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Influence of developed refractance based drying method on physical parameter of potato flakes

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Abstract
The paper aims to develop a dryer that never subjects the food product to shear force and damaging temperature. The study showed that dehydrated potato products obtained using hot air dryers have a pronounced tendency to discolor to a grayish brown. Therefore, the present study aims to develop and evaluate a pilot-scale refractance based system for dehydration of potato. The prototype was developed in Pilot plant, Department of Processing and Food Engineering, PAU and evaluated by drying potato puree. The minimally processed potatoes were unblanched and hot water blanched for different blanching times (3, 4, and 5min) and immersed in a 0.2% potassium metabisuphate (KMS) solution for 15 min. After pretreatment, the potatoes were processed into a puree and a known amount of distilled water was added to the puree to achieve desired Total soluble solid (TSS) levels i.e. 8, 10, and 12ºBrix. The drying experiments were carried out at varying temperatures 70, 80, and 90 ºC. It was observed that the physical properties of potato flakes were significantly affected by TSS, blanching time, and drying temperature ($p<0.05$). It was observed that the developed prototype when used for drying potato puree maintained better quality potato flakes.

Keywords: Refractance, drying system, TSS, potato puree, flakes

Introduction

Drying is an energy-intensive unit operation, used for removing moisture from the food materials. Dehydrated materials are more stable to deterioration due to microbial growth and enzymatic activity. Drying technology belongs to four generations in which a refractance based dryer comes under the fourth generation. Scientist (Abonyi *et al*., 2001; Clarke, 2004; Raghavan *et al*., 2005; Nindo *et al*., 2006; Caparino *et al*., 2012 and Faisal *et al*., 2013) [2, 10, 21, 20, 6, 11] have been continuously working to explore this innovative technique of drying that helps in reducing losses in end-product quality due to the direct heat application.

Refractance based drying system is a novel thin-layer drying method. It belongs to contact or indirect drying technique. Therefore, contamination due to direct exposure to food material during heat transfer does not occur, making it safer to use. It is an effective drying technique as the heat transfer medium is not directly in contact with the wet material but transfers energy indirectly through a metalized polyester sheet (Caparino *et al*., 2012; Zalpouri *et al.*, 2020) [6, 26]. The distinctive feature of this system is that liquid or semi-solid foods are exposed for a short time to relatively low temperatures (Nindo *et al*., 2006) [20]. This method is used for producing high quality dry or very low moisture content products in the form of powder, flakes, or sheets (Chakraborty *et al*., 2015) [7].

Refractance based drying system is a relatively new drying method that utilizes water at 95-100°C and at atmospheric pressure as a medium of transporting thermal energy to materials that need to be dried (Baeghbali *et al*., 2016) [4]. The pureed products are uniformly spread over the metalized polyester conveyer belt which passes over hot water trough. The unutilized heat is recycled in the hot water. As the dried product reaches the cold water section, product hardens which allows easy separation of the product from the polyester belt by employing a scraping instrument. The product dries quickly on the mobile belt. This drying method has a similarity to drum drying when the product is dried in a thin layer on a heated surface. The only difference between the two drying techniques is that the much lower temperature is maintained in the refractance based dryer than in the drum dryer (Abonyi *et al*., 1999) [1]. This

technology is comparatively economical, equipment is easy to operate and maintain (Nindo and Tang, 2007) [19].
The preceding studies on the refractance based drying system showed high-quality retention than the conventional method (Abonyi *et al*., 2001) [2]. A study showed that the paprika sample dried in a refractance based drying system had better quality retention than those dried in hot air dryer (Topuz *et al*., 2009) [24].
Taking the above facts and situations into consideration, the study aimed to develop a batch type pilot-scale refractance based system for dehydration of potato and evaluate the performance of the developed system.

Material and methods

Design consideration for refractance based drying system

Theoretical concept

While heating of water, heat transfer is due to conduction and evaporation through convection as shown in Fig 1. When the metalized polyester sheet is placed on the water surface, the transfer of energy can only occur due to conduction. Therefore, using conduction through the composite wall equation the refractance based drying system was designed. The refractance based drying system was designed and fabricated in the Pilot plant, in the Pilot plant, Department of Processing and Food Engineering, Punjab Agricultural University, Ludhiana, Punjab, India.

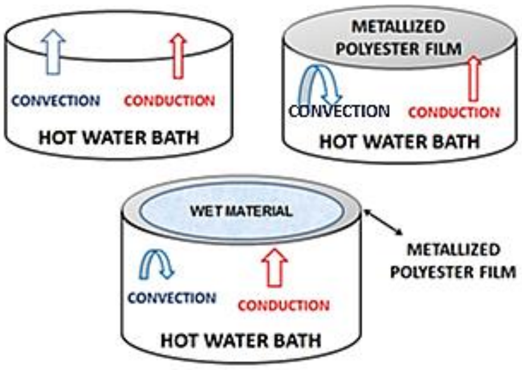

Fig 1: Theoretical concept of refractance based drying system

Design and calculation of refractance based drying system

Refractance based drying system was designed using the following assumptions

Assumption,

1. Conduction takes place under steady-state conditions.
2. There was no convective heat loss.
3. Heat flow is unidirectional.

Material of belt = Metalized polyester sheet
Thermal conductivity of belt (k_s) = 0.14 J/mKsec
Thickness of belt (l_s) = 0.0254mm (100gauge)
Width of belt (w_s) = 420mm (0.42m)
Thermal conductivity of potato puree (k_p) = 0.476 J/mKsec
Thickness of the potato puree layer (l_p) = 2mm
Temperature of potato puree (t_2) = 303K (30 °C)
Temperature of water bath (t_1) = 373K (100 °C)
Area of water surface in contact with belt = A m^2
Conductive heat = q_1 Joule/kg
Heat provided by water bath = q_2 Joule/kg

Using conduction through a composite wall,
q_1 = UAΔT ………. (i)
q_2 = c_p.ΔT + h_{fg} Joule/kg……... (ii)

Using the heat balance equation, $q_1 = q_2$……... (iii)
A = 0.405m^2
Length of the belt in contact with water surface = $\frac{0.405}{0.42}$ = 0.96m = 960mm

Experimental evaluation of refractance based drying system

Material

Fresh potato cultivar Kufri Pukhraj crop was procured from the Director (Seeds), Punjab Agricultural University, Ludhiana, and was stored at 10±1 °C temperature and 85±2% RH in the walk-in cold room in Department of Processing and Food Engineering, PAU, Ludhiana, India till further processing.

Preparation of potato for processing into a puree

The raw potatoes were washed to remove undesirable materials by clean water. The cleaned potatoes were peeled manually using a hand peeler and cut into quarters. Quarters were blanched and unblanched. To inhibit enzymatic action, quartered potatoes were hot water blanched at 90-100ºC for three different time periods i.e. 3, 4, and 5 min, and then instantaneously dipped in cold water to halt thermal inactivation rapidly (Rudra *et al*., 2008) [23]. The blanched quarters were immersed in a 0.2% potassium metabisulphite (KMS) solution for 15min.

Processing of potato puree into flakes

After pretreatment, the potatoes were processed into a puree using a food processor (Sujata Powermatic Plus India). A known amount of distilled water was added to the puree to achieve desired TSS levels of 8, 10, and 12°Brix. For every decrease in 1°Brix, 10ml distilled water was added to 100ml of processed puree. The processed puree was spread on the flexible belt keeping the thickness of the puree as 2mm. The puree was dried in the developed dryer at three different temperature i.e. 70, 80, and 90°C of the water bath.

Quality analysis

Determination of Moisture Content (MC)

The direct method i.e. oven method was used to determine the moisture content of fresh potato and potato flakes. Five-gram sample was dried at 103± 2 ºC for 16hrs in uncovered pre-weighed Petri-dishes (Anonymous, 1975).

Moisture content (% db) = $\frac{W_1 - W_2}{W_2}$ x 100 ………. (ii)

Where,
W_1 = initial weight of the sample (g)
W_2 = final weight of the sample (g)

Bulk Density

The bulk density of the potato flakes was determined using a measuring cylinder and electronic balance. The weight and volume of a measuring cylinder filled with the sample were determined. The bulk density of powder was determined as:

Bulk density = $\frac{M}{V}$

Where, M = mass of the sample in grams and V = volume of the same sample in cc

Porosity

The porosity (ε) of potato flakes was calculated by using the following relationship which was expressed in percentage from the bulk density and true density (Jha, 1999) [14].

$$\varepsilon = \frac{(p_p - p_b) \times 100}{p_p}$$

Where, p_p is true density and p_b is bulk density of potato flakes

Statistical analysis

The experimental analysis was done in duplicate. The two-way factorial ANOVA (version 9.2 SAS software, USA) was used to study the effect of factors and their interactions on potato flakes. The results of the analysis were used to estimate the significant difference among the various parameters at $p < 0.05$.

Result & discussion

Fabrication of developed dryer

A batch type hand operated refractance based drying system (shown in Fig 2) was designed as per the assumptions and calculations in the preceding section. The designed setup consisting of a water bath, belt, and roller system, and the mainframe was then fabricated (shown in Table 1).

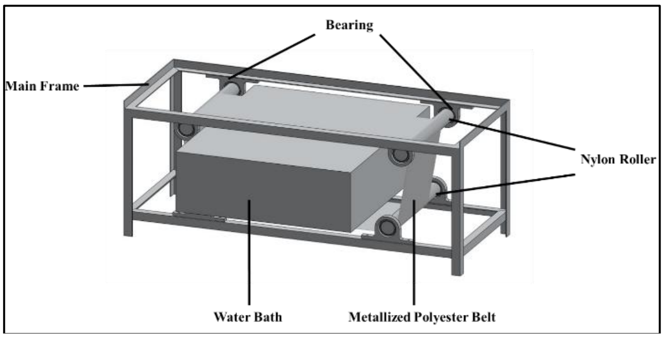

Fig 2: 3D model of refractance based drying system

Mainframe

The mainframe, rectangular in shape, having length 140cm, width 77cm and height 42 cm were fabricated using mild-steel angle (MS angle: 2-inch x 2-inch x $^1/_4$ -inch). This frame was used for the mounting of different parts of the refractance based drying system i.e. roller, belt, and water bath.

Belt-roller unit

The belt-roller unit was designed as a hand-driven system having a flexible belt made of a flat metalized polyester sheet of 100 gauge thickness. To provide for the smooth and frictionless running of rollers, eight bearings (P 210) made of gunmetal were used in the setup. Metalized polyester sheet is ideally suitable for a various array of uses such as apparel, barrier protection, die-cutting, electronics packaging, printing, protective overlay, and other industrial applications. It has special features like dimensional stability, chemical and electrical resistance, non-tearing, and heat resistance to 230 °C.

Water bath

Insulated aluminum sheet tray of outer dimension 40 x 26 x 6 inch and inner dimension 38 x 24 x 5 inch was used to make a water bath. The center of the water bath was covered with a metalized polyester belt and the sides were covered with aluminum sheet lid on which two heaters of 1000W were mounted. The thermal sensor was immersed in a water bath to note the temperature of the water. It was connected to the temperature controller, to set the temperature of the water as required.

Table 1: Components of the machine

Components	Specification
Mainframe	
Material	Angle MS iron
Length	140 cm
Width	77 cm
Height	42 cm
Belt- roller unit	
Flexible belt	
Material	Metalized polyester
Thickness *Roller*	100 gauge
No. of rollers	4
Material	Nylon
Length	28 inch
Diameter *Bearings*	2.5 inch
No. of bearings	8
Material	Gunmetal
Type	P210
Water bath	
Material	Aluminum
Outer dimensions	40 x 26 x 6 inch
Inner dimensions	38 x 24 x 5 inch
Heating system	
No. of heaters	2
Watt	1000 Watt each
Thermal sensor	PT100

Quality analysis of potato flakes

Moisture content

The moisture content is the quantity of water present in the food material. The moisture content of potato flakes ranged from 5.63-3.13% (db) for blanched samples and 4.05-3.01% (db) for an unblanched sample. The maximum moisture content was observed in a blanched sample obtained from potato sample blanched for 4mins, pureed to 8°Brix and dried at 70°C and the minimum moisture content was observed in flakes obtained from potato sample blanched for 5mins, pureed to 8°Brix and dried at 90°C. It can be perceived from Table 2 that there was a significant (p<0.05) effect of blanching time, TSS, and drying temperature on the moisture content of potato flakes. The potato samples that were blanched had higher moisture content than the potato samples that were unblanched (shown in Figure 3). This can be attributed to the reason that blanching can lead to starch gelatinization and during the subsequent drying process a resistant film layer was formed on the surface of the samples, which reduced water transfer (Xiao *et al*.; 2012 and Chen *et al*.; 2017) [25, 8]. Further, it was observed that with an increase in drying temperature there was a decrease in the moisture content of potato flakes.

Table 2: *p* values of different physical characteristics of potato flakes

Source	Moisture Content	Bulk Density	Porosity
DT	<0.0001*	0.035*	0.0444*
BT	<0.0001*	0.0004*	<0.0001*
TSS	<0.0001*	0.2561	0.3001
DT × BT	<0.0001*	0.0192*	<0.0001*
DT × TSS	<0.0001*	0.0097*	0.0014*
BT × TSS	<0.0001*	0.1097*	<0.0001*
DT × BT × TSS	<0.0001*	0.0064*	<0.0001*

Note: DT= Drying temperature, BT= Blanching time, TSS= Total soluble solid *p<0.05 indicates a significant effect of specific factors listed above or their combinations (2-way interaction) on the quality parameters

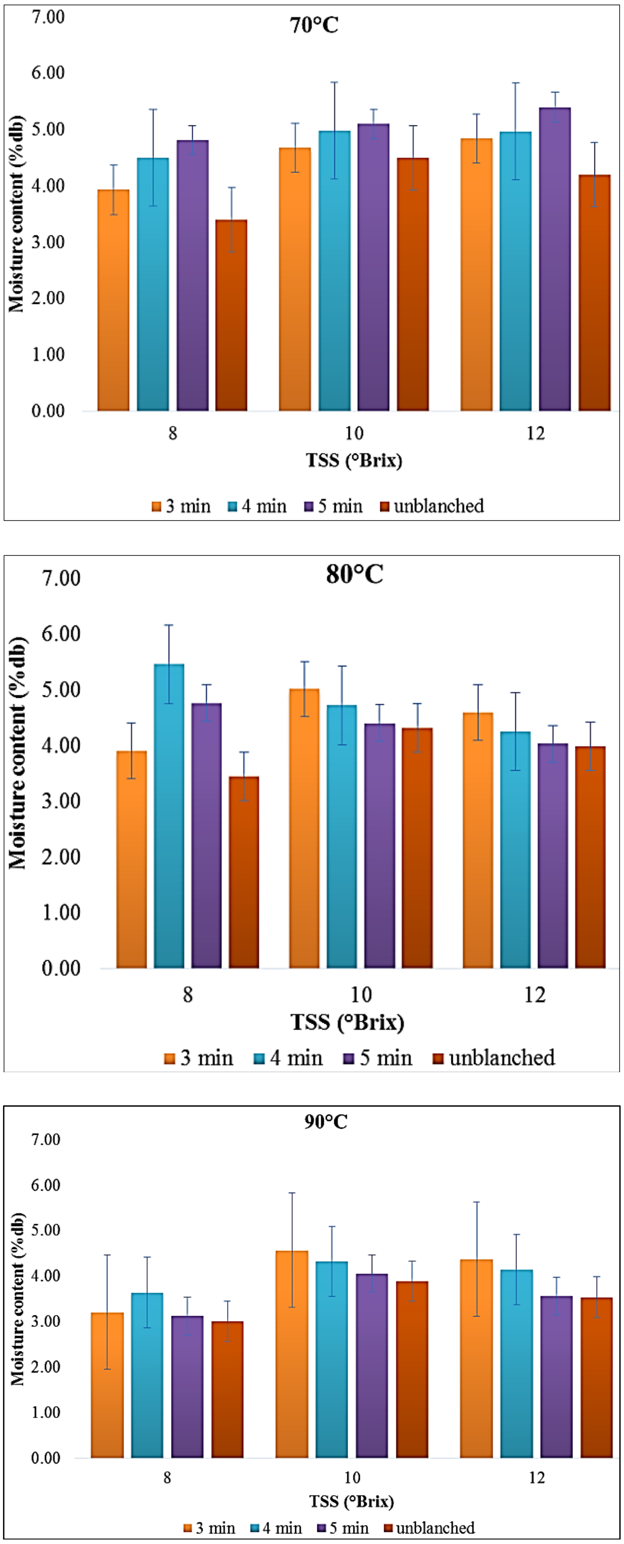

Fig 3: Effect of blanching time, TSS and drying temperature on the moisture content of potato flakes

Bulk Density

The bulk density is an essential physical parameter during processing, packaging, storage, and storage of flakes. The bulk density of potato flakes ranged from 0.370-0.410g/ml for a blanched sample and 0.399-0.578g/ml for the unblanched sample. It was analyzed that bulk density was significantly ($p<0.05$) affected by blanching time and drying temperature (shown in Table 2). It can be concluded that maximum bulk density from the blanched sample was found in flakes obtained from potato sample blanched for 3mins, pureed to 8°Brix, and dried at 70 °C. The increase in temperature decreased the bulk density owing to creating extensive porosity in particles (shown in Fig 4). A similar effect of temperature on bulk density was observed by Goula *et al*. (2004) [13] on tomato powder. Bazaria and Kumar (2016) [5] also emphasized a similar pattern while drying sugar beet. Also Chegini and Ghobadian (2005) [9]; Farahnaky *et al*. (2016) [12] and Moghbeli *et al*. (2019) [18] determined that with an increase in drying temperature there was a reduction in bulk density of food flakes. The bulk density decreased slightly with blanching time but was severely affected by drying temperature. The sample that was unblanched had more bulk density than a blanched sample. It was attributed to the reason that soluble solids loss and water uptake were reflected during blanching as the density of water is lower than the density of solid (Mate *et al*., 1998) [17].

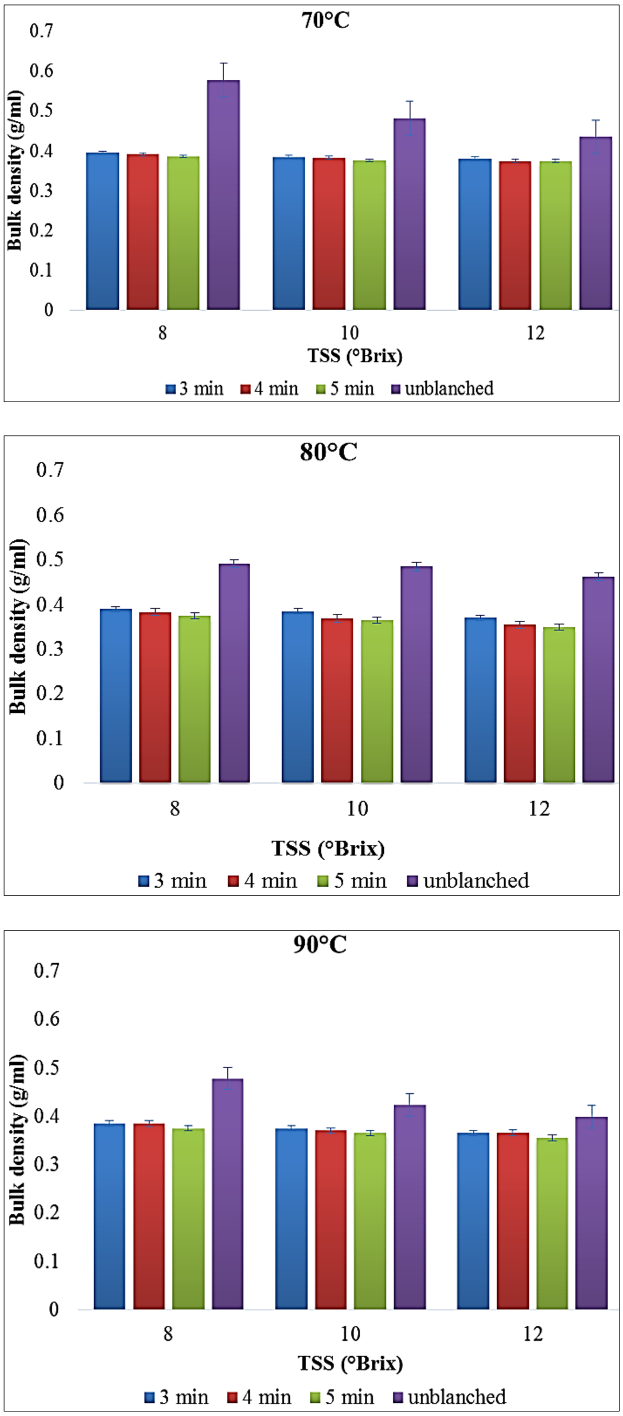

Fig 4: Effect of blanching time, TSS and drying temperature on the bulk density of potato flakes

Porosity

The porosity values were determined using the standard formula from the bulk density and true density values. It is defined as the percentage of voids of an unconsolidated mass of materials. It is often needed in airflow and heat flow studies as well as other applications (Masoumi *et al*., 2006) [16]. The porosity ranged 62.81-70.99% for a blanched sample and ranged% for the unblanched sample. The sample blanched for 3 min having TSS 8°Brix and dried at 70°C had maximum porosity than sample blanched for 5 min having TSS 12°Brix and dried at 90 °C (shown in Fig 5). It was concluded that the porosity of dried potato flakes was significantly affected by drying temperature and blanching time (shown in Table 2). It was observed that the porosity of potato flakes increased with a decrease in moisture content during the drying period (Rahman *et al*., 2001) [22]. The porosity of potato flakes was directly affected by the bulk density of potato products. Therefore, the unblanched sample had more porous flakes than a blanched sample. The decrease in bulk density decreased porosity. This may be attributed to the fact that the removal of moisture from the intercellular spaces during drying creates void spaces leading to increased values of porosity (Koocheki *et al*., 2007) [15].

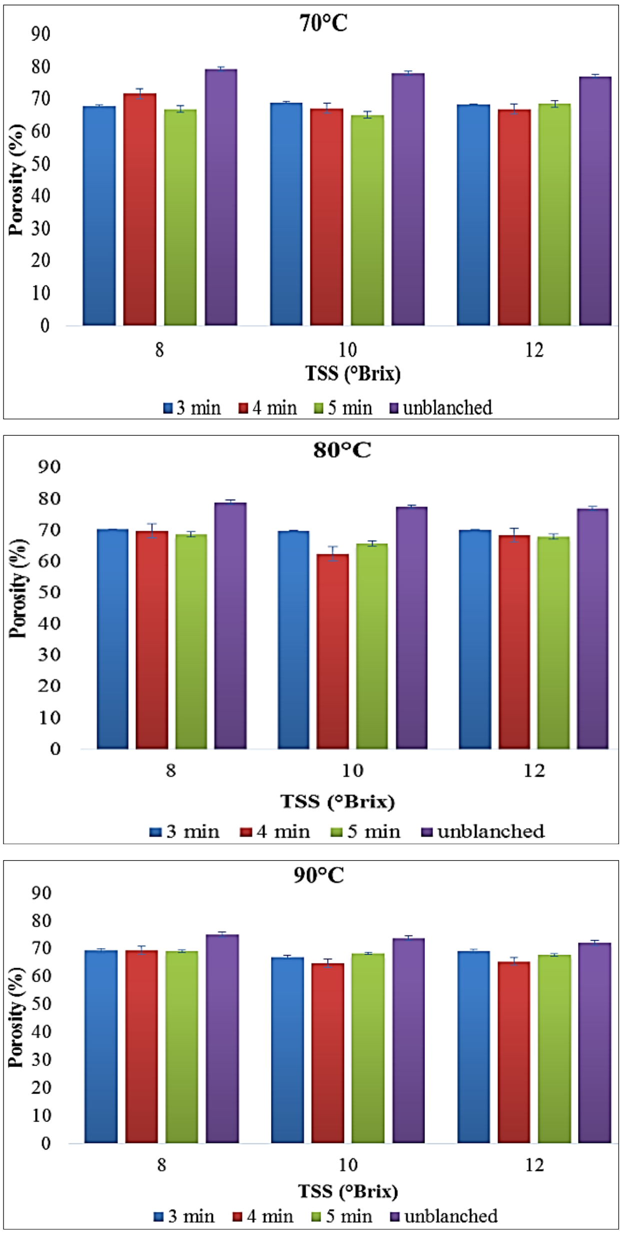

Fig 5: Effect of blanching time, TSS and drying temperature on porosity of potato flakes

Conclusion

In this study, a novel drying equipment i.e. refractance based drying system was designed and developed. It was observed that after considering all the factors blanched sample had better quality retention than an unblanched sample. The samples blanched for 3min having TSS 8°Brix and dried at 70 °C had better quality retention than other samples. Although having too many advantages have been quoted by different researchers but research studies on vegetable drying using the refractance mechanism is limited. So, it is recommended that studies on drying several vegetables using a refractance based drying system should be performed in the future for performance evaluation of the dryer. It also avails its utilization in the food processing industry.

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