order regression equations were developed for all four sensory attributes to explain the relationship between the response and independent variables. An insight into the ANOVA summary statistics reveals the TA was significantly influenced ($P < 0.0001$) by the variation in thickness only (Fig. 1d). This thickness induced variation in TA was mainly occurred by

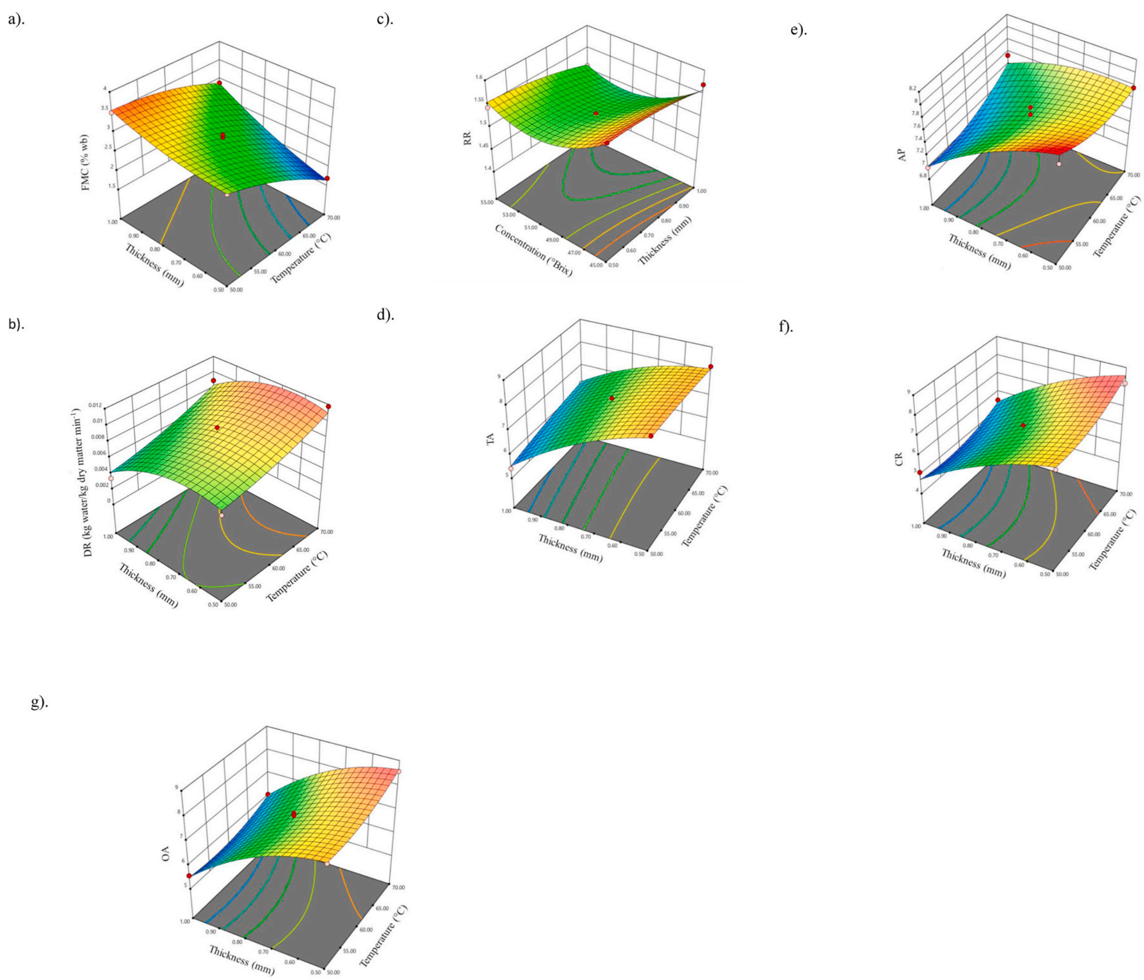


**Fig. 1.** Effect of independent variables on responses (a) Final moisture content (FMC). (b) Drying rate (DR). (c) Rehydration ratio (RR). (d) Taste (TA). (e) Appearance (AP). (f) Crispness (CR). g) Overall acceptability (OA).

the undesirable leathery nature of thickly sliced chips samples. The sensory score of AP also followed a similar trend with thickness as the only deciding factor (Fig. 1e). The chips prepared from thinly sliced kernels were more resembling traditional coconut chips. So, they received a higher AP sensory score.

CR is an essential sensory attribute for dried snacks. The model fitted for the response CR was observed as linear with insignificant quadratic and interaction terms. In which, the ST exhibited a strong negative correlation ($p < 0.0001$) with CR. The linear term for DT also observed as a significant model term, which influences CR positively but one order lower than ST (Fig. 1f). Other responses such as FMC, DR and RR exhibited close relation with CR. Those products with low FMC and high DR and RR resulted in a product with more crispness. These findings were in line with other reported investigations (Ando et al., 2019; Mazumder et al., 2007)

Based on the processing parameters, OA ranged from 5.20 to 8.42 (Table .1). From the ANOVA summary statistics, the fitted model for OA was significant and which can explain 98.82% of the total variations. Moreover, a small difference between $R^2$ and adjusted $R^2$ implied the model does not include any unnecessary terms (Bajić et al., 2020). Table .3 shows that linear and quadratic terms of ST and DT were exhibiting a significant role in the response OA. Conversely, the model coefficient term of SC was insignificant for OA.

From Fig. 1.g, it was observed that OA increased with a decrease of ST. This desirable characteristic of thinly sliced samples was most likely because of the unique crispness of the product experienced by the panellist during mastication. Likewise, high temperature processed samples also got high OA score. This positive influence of DT on OA was due to the excellent texture of those high temperature dried samples. Appearance-wise all the samples got a similar score; hence mainly texture was the deciding factor for the variation of OA for different processing condition.

### *3.5. Optimization and validation*

Optimization of processing parameter for jaggery assisted osmo-dehydration process of coconut slices was done by the numerical optimization method. An insight into the experimental results implied that the selected independent variables were equally competitive. So the process of simultaneous optimization of these three mutually important variables is not an easy task to perform, since it involves a compromise between different attributes of the final product. By considering the nature of the end product here the optimization was done to minimize FMC and maximize DR, RR, TA, AP, CR and OA. Based on these criteria optimized condition within the constraints of the model was obtained by using Derringer's desirability function. During this optimization process, 50 solutions were obtained and among which, a combination of independent variables with the highest desirability of 0.93 was selected. This highest desirability value was attained at ST- 0.55 mm, SC- 46.18 °Brix and DT- 66.22 °C. The selected model was further validated by conducting the experiment in that particular condition and comparing the results with the predicted value. For operational convenience, SC and DT were rounded off to the next whole number (46 °Brix and 66 °C) and ST value kept at 0.6 mm. From Table .4, residual error ranged from 0.56 to

**Table 4**
Predicted and experimental values of responses at optimum conditions for jaggery based coconut chips.

| Process parameters | Goal | Experimental range | | Optimum condition | Actual value ± SD | Error (%) |
|---|---|---|---|---|---|---|
| FMC | Minimize | 1.69 | 3.67 | 2.03 | 2.16 ± 0.14 | 6.40 |
| DR | Maximize | 0.00104 | 0.01177 | 0.00716 | 0.00720 ± 0.00014 | 0.56 |
| RR | Maximize | 1.43 | 1.59 | 1.55 | 1.53 ± 0.022 | 1.29 |
| TA | Maximize | 5.42 | 8.71 | 8.71 | 8.42 | 4.01 |
| AP | Maximize | 7 | 8 | 7.704 | 7.53 | 2.25 |
| CR | Maximize | 4.714 | 8.571 | 8.572 | 8.20 | 4.33 |
| OA | Maximize | 5.20 | 8.571 | 8.24 | 8.13 | 1.33 |

FMC, Final moisture content (% wb); DR, Drying rate (kg water/kg dry matter $min^{-1}$); RR, Rehydration ratio; CR, Crispness; AP, Appearance; TA, Taste; OA, Overall acceptability.

6.4% indicated the model was adequate for the prediction.

### 3.6. Characterization and comparison of optimized chips with refined sugar osmosed chips

#### 3.6.1. Proximate analysis, mineral composition and water activity

Proximate and mineral composition of jaggery osmosed and refined sugar osmosed coconut chips were given in Table .5. For both samples, a considerable increase in carbohydrate content was observed as compared to dry kernel carbohydrate value (carbohydrate- 22.4%) reported in the literature (Appaiah et al., 2014). This elevated level of carbohydrate was mainly contributed by the osmotic dehydration process. Although both osmo-dehydrated chips were similar in proximate composition, a remarkable difference was observed in the mineral contents. Jaggery based samples were having nearly two-fold higher Fe, Zn and Na values and six-fold higher K values than refined sugar-based chips. This was mainly due to the presence of higher mineral content in jaggery as compared with refined sugar (Jaffé, 2015; Lee et al., 2018). Hence the substitution of jaggery with traditional refined sugar treatment was strongly justified by this mineral enrichment of the final product. Low water activity levels, 0.39 and 0.36 respectively for jaggery based chips and refined sugar-based chips, ensured the safety for product from the microbial contamination (Hnin et al., 2019).

#### 3.6.2. Water loss and solid gain

From Table .5, it can be seen that refined sugar solution acting as a strong osmotic agent than jaggery solution, because the former solution causes more water loss (WL) in coconut kernels during osmotic dehydration. This lower osmotic dehydration ability of jaggery could be explained with the viscosity difference of these two. It was reported that jaggery juice is more viscous than refined sugar syrup by the presence of large number of dissolved solids (Alarcón et al., 2020). This increased viscosity can lower the osmotic dehydration ability of osmotic agents (El-Aouar et al., 2006). Besides that, the presences of large number of solutes in jaggery solution also make solid gain (SG) of jaggery assisted osmotic dehydration higher than the other.

#### 3.6.3. Texture analysis

Crispness or hardness of any product can be measured instrumentally by determining the force needed to crack the sample, termed fracturability. For snack foods like chips, higher crispness is desirable for better consumer acceptance (Kayacier & Singh, 2003; Meullenet et al., 2002). Lower fracturability values, indicating a lower hardness, were preferable for low moisture snacks. The fracturability value of optimized jaggery osmosed coconut chips and sugar osmosed coconut chips were given in Table .5. From the statistical analysis, the fracturability of jaggery osmosed chips and sugar osmosed chips were significantly different. This could be because the fracturability value for any product is influenced by water activity and moisture content of that product (Maetens et al., 2017). In this study, sugar osmosed samples exhibited low moisture content and water activity values, thus resulted in lower fracturability. Although fracturability value of the jaggery infused chips were relatively inferior to sugar osmosed chips, the values were superior to many other snack foods such as germinated soybean snack chip (Maetens et al., 2017) and corn chips made by continuous vacuum drying and deep-fat frying (Xu & Kerr, 2012).

#### 3.6.4. Colour

The colour attributes (L*, a*, b*, C*, and h°) of the jaggery infused coconut chips and the sugar osmosed coconut chips were given in Table 5. It was observed that the use of jaggery significantly affected the colour values. The jaggery infused coconut chips were characterized by

**Table 5**
Characterization and comparison of optimized jaggery infused chips with traditional coconut chips.

| | Properties | Jaggery chips | Sugar osmosed chips |
|---|---|---|---|
| **Proximate composition (g/100 g of dry chips)** | Moisture content | 2.16 ± 0.12 $^{NS}$ | 1.91 ± 0.08 $^{NS}$ |
| | Carbohydrate | 29.83 ± 0.33 $^{NS}$ | 28.25 ± 0.77 $^{NS}$ |
| | Fat | 32.79 ± 2.11$^{NS}$ | 35.83 ± 1.56 $^{NS}$ |
| | Protein | 6.17 ± 0.20 $^{NS}$ | 6.93 ± 0.36 $^{NS}$ |
| | Ash | 1.21 ± 0.03 $^{NS}$ | 0.85 ± 0.08$^{NS}$ |
| **Mineral (mg/100 g of dry chips)** | Fe | 5.141 ± 0.3$^{a}$ | 2.46 ± 0.17$^{b}$ |
| | Zn | 3.51 ± 0.06$^{a}$ | 1.88 ± 0.11$^{b}$ |
| | Mn | 3.85 ± 0.13$^{a}$ | 3.19 ± 0.21$^{b}$ |
| | Cu | 0.92 ± 0.0$^{b}$ | 0.98 ± 0.01$^{a}$ |
| | Na | 418.67 ± 0$^{b}$ | 212.88 ± 1.06$^{c}$ |
| | K | 291.80 ± 0$^{b}$ | 45.13 ± 0$^{c}$ |
| **Osmotic dehydration parameters** | Water loss (g water/100 g) | 23.24 ± 0.47$^{b}$ | 26.71 ± 0.63$^{a}$ |
| | Solid gain (g solid/100 g) | 23.27 ± 0.76$^{a}$ | 20.24 ± 0.54$^{b}$ |
| **Colour** | L* | 61.93 ± 1.2$^{b}$ | 78.40 ± 2.42$^{a}$ |
| | a* | −7.15 ± 0.87$^{b}$ | −2.70 ± 0.41$^{a}$ |
| | b* | 46.71 ± 0.92$^{a}$ | 5.79 ± 0.14$^{b}$ |
| | Chroma | 58.53 ± 0.88$^{a}$ | 20.07 ± 0.76$^{b}$ |
| | Hue angle | −81.3 ± 0.48$^{b}$ | 20.07 ± 0.81$^{a}$ |
| **Texture** | Fracturability (N) | 10.81 ± 0.22$^{a}$ | 7.56 ± 0.17$^{b}$ |

*Any two means in the same raw followed by the different letter are significantly ($P < 0.05$) different according to Tukey's test.

lower L* value and higher a*, b*, C* and h° values. This difference in colour value could be attributed to the retention of jaggery colour pigments from the osmotic solution. The chromaticity value of the optimized chips was similar to the values reported for the pure jaggery (Solís-Fuentes et al. (2019).

## 4. Conclusions

Response surface methodology was found successful for process optimization of parameters used for converting coconut into healthy value-added product, jaggery based coconut chips, by the amalgamation of osmotic dehydration with convective drying. The experimental findings reveal that, among the tested independent variables, the level of DT and ST were most influential in drying characteristics as well as sensory attributes, while the level of SC found to be less significant for sensory attributes. Comparison between the developed product and traditional coconut chips revealed that, jaggery was an excellent alternative for non-nutritive osmotic agent to yield a mineral rich snack food with comparable textural property. The data generated in the present study would be helpful for researchers and entrepreneurs interested to work in the value addition and development of new food products. Moreover, the use of jaggery as an osmotic agent in food product development is not much exploited by researchers. Hence, further research needs to be carried out for using jaggery in various fruit processing for enhancing the health benefits of the end product.

## CRediT authorship contribution statement

**M. Pravitha:** Performed experiments, Conceptualization, Writing – original draft, review & editing. **M.R. Manikantan:** Conceptualization, Methodology, Validation, Resources, Writing – original draft, review & editing, Supervision, Project administration, Funding acquisition. **V. Ajesh Kumar:** Writing – original draft, review & editing, Conceptualization, Methodology, Validation. **Shameena Beegum:** Assisted in experiments, Conceptualization, Validation, Writing – original draft. **R. Pandiselvam:** Writing – original draft, review & editing, Validation.

## Declaration of competing interest

The following authors have declared that there is no conflict of interest in publishing manuscript entitled "***Optimization of process parameters for the production of jaggery infused osmo-dehydrated coconut chips***".

## Acknowledgment

The authors wish to acknowledge Dr.Hebbar K. B and Dr.Selvamani V for providing laboratory facilities at ICAR-CPCRI. The authors also wish to acknowledge AICRP on PHET for extending their research facilities. Authors are grateful to Indian Council of Agricultural Research for providing other facilities under "Professional Attachment Training" program.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.lwt.2021.111441.

## References

Alam, M. S., Amarjit, S., & Sawhney, B. K. (2010). Response surface optimization of osmotic dehydration process for aonla slices. *Journal of Food Science & Technology, 47*(1), 47–54. https://doi.org/10.1007/s13197-010-0014-4

Alam, M. S., Kaur, M., & Ramya, H. G. (2019). Efficacy of osmo-convective process parameters for kinnow fruit slices and its optimization using response surface methodology. *Proceedings of the National Academy of Sciences, India - Section B: Biological Sciences, 89*(2), 605–614.

Alarcón, Á. L., Orjuela, A., Narváez, P. C., & Camacho, E. C. (2020). Thermal and rheological properties of juices and syrups during non-centrifugal Sugar Cane (jaggery) production. *Food and Bioproducts Processing, 121*, 76–90. https://doi.org/10.1016/j.fbp.2020.01.016

Ando, Y., Hagiwara, S., Nabetani, H., Sotome, I., Okunishi, T., Okadome, H., Orikasa, T., & Tagawa, A. (2019). Effects of prefreezing on the drying characteristics, structural formation and mechanical properties of microwave-vacuum dried apple. *Journal of Food Engineering, 244*, 170–177. https://doi.org/10.1016/j.jfoodeng.2018.09.026

AOAC. (1975). *Official methods of analysis* (12th ed.) Washington: DC.

AOAC. (2000). *Official methods of analysis* (17th ed.). Gaithersburg, ML, USA: AOAC International.

AOAC. (2012). *Official methods of analysis of AOAC International* (19th ed.). Gaithersburg, MD: Association of Official Analytical Chemists.

Appaiah, P., Sunil, L., Kumar, P. K. P., & Krishna, A. G. G. (2014). Composition of coconut testa, coconut kernel and its oil. *Journal of the American Oil Chemists' Society, 91*(6), 917–924. https://doi.org/10.1007/s11746-014-2447-9

Aral, S., & Beşe, A. V. (2016). Convective drying of hawthorn fruit (Crataegus spp.): Effect of experimental parameters on drying kinetics, color, shrinkage, and rehydration capacity. *Food Chemistry, 210*, 577–584. https://doi.org/10.1016/j.foodchem.2016.04.128

Bajić, M., Oberlintner, A., Kõrge, K., Likozar, B., & Novak, U. (2020). Formulation of active food packaging by design: Linking composition of the film-forming solution to properties of the chitosan-based film by response surface methodology (RSM) modelling. *International Journal of Biological Macromolecules, 160*, 971–978. https://doi.org/10.1016/j.ijbiomac.2020.05.186

Bchir, B., Besbes, S., Attia, H., & Blecker, C. (2009). Osmotic dehydration of pomegranate seeds: Mass transfer kinetics and differential scanning calorimetry characterization. *International Journal of Food Science and Technology, 44*(11), 2208–2217. https://doi.org/10.1111/j.1365-2621.2009.02061.x

Bezerra, M. A., Santelli, R. E., Oliveira, E. P., Villar, L. S., & Escaleira, L. A. (2008). Response surface methodology (RSM) as a tool for optimization in analytical chemistry. *Talanta, 76*(5), 965–977. https://doi.org/10.1016/j.talanta.2008.05.019

Chandra, A., Kumar, S., Tarafdar, A., & Nema, P. (2020). Ultrasonic and osmotic pretreatments followed by convective and vacuum drying of papaya slices. *Journal of the Science of Food and Agriculture*. https://doi.org/10.1002/jsfa.10847

Doymaz, İ., & Özdemir, Ö. (2014). Effect of air temperature, slice thickness and pretreatment on drying and rehydration of tomato. *International Journal of Food Science and Technology, 49*(2), 558–564. https://doi.org/10.1111/ijfs.12337

DuBois, M., Gilles, K. A., Hamilton, J. K., Rebers, P. A., & Smith, F. (1956). Colorimetric method for determination of sugars and related substances. *Analytical Chemistry, 28*(3), 350–356. https://doi.org/10.1021/ac60111a017

El-Aouar, Â. A., Azoubel, P. M., Barbosa, J. L., & Xidieh Murr, F. E. (2006). Influence of the osmotic agent on the osmotic dehydration of papaya (Carica papaya L.). *Journal of Food Engineering, 75*(2), 267–274. https://doi.org/10.1016/j.jfoodeng.2005.04.016

Elfnesh, F., Tekalign, T., & Solomon, W. (2011). Processing quality of improved potato (Solanum tuberosum L.) cultivars as influenced by growing environment and blanching. *African Journal of Food Science, 5*(6), 324–332.

FAO. (2019). Available: http://www.fao.org/faostat/en/#data/QC/visualize [22 March 2021].

Garcia-Noguera, J., Oliveira, F. I. P., Gallão, M. I., Weller, C. L., Rodrigues, S., & Fernandes, F. A. N. (2010). Ultrasound-assisted osmotic dehydration of strawberries: Effect of pretreatment time and ultrasonic frequency. *Drying Technology, 28*(2), 294–303. https://doi.org/10.1080/07373930903530402

Guo, Y., Wu, B., Guo, X., Ding, F., Pan, Z., & Ma, H. (2020). Effects of power ultrasound enhancement on infrared drying of carrot slices: Moisture migration and quality characterizations. *LWT, 126*, 109312. https://doi.org/10.1016/j.lwt.2020.109312

Hebbar, K. B., Arivalagan, M., Pavithra, K. C., Roy, T. K., Gopal, M., Shivashankara, K. S., & Chowdappa, P. (2020). Nutritional profiling of coconut (Cocos nucifera L.) inflorescence sap collected using novel coco-sap chiller method and its value added products. *Journal of Food Measurement and Characterization, 14*(5), 2703–2712. https://doi.org/10.1007/s11694-020-00516-y

Hnin, K. K., Zhang, M., Li, Z., & Wang, B. (2019). Comparison of quality aspects and energy consumption of restructured taro and potato chips under three drying methods. *Journal of Food Process Engineering, 42*(7), e13249. https://doi.org/10.1111/jfpe.13249

Jaffé, W. R. (2015). Nutritional and functional components of non centrifugal cane sugar: A compilation of the data from the analytical literature. *Journal of Food Composition and Analysis, 43*, 194–202. https://doi.org/10.1016/j.jfca.2015.06.007

Kadam, U. S., Ghosh, S. B., De, S., Suprasanna, P., Devasagayam, T. P. A., & Bapat, V. A. (2008). Antioxidant activity in sugarcane juice and its protective role against radiation induced DNA damage. *Food Chemistry, 106*(3), 1154–1160. https://doi.org/10.1016/j.foodchem.2007.07.066

Kaur, P., Zalpouri, R., Singh, M., & Verma, S. (2020). Process optimization for dehydration of shelled peas by osmosis and three-stage convective drying for enhanced quality. *Journal of Food Processing and Preservation, 44*(12), Article e14983. https://doi.org/10.1111/jfpp.14983

Kayacier, A., & Singh, R. K. (2003). Textural properties of baked tortilla chips. *Lebensmittel-Wissenschaft und -Technologie- Food Science and Technology, 36*(5), 463–466. https://doi.org/10.1016/S0023-6438(02)00222-0

Khubber, S., Chaturvedi, K., Taghi Gharibzahedi, S. M., Cruz, R. M. S., Lorenzo, J. M., Gehlot, R., & Barba, F. J. (2020). Non-conventional osmotic solutes (honey and glycerol) improve mass transfer and extend shelf life of hot-air dried red carrots: Kinetics, quality, bioactivity, microstructure, and storage stability. *LWT, 131*, 109764. https://doi.org/10.1016/j.lwt.2020.109764

Kingcam, R., Devahastin, S., & Chiewchan, N. (2008). Effect of starch retrogradation on texture of potato chips produced by low-pressure superheated steam drying. *Journal of Food Engineering, 89*(1), 72–79. https://doi.org/10.1016/j.jfoodeng.2008.04.008

Lee, J. S., Ramalingam, S., Jo, I. G., Kwon, Y. S., Bahuguna, A., Oh, Y. S., Kwon, O.-J., & Kim, M. (2018). Comparative study of the physicochemical, nutritional, and antioxidant properties of some commercial refined and non-centrifugal sugars. *Food Research International, 109*, 614–625. https://doi.org/10.1016/j.foodres.2018.04.047

Madamba, P. S. (2003). Thin layer drying models for osmotically pre-dried young coconut. *Drying Technology, 21*(9), 1759–1780. https://doi.org/10.1081/DRT-120025507

Madhavan, K., Arumuganathan, T., & Mathew, A. C. (2010). *Commercial production of coconut chips* (pp. 1–14). Kasaragod, Kerala, India: ICAR- Central Plantation Crops Research Institute. Technical bulletin No. 62.

Maetens, E., Hettiarachchy, N., Dewettinck, K., Horax, R., Moens, K., & Moseley, D. O. (2017). Physicochemical and nutritional properties of a healthy snack chip developed from germinated soybeans. *LWT, 84*, 505–510. https://doi.org/10.1016/j.lwt.2017.06.020

Manikantan, M. R., Mathew, A. C., Madhavan, K., Arumuganathan, T., Arivalagan, M., ShameenaBeegum, P. P., & Hebbar, K. B. (2016). *Coconut Chips -Entrepreneurship driven ICAR-CPCRI technology for healthy alternative nonfried snack food. Technical bulletin No. 107*. Kasaragod, Kerala, India: ICAR- Central Plantation CropsResearch Institute.

Marey, S., & Shoughy, M. (2016). Effect of temperature on the drying behavior and quality of citrus peels. *International Journal of Food Engineering, 12*(7), 661–671. https://doi.org/10.1515/ijfe-2015-0296

Mazumder, P., Roopa, B. S., & Bhattacharya, S. (2007). Textural attributes of a model snack food at different moisture contents. *Journal of Food Engineering, 79*(2), 511–516. https://doi.org/10.1016/j.jfoodeng.2006.02.011

Meullenet, J.-F., Xiong, R., Monsoor, M. A., Bellman-Homer, T., Dias, P., Zivanovic, S., Fromm, H., & Liu, Z. (2002). Preference mapping of commercial toasted white corn tortilla chips. *Journal of Food Science, 67*(5), 1950–1957. https://doi.org/10.1111/j.1365-2621.2002.tb08751.x

Mewa, E. A., Okoth, M. W., Kunyanga, C. N., & Rugiri, M. N. (2018). Effect of drying air temperature and slice thickness on the physical and microbiological quality of dried beef. *LWT, 92*, 484–489. https://doi.org/10.1016/j.lwt.2018.02.068

Mishra Pandey, S., & Mishra, H. N. (2015). Optimization of the prebiotic & probiotic concentration and incubation temperature for the preparation of synbiotic soy yoghurt using response surface methodology. *Lebensmittel-Wissenschaft und -Technologie- Food Science and Technology, 62*(1, Part 2), 458–467. https://doi.org/10.1016/j.lwt.2014.12.003

Ramallo, L. A., & Mascheroni, R. H. (2005). Rate of water loss and sugar uptake during the osmotic dehydration of pineapple. *Brazilian Archives of Biology and Technology, 48*(5), 761–770. https://doi.org/10.1590/S1516-89132005000600012

Rastogi, N. K., Nayak, C. A., & Raghavarao, K. (2004). Influence of osmotic pre-treatments on rehydration characteristics of carrots. *Journal of Food Engineering, 65*(2), 287–292. https://doi.org/10.1016/j.jfoodeng.2004.01.027

Sadin, R., Chegini, G.-R., & Sadin, H. (2014). The effect of temperature and slice thickness on drying kinetics tomato in the infrared dryer. *Heat and Mass Transfer, 50*(4), 501–507. https://doi.org/10.1007/s00231-013-1255-3

Salvador, A., Varela, P., Sanz, T., & Fiszman, S. M. (2009). Understanding potato chips crispy texture by simultaneous fracture and acoustic measurements, and sensory analysis. *Lebensmittel-Wissenschaft und -Technologie- Food Science and Technology, 42*(3), 763–767. https://doi.org/10.1016/j.lwt.2008.09.016

Seguí, L., Calabuig-Jiménez, L., Betoret, N., & Fito, P. (2015). Physicochemical and antioxidant properties of non-refined sugarcane alternatives to white sugar. *International Journal of Food Science and Technology, 50*(12), 2579–2588. https://doi.org/10.1111/ijfs.12926

Shi, X. Q., Fito, P., & Chiralt, A. (1995). Influence of vacuum treatment on mass transfer during osmotic dehydration of fruits. *Food Research International, 28*(5), 445–454. https://doi.org/10.1016/0963-9969(96)81391-3

da Silva, W. P., da Silva e Silva, C. M. D. P., de Farias Aires, J. E., & da Silva Junior, A. F. (2014). Osmotic dehydration and convective drying of coconut slices: Experimental determination and description using one-dimensional diffusion model. *Journal of the Saudi Society of Agricultural Sciences, 13*(2), 162–168. https://doi.org/10.1016/j.jssas.2013.05.002

da Silva, W. P., do Amaral, D. S., Duarte, M. E. M., Mata, M. E., e Silva, C. M., Pinheiro, R. M., & Pessoa, T. (2013). Description of the osmotic dehydration and convective drying of coconut (cocos nucifera L.) pieces: A three-dimensional approach. *Journal of Food Engineering, 115*(1), 121–131. https://doi.org/10.1016/j.jfoodeng.2012.10.007

Singh, J., Solomon, S., & Kumar, D. (2013). Manufacturing jaggery, a product of sugarcane, as health food. *Agrotechnology S11, 7*(2).

Solís-Fuentes, J. A., Hernández-Ceja, Y., del Rosario Hernández-Medel, María, García-Gómez, R. S., Bernal-González, M., Mendoza-Pérez, S., & Durán-Domínguez-de-Bazúa, M. del C. (2019). Quality improvement of jaggery, a traditional sweetener, using bagasse activated carbon. *Food Bioscience, 32*, 100444. https://doi.org/10.1016/j.fbio.2019.100444

Srikanth, K. S., Sharanagat, V. S., Kumar, Y., Bhadra, R., Singh, L., Nema, P. K., & Kumar, V. (2019). Convective drying and quality attributes of elephant foot yam (Amorphophallus paeoniifolius). *LWT, 99*, 8–16. https://doi.org/10.1016/j.lwt.2018.09.049

Tan, M., Chua, K. J., Mujumdar, A. S., & Chou, S. K. (2001). Effect of osmotic pre-treatment and infrared radiation on drying rate and color changes during drying of potato and pineapple. *Drying Technology, 19*(9), 2193–2207. https://doi.org/10.1081/DRT-100107494

Vega-Gálvez, A., Lemus-Mondaca, R., Bilbao-Sáinz, C., Fito, P., & Andrés, A. (2008). Effect of air drying temperature on the quality of rehydrated dried red bell pepper (var. Lamuyo). *Journal of Food Engineering, 85*(1), 42–50. https://doi.org/10.1016/j.jfoodeng.2007.06.032

Verma, P., Shah, N. G., & Mahajani, S. M. (2019). Why jaggery powder is more stable than solid jaggery blocks. *LWT, 110*, 299–306. https://doi.org/10.1016/j.lwt.2019.04.093

Xu, S., & Kerr, W. L. (2012). Comparative study of physical and sensory properties of corn chips made by continuous vacuum drying and deep fat frying. *Lebensmittel-Wissenschaft und -Technologie- Food Science and Technology, 48*(1), 96–101. https://doi.org/10.1016/j.lwt.2012.02.019

Zhou, Y.-H., Vidyarthi, S. K., Zhong, C.-S., Zheng, Z.-A., An, Y., Wang, J., Wei, Q., & Xiao, H.-W. (2020). Cold plasma enhances drying and color, rehydration ratio and polyphenols of wolfberry via microstructure and ultrastructure alteration. *LWT, 134*, 110173. https://doi.org/10.1016/j.lwt.2020.110173