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Optimisation of ready-to-cook chayote slices using pilot scale vacuum drying process

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Chayote (*Sechium edule*) fruits have very high moisture content and very soft skins, thus susceptible to spoilage and mechanical damage. Furthermore, due to a lack of suitable storage, transport and processing facilities, huge losses are incurred in terms of quality and quantity. Therefore, the study was conducted to optimise the process parameters of vacuum drying of chayote slices to produce a good quality dehydrated product. The experiments used slice thicknesses of 1, 3, and 5 mm at different temperatures (54 to 66°C). From the analysis using full factorial design and Duncan's multiple range tests, it was observed that the optimum responses (final moisture content, rehydration ratio, energy consumption, production rate, and total cost) were obtained during vacuum drying of 1 mm chayote slices at 58°C. The results were at par with the treatment consisting of vacuum drying of 3 mm chayote slices at 58°C. From experience, slicing the chayote to 1 mm thickness was too difficult; hence, treatment at 58°C and 3 mm slice thickness may be considered as optimum process condition, which produced dried product with a moisture content of 3.5% at a production rate of 1.662 g d.p./h and had a rehydration ratio of 5.833.

Keywords: Chayote, Optimization, Ready-to-Cook, Rehydration, Vacuum drying

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Introduction

Chayote (*Sechium edule*, Cucurbitaceous), commonly known as vegetable pear or mirliton, is indeed native to Mexico and Central America, specifically in regions such as southern Mexico and Guatemala. While it may not have had significant commercial value in its native regions historically, it has gained popularity as a vegetable in various parts of the world due to its versatility and nutritional benefits[1]. It is grown all over the world as a vegetable for local communities[1,2]. The chayote has been grown successfully in the northeastern and southern parts of India, like Sikkim, Meghalaya, Arunachal Pradesh, Darjeeling, Himachal Pradesh, Karnataka, and Kerala.

The chayote fruit is highly perishable due to its high moisture content, i.e. up to 96%. The fruit also has nutrients like crude protein (1.1%), crude fat (0.3%), carbohydrates (7.5) and crude fibre (0.7%) on a wet basis[3]. It is also a rich source of calcium 17-140 mg/100 g (dry weight), and hence, it can be a good supplement in tropical diets[4]. It is mostly consumed as puree, soup and salad[5]. Chayote is also popular in South Indian cuisines where it is used in vegetable stews like "*Palya*", "*Saambar*", or "*Kootu*"[1]. In many regions, sun-dried slices are rehydrated in warm water before being used in different preparations.

Drying limits the quality and quantity of fruits like chayote, which are sensitive to chemical and microbial deterioration during postharvest storage and handling, thereby saving heavy economic losses[6]. In addition, the ready-to-cook dehydrated vegetable products show potential application as ingredients in vegetables and soup mixes[7]. Conventional air drying was reported as the most frequent dehydration method in the food industry, especially for vegetables and fruits[8]. Many studies have been carried out for various types of vegetables like carrots, pepper, corn, tomatoes, mushrooms, garlic, onions, potato, spinach and pumpkin[8-11]. Furthermore, the drying of chayote was reported by Alvarez-Morales *et al.*[12] and Kaur *et al.*[13], who studied drying kinetics and the effect of drying on physico-chemical and rehydration characteristics of chayote, respectively. The vacuum drying process for the dehydration of chayote was optimised by Perez-Francisco *et al.*[14].

Recently, it was reported that drying improved the physico-chemical characteristics of dried vegetable

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pear[14]. Therefore, drying is a feasible method to preserve vegetal pear/chayote. Vacuum enhances the mass transfer because of an increased pressure gradient between the inside and outside of the sample to dry and maintain a low-temperature level essential for thermo labile products[15]. Thus, the study used vacuum drying to produce ready-to-cook dried slices. Optimisations of the processing conditions are required to improve the end product quality at minimum cost and maximum throughput, which, in turn, may improve the degree of acceptance of dehydrated products in the market.

Materials and Methods

Procurement of raw materials and sample preparation

Fresh, mature and tender fruits of chayote (*Sechium edule*) were procured from the local market, Ranipool, South Sikkim, Sikkim. In order to do taxonomic identification of raw material, help was taken from Department of Horticulture, government of Sikkim and faculty of College of Horticulture, Bermiok, Sikkim. The fruits are light green, ovide in shape and without spiny hairs on the skin. The fruits were stored at 8±0.5°C in the refrigerator before use. The storage time was not more than 12 h in this study. The samples were removed from the refrigerator about 2 h before experimentation and were allowed to attain room temperature. Then, fruits were washed thoroughly in water and evaluated for initial moisture content using an infrared moisture meter (d.b.%) (MA 35, Sartorius, Made in Japan). The fruits were then cut into slices of different diameters and thicknesses based on the experimental design, ranging from 1 to 5 mm thickness. After slicing, kernels were carefully removed from the centre of the slices. To prevent browning, samples were subjected to blanching, where the samples were immersed in hot water at 80°C for 3 min and then cooled at room temperature. The fresh samples of chayote had 95% (w.b.) average initial moisture content.

Vacuum drying of the sample

A pilot scale vacuum dryer was used for drying slices of chayote samples (Fig. 1). The system primarily consists of a water ring vacuum pump (81.3 kPa), forced convective drying chamber, control panel to control experimental temperatures in a side chamber and pressure gauge.

The untreated samples were dried in a preheated (40°C) drying chamber at different plate temperatures ranging from 54 to 66°C. All the experiments were carried out at a constant vacuum pressure of 81.3kPa. About 200 g of sliced chayote (Slice thickness: 1 to 5 mm) were cut using a sharp and clean knife. The samples were blanched and spread uniformly over butter paper placed in an aluminium tray to avoid direct contact between the surface of the tray and the slices. At every one-hour interval, the samples were withdrawn from trays, and the moisture content was measured using an Infrared Moisture meter. The process was repeated until there was a negligible difference in successive moisture contents. Dried samples were cooled in desiccators and then sealed in moisture-proof polythene bags.

Experimental design and optimisation

The full factorial experimental design was used from Minitab 16 to optimise vacuum drying to minimise energy consumption, increase production and have quality ready-to-cook dried products. Duncan's new multiple-range test was used to rank the mean at the 0.05 level in all cases. The drying temperature and slice thickness were regarded as independent variables. Twelve different experiments covering four temperatures and three thicknesses were conducted with three replications, making 36 experiments. The responses commonly used to evaluate the vacuum drying process are final moisture content, rehydration ratio, energy consumption, production rate and total cost.

Quality evaluation of dried products

Moisture content

The moisture content was measured by an Infrared Moisture meter (MA 35, Sartorius, made in Japan).

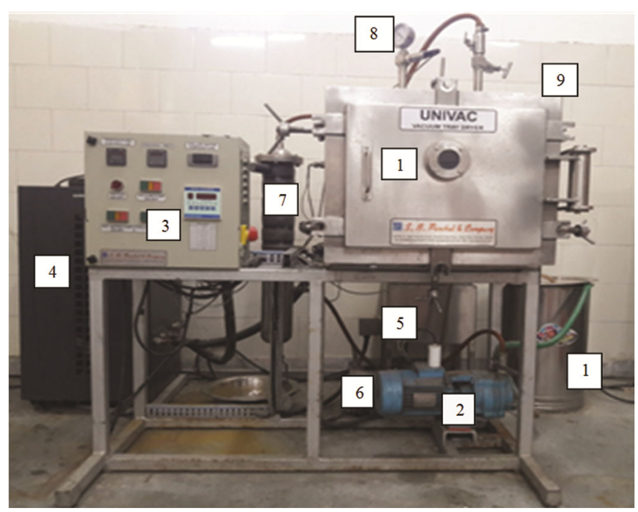

Fig. 1 — Pilot Scale Vacuum Dryer. 1) Drying chamber, 2) Vacuum pump, 3) Control panel, 4) Refrigeration unit with water chiller, 5) Hot water tank, 6) Hot water pump, 7) Condenser, 8) Pressure gauge, 9) Vacuum release valve, 10) Water storage drum for vacuum pump.

Energy consumption

The energy resources required to obtain dried chayote at a given moisture content. Energy consumption by the sample to dry in a vacuum dryer was measured using the following equation

$$E_T = E_1 + E_2 + E_3$$

where E_T = Total energy consumption by the vacuum dryer (kW), E_1 = Energy required to run the vacuum pump, E_2 = Energy required to run the hot water pump, E_3 = Energy required to increase the temperature of the drying chamber, and $E_3 = C_v \delta T$.

Rehydration ratio

The rehydration ratio of dried chayote slices was determined as the ratio of rehydrated mass to the initial dehydrated mass, which measures the ability of dried chayote slices to reabsorb water. The procedure explained by Prakash *et al.*[16] was used to determine the rehydration ratio. The experiments were conducted in triplicates, and the rehydration ratio was calculated using the following equation:

$$\text{Rehydration Ratio} = W_r/W_D$$

where W_r = rehydrated sample mass (g) and W_D = initial sample mass before rehydration (g).

Results and Discussion

Results obtained from various vacuum drying experiments and calculations, i.e. final moisture content of the dried product, production rate (g d. p./h), energy consumption and total cost of processing, are presented in Table 1. Fig. 2 shows the dried chayote slices.

The initial moisture of chayote (white variety) slices varied from 94.39% to 98.00% (w.b.), averaging 96.06% (w.b.). Statistical analysis indicated that the drying temperature and slice thickness significantly affected the final moisture content (%, w.b.), production rate (g d. p./h), energy consumption (kWh), the total cost of processing (₹/g, dry product) and rehydration ratio of the dried chayote slices in the vacuum drying process.

Effect of drying temperature and slice thickness on final moisture content

The results showed that the final moisture content (Y_1) decreased with increasing temperature except at

Table 1 — The full factorial analysis of vacuum drying of chayote

T (°C)	t (mm)	IMC (%, w.b.)	Y_1 (%, w.b.)	Y_2 (g d.p./h)	Y_3 (kWh)	Y_4 (₹/ g d.p.)	Y_5 (₹/g)	Y_6 (₹/g)	Y_7
66	5	98.00	6.15^{abcd}	0.53^{a}	16.80^{d}	21.03	0.03	21.06^{k}	4.01^{a}
66	3	96.34	5.60^{abc}	1.39^{e}	10.50^{ab}	7.23	0.03	7.26^{c}	3.92^{a}
66	1	97.12	5.43^{abc}	1.52^{f}	10.50^{ab}	9.20	0.03	9.23^{h}	3.81^{a}
62	5	96.34	4.64^{ab}	1.07^{b}	18.13^{ef}	12.60	0.03	12.63^{j}	4.97^{abc}
62	3	96.21	6.15^{abcd}	1.68^{g}	12.08^{bc}	7.98	0.03	8.01^{e}	4.01^{a}
62	1	97.00	7.25^{bcd}	1.16^{c}	10.07^{a}	8.31	0.03	8.34^{f}	4.71^{ab}
58	5	94.94	6.92^{bcd}	1.36^{e}	17.60^{e}	8.64	0.03	8.67^{g}	5.84^{cd}
58	3	95.51	3.50^{a}	1.66^{g}	11.74^{b}	6.73	0.03	6.76^{b}	5.83^{bcd}
58	1	95.08	5.23^{abc}	2.16^{h}	11.736^{b}	6.03	0.03	6.06^{a}	7.03^{d}
54	5	95.95	6.30^{ab}	1.20^{d}	18.98^{f}	11.72	0.03	11.75^{i}	4.34^{a}
54	3	94.39	7.66^{cd}	3.04^{j}	13.29^{c}	5.83	0.03	5.86^{a}	4.01^{a}
54	1	95.78	8.66^{d}	2.89^{i}	13.29^{c}	7.67	0.03	7.70^{d}	6.04^{cd}

Note: Means within columns with different superscripts indicate significant different values (P <0.05) obtained using Duncans' multiple range test.

Where, T – Temperature, t – Thickness, IMC – Initial moisture content, Y_1 – Final Moisture content, Y_2 - Production, Y_3 – Energy consumption, Y_4 – Cost of Energy consumed, Y_5 – cost of raw material, Y_6 – Total cost of processing and Y_7 – rehydration ratio.

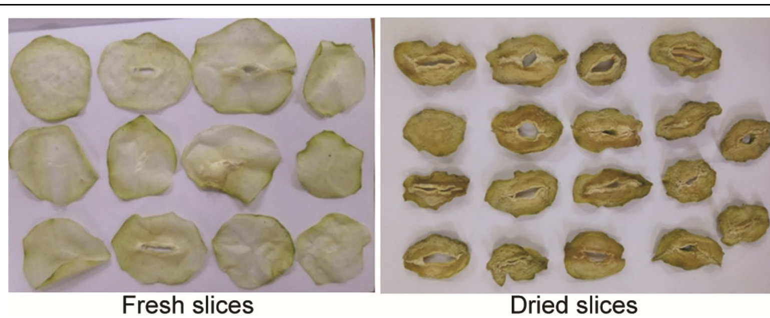

Fig. 2 — Dehydrated Ready-to-Cook Chayote Slices. a) Fresh slices; and b) Dried slices.

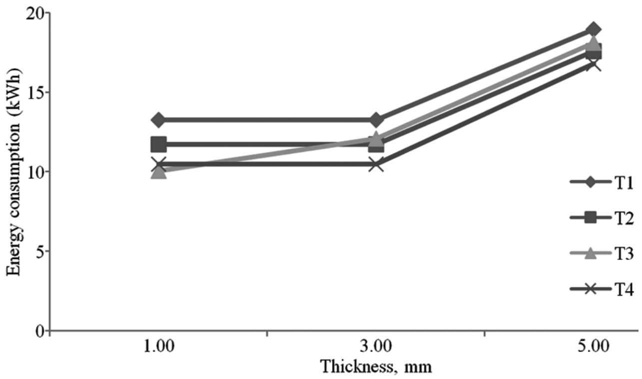

Fig. 3 — Effect of vacuum drying temperature and slice thickness on energy consumption (kWh) (T_1 – 54°C, T_2 – 58°C, T_3 – 62°C and T_4 – 68°C).

62°C. The effect of thickness on the final moisture content was more pronounced at a higher temperature, but at temperatures 54 and 62°C, final moisture content (w.b.) increased with an increase in slice thickness. In other cases, Y_1 decreased slightly in the case of thinner slices. Since the moisture content of vacuum-dried chayote slices was well within the moisture content range of safe moisture level, further reduction was not required. The contrary results may be due to different initial moisture contents and drying periods.

The ANOVA showed that the temperature has a significant effect on the Y_1, but the slice thickness has no significant effect on the Y_1 values obtained during experimentation. According to Kaur *et al.*[13], as the temperature of drying increased, the time for drying decreased significantly. This may be the reason for the non-significant effect of thickness. Duncan's Multiple Range test (DMRT) showed that the highest Y_1 (8.66%) was obtained at 54°C and 1 mm thickness while the lowest (3.50%) was at 58°C and 3 mm thickness.

Effect of drying temperature and slice thickness on production rate (g d. p./h)

The production rate indicates the yield of dried slices obtained at different treatment combinations per hour. The production rate decreased with the increase in temperature of drying and thickness, except at 62°C and 1 mm slice thickness and at 54°C and 5 mm thickness. The decrease in production rate may be due to more loss of moisture at high temperatures. As slice thickness increased, the duration of drying increased, which caused the highest removal of moisture due to a longer exposure period.

It was observed that both vacuum drying temperature and slice thickness have a significant effect on production rate, which supports the results obtained by Perez-Francisco *et al.*[5] and Kaur *et al.*[13]. Also, the interactive effect of temperature and slice thickness was there while vacuum during of chayote slices. The DMRT results showed that the production rate was significantly different for each treatment. However, the highest production rate (3.04 g d. p./h) was obtained at 54°C and 3 mm thickness and the lowest (0.53 g d. p./h) at 66°C and 5 mm.

Effect of drying temperature and slice thickness on energy consumption (kWh)

The energy required for drying each sample (250 g) was calculated from the energy required to raise the temperature using a heater, the energy required for circulating hot water through a vacuum dryer using a water pump and the energy required for creating a vacuum inside the tray drier using a water vacuum pump. Fig. 3 shows the effect of vacuum drying temperature and slice thickness on energy consumption (kWh). It was observed that energy consumption decreased within temperature and slice thickness as well. When there was an increase in temperature, the rate of moisture removal increased, which caused a reduction in drying time, which may be the reason behind the reduction in energy consumption. In addition, a decrease in slice thickness increases the surface area, which exposes more area to increased temperature, causing speedily drying of chayote slices. Ultimately, all the above reasons might reduce energy consumption with a decrease in slice thickness.

The DMRT analysis showed more energy consumption (18.98 kWh) at 54°C and 5 mm thickness and lowest (10.07 kWh) at 62°C and 1 mm slice thickness.

Effect of drying temperature and slice thickness on total cost of processing (₹/g)

While calculating the total cost of processing, capital investment, such as the cost of equipment, water charges, and labour investment, was ignored. The addition of raw material cost and the cost of energy consumed gave the total cost of processing (₹/g d.p.). It was observed that there was a significant effect of treatments on the total cost of processing, which is mainly due to variations in energy consumption values. The DMRT results showed that the highest cost of processing (12.630 ₹/g) required for treatment consisting of 62°C and 5 mm Thickness, and the lowest cost of processing (5.864 ₹/g) was at 54°C and 3mm slice thickness.

Effect of drying temperature and slice thickness on rehydration ratio

The rehydration ratio gives the amount of water required to rehydrate the dried sample, which describes the quality of dried slices.

The rehydration characteristics of dried products are associated with their structural characteristics, particularly internal and/or surface pores[17]. The results showed that the rehydration ratio was significantly affected by vacuum drying temperature and slice thickness. The lowest rehydration ratio (3.81) was obtained at 66°C and 1 mm slice thickness, while the highest rehydration ratio (7.03) was at 58°C and 1 mm slice thickness. Other researchers reported similar results for drying of similar products[13,18,19]. Alvarez-Morales *et al.*[12] reported that the shape of the sample also has a significant effect on the drying and rehydration. For the same volume, the cube has more surface area than the slice. Therefore, both rehydration and drying rates were higher in those results. However, this might be observed only in fluidised conditions where all the surfaces get exposed, and relatively uniform drying occurs. However, in the case of tray drying, uniform drying from all surfaces is not feasible.

Moreover, the tray drying has changed the colour of slices to darker, possibly due to the concentration or binding of pigments or enzymatic reactions[20]. Vacuum drying prevents the degradation of colour, which is an obvious case in other types of hot air drying methods[21].

Optimisation of process parameters for vacuum drying of chayote slices

During the optimisation of process parameters of the vacuum drying process, the objective is to minimise the cost of processing and to have an optimum rehydration ratio. From the analysis using full factorial design and DMRT, it was observed that the optimum vacuum drying was 58°C and slice thickness was 1 mm. The results were at par with the treatment consisting of a vacuum drying temperature of 58°C and a slice thickness of 3 mm. From experience, slicing the chayote to 1 mm thickness was too difficult; hence, treatment of 58°C temperature and 3mm slice thickness may be considered optimum process parameters.

Conclusion

The study showed that the chayote has significant scope to convert into dried slices, which can be rehydrated and used for different value-added products. The study showed that the temperature has a significant effect on the final moisture content, but the slice thickness has no significant effect on it. It was also observed that both drying temperature and slice thickness have a significant effect on production, energy consumption, total cost of processing, and rehydration ratio. From the analysis using full factorial design and DMRT, it was observed that the optimum vacuum drying was 58°C and slice thickness was 1 mm. The results were at par with the treatment consisting of a vacuum drying temperature of 58°C and a slice thickness of 3 mm. From experience, slicing the chayote to 1 mm thickness was too difficult; hence, treatment at 58°C temperature and 3mm slice thickness may be considered as optimum process parameters.

Conflict of interest

The authors have no conflicts of interest to declare.

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