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Vacuum Drying of Kiwi Slices: Drying Characteristics and Effect of Process Parameters on Functional Properties

Malemnganba Saikhom and Sujata Jena*

*College of Agricultural Engineering and Post Harvest Technology

(Central Agricultural University), Ranipool -737135, Gangtok, Sikkim, India

*Corresponding Author E-mail: drsujatajena@gmail.com

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ABSTRACT

Kiwifruit (Actinidia deliciosa) is a multi-nutritional high value fruit due to its high contents of Vitamin C and total polyphenols. In the present study, vacuum drying of kiwi was undertaken to investigate the effects of slice thickness (4mm, 6mm and 8mm) and plate temperature (50, 60 and 70°C) on vacuum drying characteristics, percentage shrinkage and rehydration ratio. During vacuum drying at a constant vacuum of 630 ± 10 mmHg. Drying took place entirely in the falling rate period. The drying rate constant varies from 0.005 min^{-1} to 0.025 min^{-1} for the temperature range studied. The drying rate increased with increase in temperature and decreased with increase in kiwi slice thickness. The percentage shrinkage varied in the range of 60 % -75% and rehydration ratio in the range of 2.03 - 3.06 for various experimental conditions. Percentage shrinkage increased by14.29 % to 16.67 % as the plate temperature increased from 50°C to 70°C. A decrease in percentage shrinkage in the range of 4% - 6.67 % was observed as thickness increased from 4 mm to 8 mm at same plate temperature. Rehydration ratio decreased in the range of 26.76% - 33.01% with increase in plate temperature at different slice thicknesses.

Keywords: *Kiwi, Vacuum drying, Drying rate, Rehydration ratio, Percentage shrinkage*

INTRODUCTION

Kiwifruit *(Actinidia deliciosa)* is or Chinese gooseberry is the edible berry of several species of woody vines in the genus *Actinidia*. It is a nutrient rich high value fruit due to its high contents of Vitamin C and total polyphenols, which range from 92 mg – 132 mg per 100 g of fresh weight (Park et al. 2006). The fresh fruit contains a significant amount moisture leading to a limited shelf life after it is fully ripened (Orikasa et al., 2014). The shelf life can be increased through drying. In addition to increase in shelf life, the dehydrated kiwi slices can be used by the confectionary, bakery, sweet and distilling industries in various sauce, teas, and puddings. The dehydrated kiwi slices can also be ground into suitable powder form to be used in beverage industry, as functional food additives as well as a flavouring agent in ice creams, and yogurts.

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Drying is a simultaneous heat and mass transfer process in which water is removed to arrest the growth of spoilage microorganisms thereby retard the rate of chemical and bio-chemical spoilage reactions. In addition to preservation, drying also facilitates packaging, handling, storage, and transport operations by reducing the bulk of the fresh wet food. Conventional hot air drying is a simple and economical drying method for many fruits and vegetables (Leonid et al., 2006). However, its disadvantages *viz.*, low energy efficiency, color and nutrient degradation, prolonged drying time and poor rehydration properties (Drouzas et al., 1999; Leonid et al., 2006; Maskan, 2000; Oikonomopoulou & Krokida, 2013) limits its application in drying of nutrient rich heat sensitive fruits like kiwi. Hence, vacuum drying is a suitable alternative for drying such heat sensitive fruits under partial vacuum of about 5-10 kPa through conduction or radiation drying at temperatures below 75°C (Arevalo-Pinedo & Murr, 2006). Vacuum drying not only overcomes the disadvantages of hot air drying but also has added advantages of higher product porosity, lower apparent density, and lower shrinkage rates than hot air-dried materials (Karam et al., 2016).

Knowledge of the drying kinetics of the kiwi slices is required to design, optimize, and control the drying process. It is also necessary to investigate the vacuum drying characteristics of the kiwi to evaluate the practicability of vacuum drying for improving the quality of the dried product. Very few studies have been carried out to investigate vacuum drying characteristics of kiwi (Orisaka et al. 2014). Vacuum drying temperature and thickness of fruit plays a major role in deciding the final functional quality attributes of the dehydrated product. In this context, the present study was undertaken to investigate the vacuum drying characteristics and effect of slice thickness and plate temperature on rehydration ratio and percentage shrinkage.

MATERIALS AND METHODS

2.1 Sample Preparation

Fresh kiwi fruits were procured from Lal market, Gangtok, India. The samples were packed in polythene pouches and stored in the refrigerator till further experiments. The average equivalent diameter of the fresh kiwi fruits was 49.74 ± 0.08 mm. The kiwi fruits were sorted, washed and peeled manually using a knife. The peeled fruits were sliced manually into different thicknesses viz., 4 mm, 6 mm and 8 mm using a sharp knife. The thickness of the slices were measured using a digital vernier caliper. The initial moisture content of the kiwi samples was determined by digital infrared moisture analyzer (Sartorius, MA35M, India). The initial moisture content of the slices was 503.35 ± 30.5 % dry basis. The prepared slices were used for further drying experiments.

2.2 Vacuum Drying Experiments

For vacuum drying, the prepared kiwi slices were spread uniformly on stainless steel trays in thin layers. Drying experiments were conducted at three different plate temperatures of 50°C, 60°C and 70°C at constant vacuum level of 630 ± 10 mmHg in a laboratory scale vacuum tray dryer. The sample trays were removed at 30 mins interval for the first one and half hour and then 1 h interval during further drying for weight measurement. The weight was measured using a digital weighing balance. The vacuum was released and restored before and after the weight measurements and this process took less than 30 s. Drying was continued till the moisture content reduced to less than 10% db. Initial and final moisture content of the kiwi samples were measured using a digital infrared moisture analyser. Moisture reduction in the kiwi samples during drying was calculated from the initial moisture content and the weight loss. Before each drying experiment, vacuum dryer was run for 30-45 mins on empty load to obtain the desired steady temperature of the plate. The dried samples were sealed tightly in the polythene pouches and stored in desiccators till further analysis.

2.3 Modelling of Vacuum Drying Characteristics of Kiwi

The experimental drying data was analysed in terms of reduction of moisture content with drying time. The data were graphically represented in terms of moisture ratio (MR). The moisture ratio curve can better explain the drying behaviour than that of moisture content curve. To understand the influences of drying temperature on the drying rate, relationship between moisture ratio, MR and drying time was plotted. Moisture Ratio (MR) was calculated as,

$$MR = \frac{M_t - M_e}{M_i - M_e} \quad \text{… Eq. (1)}$$

Where, M_t is the moisture content of the kiwi at time t, M_e is the equilibrium moisture content of kiwi at drying conditions and M_i is the initial moisture content of kiwi.

The values of equilibrium moisture content M_e is relatively small compared to M_t or M_i(Taniguchi & Nisshio, 1991) and the expression of moisture ratio was reduced to

$$MR = \frac{M_t}{M_i} \quad \text{… Eq. (2)}$$

2.3.1 Estimation of drying rate constant

Drying rate was calculated from the change in weight of sample for a particular time interval. Assuming the thin-layer theory of drying, the drying rate can be expressed by equation 3.

$$MR = e^{(-k\theta)}. \quad \text{... Eq. (3)}$$

Where, k is the drying rate constant in min^{-1}, θ is the drying time in min

The drying rate constant k was determined by calculating the slope of the straight line plot of ln MR vs θ. Drying rate constant was estimated for all experimental conditions.

2.4 Analysis of Functional Properties of Dried Kiwi Samples

Functional properties *viz.*, percentage shrinkage and rehydration ratio of vacuum dried kiwi slices were analysed as per the following procedures. The effect of the experimental parameters *viz.*, plate temperature and slice thickness on these properties were analysed.

2.4.1 Percentage shrinkage of dried kiwi slices

Shrinkage which occurred during drying as a result of water evaporation was evaluated by determination of the relative volume of dried material. Percentage shrinkage of the kiwi during drying was measured by liquid displacement method (Maskan, 2001; Artnaseaw et al., 2010). Measurements were made using toluene so as to avoid water uptake by samples. Shrinkage of the sample was evaluated in terms of percentage change of the volume of the sample, calculated as,

$$\%\ \text{Shrinkage} = \frac{(V_o - V)}{V_0} \text{x}100 \quad \text{… Eq. (4)}$$

Where, V_0 and V are the initial and final volume of the kiwi samples, ml

2.4.2 Rehydration ratio

The rehydration ability of dried samples to reconstitute to their original state is commonly described by their rehydration ratio. Higher the rehydration ratio, higher is the recovery of the original structure in the final product. Rehydration ratio of dried kiwi samples was determined using a method described by Giri and Prasad (2007). In this method,1g of dried samples were immersed in approximately 100ml of distilled water at 100°C temperature for 10 mins. The temperature was maintained using a water bath. After 10 min the sample was taken out and blotted with paper towel to eliminate excess water on its surface. The mass of the dried and rehydrated sample were measured by an electronic balance with an accuracy of± 0.01 g. Triplicate samples were used. Rehydration Ratio (*RR*) was defined as the ratio of the weight of rehydrated samples to the dry weight of the sample. The rehydration ratio of the samples was then calculated by

$$RR = \frac{m_{after}}{m} \quad \text{… Eq. (5)}$$

Where m and m_{after} are the mass of the dried and rehydrated samples respectively in g.

2.5 Statistical Design

A full factorial experimental design consisting of two independent parameters viz., slice thickness and plate temperature each at three levels was followed. All the experiments were carried out in triplicate. A total number of 27 experiments were carried out. ANOVA was used to assess the effect of process parameters on the functional properties.

RESULTS AND DISCUSSION

3.1 Vacuum Drying Characteristics and Drying Rate

The kiwi slices of various thicknesses were dried to a final moisture contents between 2.04±0.02 and 8.67±0.13 % db. The total drying time varied in the range of 210 to 640 minutes. The calculated moisture ratio was plotted against drying time to show the moisture variation in kiwi slices at different experimental conditions. Fig. 1 shows the moisture reduction during vacuum drying of kiwi slices at all experimental conditions. It can be observed from the figure that moisture content continuously decreases with time.

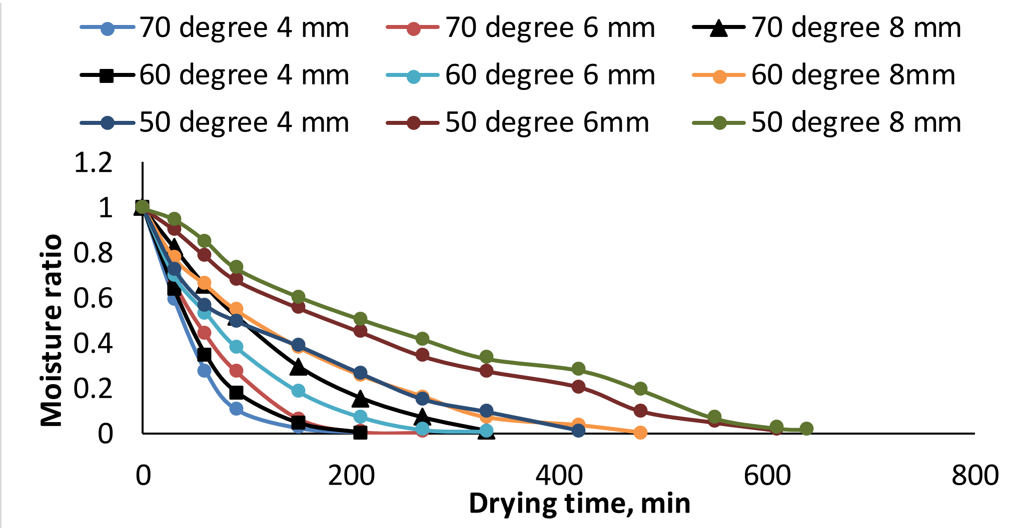

Fig. 1: Moisture reduction during vacuum drying of kiwi at different experimental conditions

In order to assess the drying characteristics, drying rate was calculated as described in section 2.3.1. The average drying rate varied between 0.02 and 0.044 g moisture/min-g dry solids at 70°C, between 0.021 and 0.045g moisture/min-g dry solids at 60°C, and 0.011 and 0.025g moisture/min-g dry solids at 50°C respectively for different slice thicknesses. Figs. 2, and 3 show the variation of drying rate with average moisture content and slice thickness at 60° and 70° C respectively. From the figures, the absence of constant drying rate period is evident during vacuum drying of kiwi slices at all experimental conditions. Hence, it can be inferred that vacuum drying of kiwi slices takes place in the falling rate drying period. This is due to the quick removal of moisture from the kiwi slices through diffusion process (Kaleemullah and Kailappan, 2006).

From the figures, it can be seen that the drying rate decreases with decrease in moisture content and increase in slice thickness. This is because thinner slice of kiwi enable the moisture to travel in a shorter distance from interior to the surface leading to less resistance and higher drying rate. The average drying rate decreased by 50.86% - 56.78% as the slice thickness increased from 4 mm to 8 mm within the studied temperature range. From the analysis of results, the effect of slice thickness on drying rate was found to be highly significant ($p<0.05$). Similar behaviour has been reported during vacuum drying by Wu et al. (2007) for egg plants, and Orisaka et al. (2014) for kiwi.

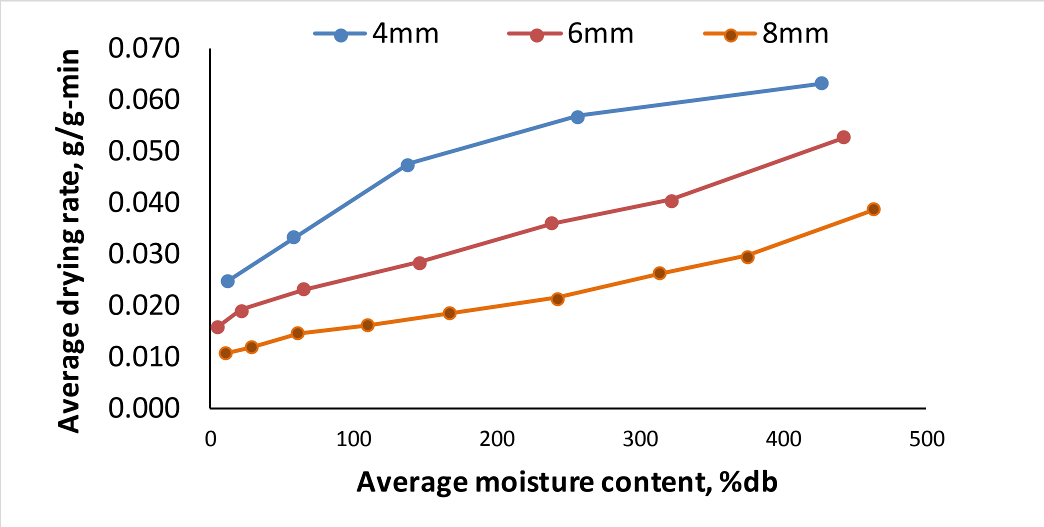

Fig. 2: Variation of drying rate with average moisture content and slice thickness at 60°C

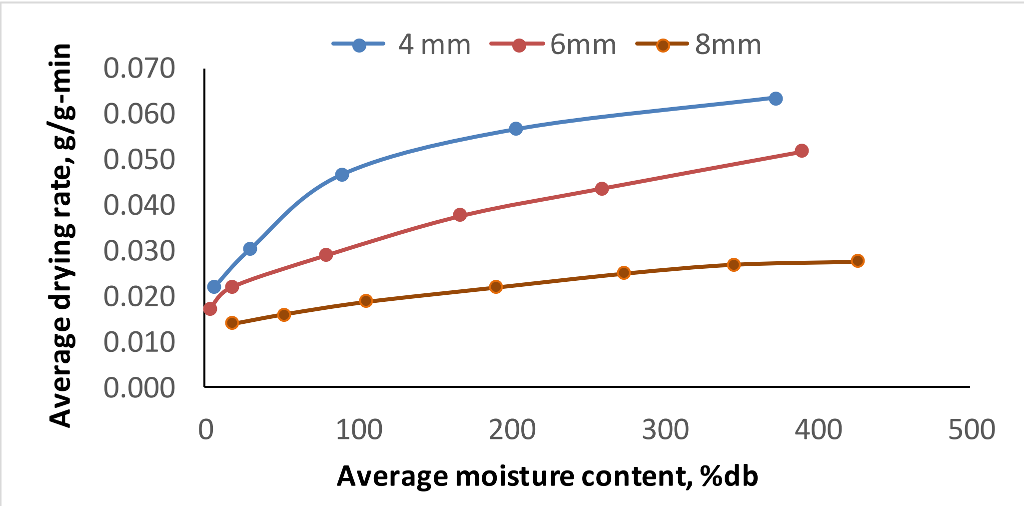

Fig. 3: Variation of drying rate with average moisture content and slice thickness at 70°C

Fig. 4 and 5 represent the variation of average drying rate with average moisture content and temperature at 4 mm and 6 mm slice thickness respectively. From the figures and ANOVA, it was observed that drying rate increased significantly ($p<0.05$) with increase in plate temperature at all slice thicknesses. Higher drying temperature contributes to higher rate of heat transfer due to increased moisture diffusion rate from the interior to the surface. The average drying rate increased by 44.12% - 61.21 % as the plate temperature increased from 50°C to 70°C at same slice thickness. Similar results have been reported by Lee and Kim (2008) for vacuum drying of Asian white radish slices within temperature range 40°C to 60°C.

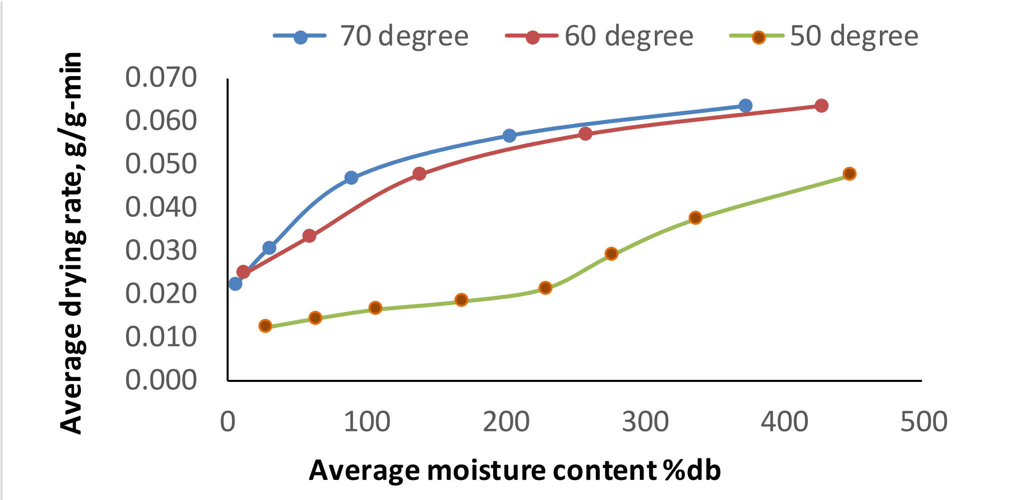

Fig. 4: Variation of drying rate with moisture content and plate temperature for 4 mm slice thickness

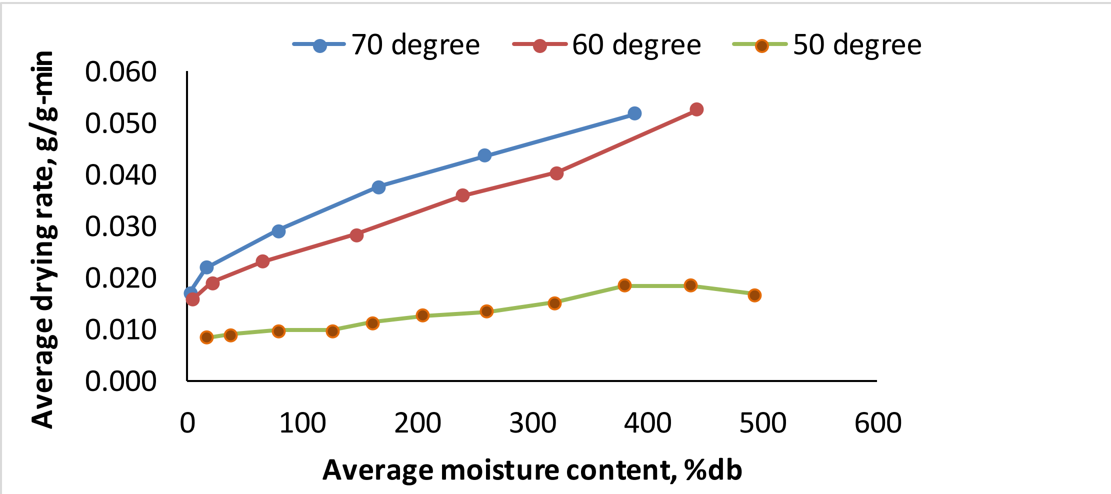

Fig. 5: Variation of drying rate with moisture content and plate temperature for 6 mm slice thickness

3.2 *Effect of Process Parameters on Drying Rate Constant*

Drying rate constant was estimated by as per the procedure given in section 2.3.1. Fig. 6 shows the sample graph of ln MR vs drying time at 70°C and different slice thickness used for calculation of drying rate constant. The drying rate constant varied from 0.005 min^{-1} to 0.025 min^{-1} within the experimental range of temperatures and slice thicknesses. The maximum value of 0.025 min^{-1} was observed at 70°C and 4 mm slice thickness whereas the minimum value of 0.005 min^{-1} was observed at 50°C and 8 mm slice thickness. Fig. 7 shows the variation of drying rate constant with slice thickness and plate temperature during vacuum drying of kiwi slices. From the Fig. 7 and ANOVA, it is seen that the drying rate constant decreased with the increase in slice thickness and increased significantly ($p<0.05$) with increase in plate temperature. This refers to higher drying rate at higher temperatures and lower drying rates for thicker slices as explained in previous section.

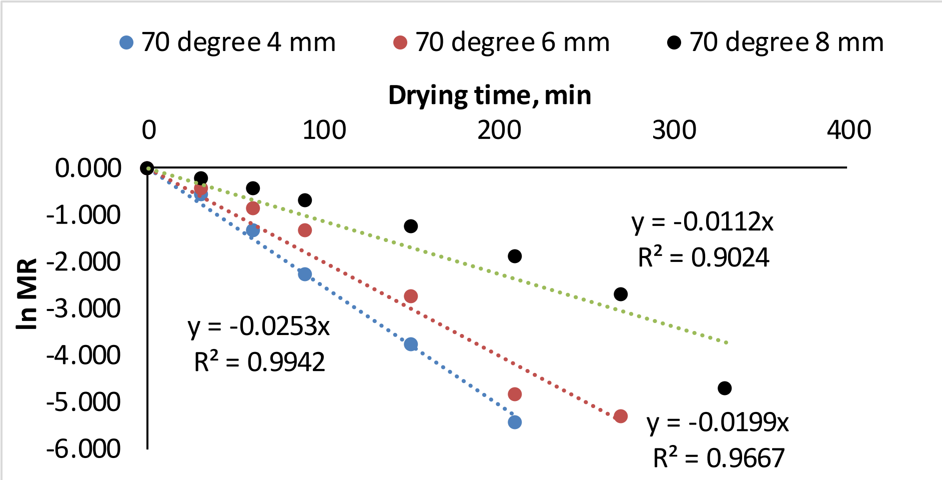

Fig. 6: Estimation of drying rate constant at plate temperature of 70°C

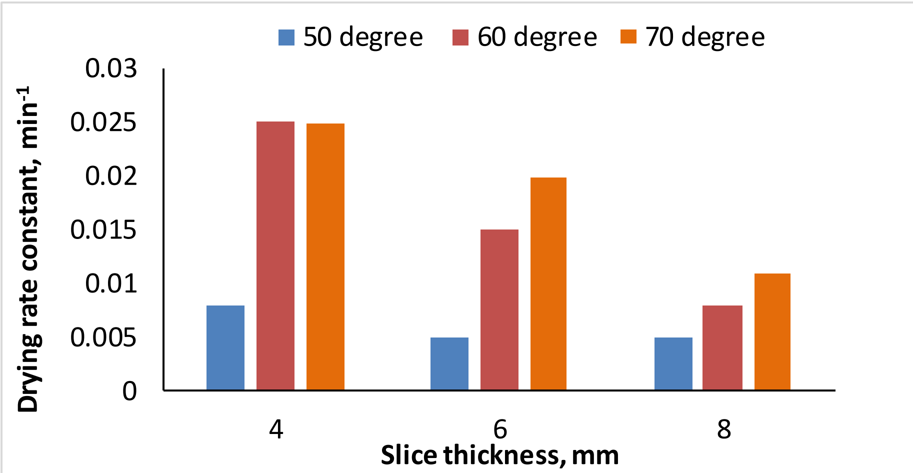

Fig. 7: Variation of drying rate constant with plate temperature and slice thickness

3.3 Effect of Process Parameters on Percentage Shrinkage

The values of percentage shrinkage and rehydration ratio at various experimental conditions were calculated. The percentage shrinkage varied between 60% and 75% for different experimental conditions**.** The highest percentage shrinkage was observed at highest drying temperature of 70°C of 4 mm slices and the lowest was observed at 50°C of 6 mm slice. Fig. 8 shows the variation of percentage shrinkage with plate temperature and slice thickness. From the figure, it can be observed that percentage shrinkage in dried kiwi slices increases with increase in plate temperature. A significant increase (p<0.05) of about 14.29% to 16.67% was observed in percentage shrinkage as the plate temperature increased from 50°C to 70°C at same slice thickness. It may be due to higher drying rates at higher temperatures resulting in shrinkage of bottom part of slices which is in immediate contact with the heating plate. A significant decrease ($p<0.05$) in percentage shrinkage with increase in slice thickness can be observed from Fig. 8 and ANOVA. The decrease in percentage shrinkage was in the range of 4% - 6.67% with increase in thickness from 4 mm to 8 mm at same plate temperature. However, the % shrinkage decrease at 6 mm and 8 mm were in the same range of 6.25 - 6.67%.

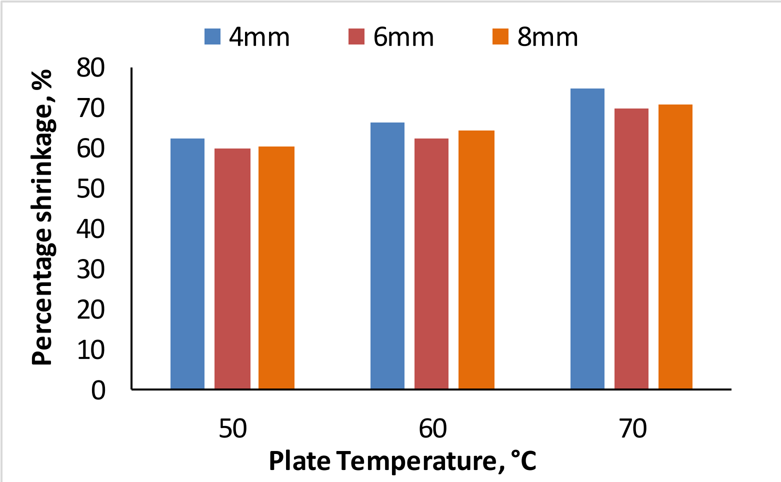

Fig. 8: Effect of plate temperature and slice thickness on percentage shrinkage of vacuum dried kiwi slices

3.4 Effect of Process Parameters on Rehydration Ratio

The rehydration ratio in different dried kiwi samples varied between 2.03 to 3.06 for various experimental conditions. The highest rehydration ratio was observed at lowest plate temperatures of 50°C and 8 mm slice thickness and the lowest value was observed at highest plate temperature of 70°C and 6mm slice thickness. The variation of rehydration ratio with different plate temperatures and slice thicknesses is plotted in Fig. 9. From Fig. 9 and ANOVA results, it can be observed that rehydration ratio decreased significantly ($p<0.05$) with increase in plate temperature. This may be due to increased percentage shrinkage in samples dried at higher temperatures which resulted in collapse of internal structure of the samples. The decrease in rehydration ratio was in the range of 26.76 % - 33.01% with increase in plate temperature at different slice thicknesses. The effect of slice thickness on rehydration ratio was found insignificant ($p>0.05$). Similar results have been reported by Šumic´ et al. (2016) for vacuum drying of red currants.

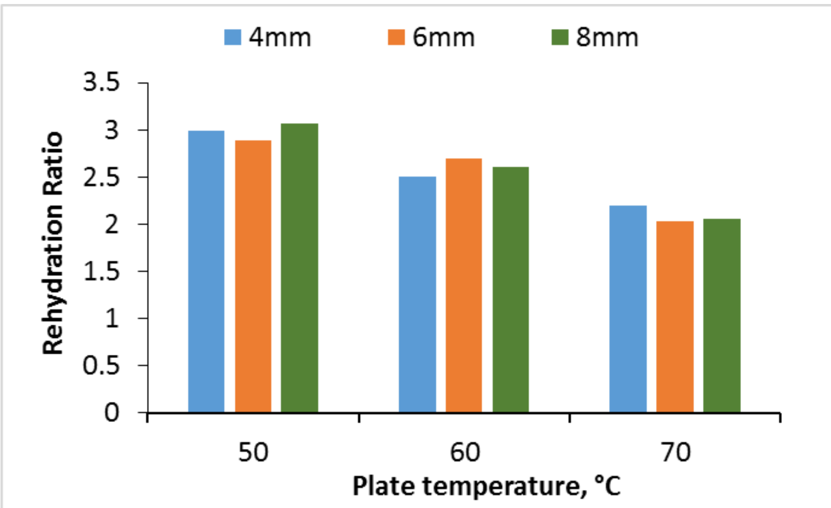

Fig. 9: Effect of plate temperature and slice thickness on rehydration ratio of vacuum dried kiwi slices

CONCLUSIONS

Kiwi slices were vacuum dried at temperatures of 50°, 60° and 70° C at different slice thicknesses of 4mm, 6 mm and 8 mm. The entire drying process of kiwifruit slices occurred in the falling rate period during vacuum drying. The average drying rate decreased by 50.86% - 56.78% as the slice thickness increased from 4 mm to 8 mm within the studies temperature range. It increased by 44.12% - 61.21 % as the plate temperature increased from 50°C to 70°C at same slice thickness. Significant effect of plate temperature was observed on both rehydration ratio and percentage shrinkage. Percent shrinkage was significantly affected by slice thickness. Further studies on nutritional properties and sensory attributes of vacuum dried kiwi slices will provide more information on vacuum dried kiwi slices.

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