



Transformative effects of infrared-assisted hot air drying on neera syrup concentrated coconut flakes: a comprehensive evaluation of physical properties, composition analysis and antioxidant profiles

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Abstract

The objective of this study is to develop coconut flakes that are readily consumable, using various drying techniques following osmotic dehydration in neera syrup concentrate (50°Brix). A novel methodology and process have been established to create these coconut flakes, offering a distinct production approach. The infusion of neera syrup enhances taste, flavor, and color and augments the product's nutritional content. Through drying experiments at 55, 65, and 75 °C temperatures, the study seeks to identify the most suitable drying method and temperature. Analysis of the bioactive profile revealed that coconut flakes dried at 65 °C using infrared-assisted hot air dehydration (IRHAD) demonstrated exceptional nutritional attributes. These include a Hausner ratio of 1.04, Carr's index of 4.22, rehydration ratio of 2.37, hygroscopicity of 1.68%, bulk density of 0.552 g/mL, tapped density of 0.610 g/mL, protein content of 3.92%, carbohydrate content of 33.86%, fat content of 34.29%, ash content of 1.92%, total phenolic content of 105.38 mg GA/100 g, DPPH activity of 88.81%, and FRAP of 0.00893 mg TE/100 g. Further investigations are warranted to assess the shelf life of coconut flakes, the influence of various packaging materials, and delve deeper into the biochemical properties of the dried samples.

Keywords Infrared drying · Moisture content · Tapped density · Hausner ratio · Hybrid drying · Biochemical properties

Introduction

Cocos nucifera L., commonly known as coconut, is globally acknowledged for its versatile applications spanning multiple industries [1]. Its diverse product range encompasses copra, coconut oil, virgin coconut oil, coconut milk, desiccated coconut powder, tender coconut water, coconut sugar derived from inflorescence sap, and various items

based on raw kernel, all of which have gained significant popularity among consumers [2]. The kernel and coconut water, frequently utilized components, are esteemed for their wide-ranging beneficial properties, including antibacterial, antifungal, antiviral, antioxidant, hypoglycemic, and immune stimulant effects [3].

In response to evolving consumer preferences, there has been a surge in the exploration of innovative coconut-based products beyond its traditional utility. Notably, fruit and vegetable flakes have garnered attention as dehydrated commodities with reduced moisture content, ensuring an extended shelf life while retaining essential nutritional properties. Various types of flakes, such as soybean, corn, and potato flakes, are available in the market [4]. While potato flakes are generally safe for cooking, excessive intake may lead to digestive effects [5]. Cornflakes, containing high fructose corn syrup (HFCS) with a high glycemic index, are deemed unsuitable for daily consumption [6]. Soybean flakes, on the other hand, contain antinutrients and

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phytoestrogens, potentially causing allergies and stomach issues [7].

Coconut flakes, characterized by thin, flat pieces of dried, baked, or toasted coconut kernel, have found versatile applications in cake toppings, desserts, smoothies, baked goods, salads, and more [8]. Loaded with significant amounts of fiber, fats, carbohydrates, proteins, polyphenols, and antioxidants, coconut flakes are available in both sweetened and unsweetened variations. Research by Trinidad et al. [9] revealed that incorporating 15% and 25% of dietary fiber from coconut flakes into regular meals led to decreased total and LDL cholesterol as well as triglyceride levels in the serum of humans. Additionally, adding coconut flakes to wheat bread enhanced its nutritional value due to the increased protein and fiber content, acting as a prebiotic to support probiotic bacteria, promote digestion, and prevent constipation [10].

According to the Food Safety and Standards Authority of India (FSSAI), coconut flakes are officially described as the product obtained from the edible parts of mature coconuts, crafted through processes involving peeling, milling, and drying the coconut kernel. FSSAI sets certain standard values for coconut flakes, including a maximum moisture content of 3%, a total ash content not surpassing 2.5%, and a minimum oil content of 55%. The bakery and fried snacks industry has adopted the use of dried coconut gratings as a filling material [11]. Currently, the savory/bakery industries are urged to use sweetened coconut kernel due to its health benefits and delicious taste. Recent years have witnessed a huge development in the production of diversified snack products in the food industry. Yahya et al. [12] studied the drying parameters such as drying time and color quality of coconut flakes obtained through convective drying. In their study, they found that enzymatic browning can limit a product's shelf life when dried to a great extent. In another study, Adelekan and Alamu [10] developed wheat bread infused with coconut flakes obtained by drying coconut flakes in a cabinet dryer that operates at high temperatures (70–80 °C). The high temperature drying may cause deterioration in the nutritional quality of the flakes [13]. In this context, the present focus is on the development of naturally sweetened coconut flakes using coconut sap concentrate and the effect of different dryers on the quality of the developed products.

Neera (coconut inflorescence sap) is a natural nutritive drink loaded with all essential nutrients, minerals, and vitamins [14]. The higher contents of minerals such as sodium and potassium, the elevated level of amino acids including cysteine, tyrosine, arginine, and vitamins A and C indicate the therapeutic importance of coconut *neera* [15]. During osmotic dehydration, the minerals and vitamins from the solution along with its flavor and color were absorbed by coconut flakes, and some moisture and solutes were

leached out from gratings to the solution. The combination of *neera* infusion and innovative hybrid drying methods such as IRHAD results in a product that not only stands out for its enhanced taste but also offers improved texture and extended shelf life.

Prior research indicates that the utilization of infrared and combined drying methods is superior to the conventional hot air dryer across various temperatures for coconut and other products. In recent studies, infrared radiations are popularly used in the drying of food materials due to its advantages like low drying time, quality of final dried product, greater energy saving capacity and it is a cheaper method compared to microwave and vacuum drying methods [16]. Apart from using infrared radiation alone, combination of infrared with other methods such as hot air drying, microwave, freeze drying and electromagnetic vibration has numerous advantages like optimum energy efficiency [17]. Drying of carrot and potato slices showed approximately 48% reduction in drying time and 63% reduction in energy for infrared and its combination drying [18]. Jeevarathinam et al. [19] also observed that infrared-assisted hot air drying at 60 °C has better quality retention of turmeric slices.

To the best of our knowledge, there is no standard method or process protocol built to prepare sweetened coconut flakes. Hence, the present study aims to develop a process for the production of osmotically dehydrated sweetened coconut flakes with the aid of three different drying techniques (hot air, infrared, and infrared-assisted hot air drying) and allowing for a comprehensive comparison of biochemical characteristics across different samples.

Materials and methods

Materials

Coconuts with 10 months maturity (Var. WCT) were sourced from the farm of ICAR- Central Plantation Crops Research Institute (ICAR-CPCRI), Kasaragod, India. *Neera* syrup, concentrated to 50°Brix, was prepared from coconut sap collected from the inflorescence using a coco sap chiller (Patent number 373309) developed by ICAR -CPCRI, Kasaragod.

Sample preparation

High-quality coconuts were carefully chosen to obtain 500 g of coconut gratings. These coconuts underwent a series of unit operations, including dehusking using a dehusker with a capacity of 350 coconuts per hour and a power input of 2 hp, deshelling employing a desheller with a capacity of 150 coconuts per hour and a power input of 0.5 hp, and testa

removal using a testa removal machine with a capacity of 100 coconuts per hour and a power input of 0.5 hp. These operations were performed by the machineries developed at ICAR-CPCRI. The coconut, after testa removal, underwent a thorough washing and subsequent cutting into pieces. To deactivate enzymes, the coconut pieces were then subjected to blanching in hot water at 90–95 °C for 2 min. The blanched coconut pieces were cooled and manually grated using a standard vegetable grater from M/S Ajanta Industries in Gujarat. The resulting gratings underwent osmotic dehydration utilizing concentrated coconut sap to reduce moisture content before drying, aiming to enhance the biochemical, sensory, and textural characteristics of the coconut flakes.

Around 3 L fresh *neera* was collected using the coco sap chiller developed by ICAR-CPCRI and the fresh samples were stored in the freezer (-18 °C) until further use. The primary quality parameter of *neera* such as pH (6.5) was analyzed using a pH meter (EUTECH Instruments, Singapore, model-700). Then, the fresh *neera* was boiled in a hot pan at an average temperature of 90–95 °C for 1.5–2 h to prepare a syrup (50 °Brix). The total soluble solids (TSS) were analyzed using the pocket refractometer (ATAGO, 0–85%). Concentrated *neera* syrup (800 mL) was poured into coconut gratings (500 g) for osmotic dehydration for 1 h and then dried using different drying methods (Fig. 1). *Neera* syrup is a highly viscous osmotic medium, hence, about 800 mL is essential to ensure complete dipping of 500 g coconut gratings. After one hour of dipping/osmosis process, flakes were strained for half an hour to filter the solution, spread in the trays and dried using different drying methods. Figure 2

depicts the process flow chart for the preparation of coconut flakes.

Drying experiments

The drying experiments were promptly initiated using three distinct methods. These methods included hot-air drying (HAD), infrared drying (IRD), and infrared-assisted hot-air drying (IRHAD). In the HAD process, pretreated coconut flakes were evenly spread in a single layer on the bed. The HAD/IRD/IRHAD equipment, manufactured by M/S N P Technology in Maharashtra, allowed for the operation of infrared-assisted hot air dryers either individually (IRD/HAD) or in a hybrid (IRHAD) mode. This system operated with a 415 V power supply and a 1/2 HP motor, featuring a variable speed controller for adjusting air velocity. It incorporated three infrared bulbs (54.6×12.7×5.1 mm), each with 1 kW power. S.S.304 tubular air heaters served as heat generators on both sides, powered by a 3-phase 415-volt AC supply. The front side featured a double-walled door equipped with a food-grade rubber gasket for effective sealing. Also, the ventilation adjustments could be made near the top exhaust.

For all treatments, thin layer/single layer drying was employed. Hot-air drying involves activating heat coils, with hot air uniformly distributed by a blower. In infrared drying, the coil emitting infrared radiation was activated, and for combination drying, three heating coils, along with infrared light, were switched on. The experiments were conducted at drying temperatures of 55, 65, and 75 °C. Initial weight and moisture content were recorded, and the

Fig. 1 (a) Freshly prepared grated coconut and (b) osmotic dehydrated coconut flakes

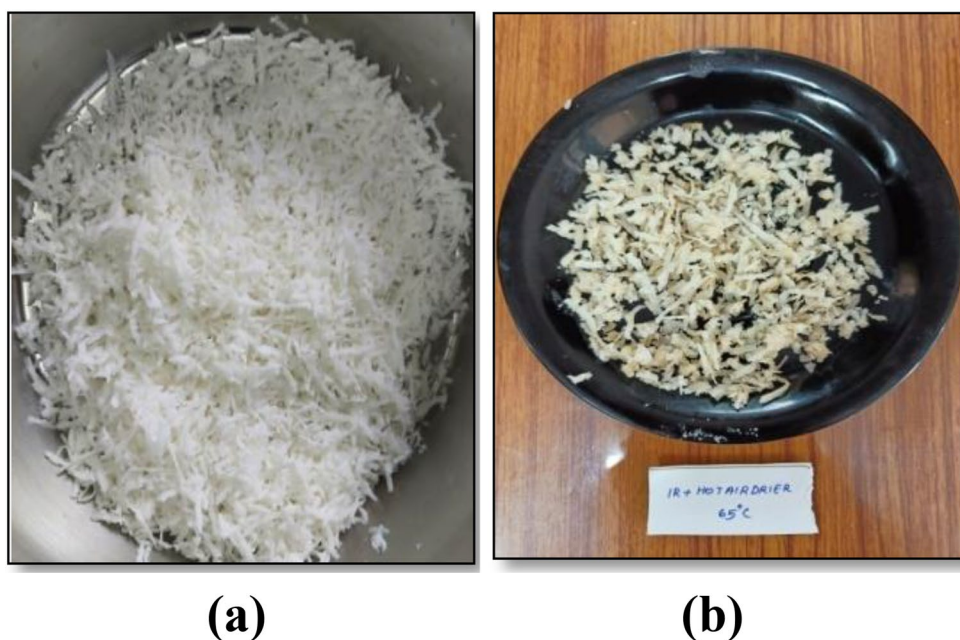
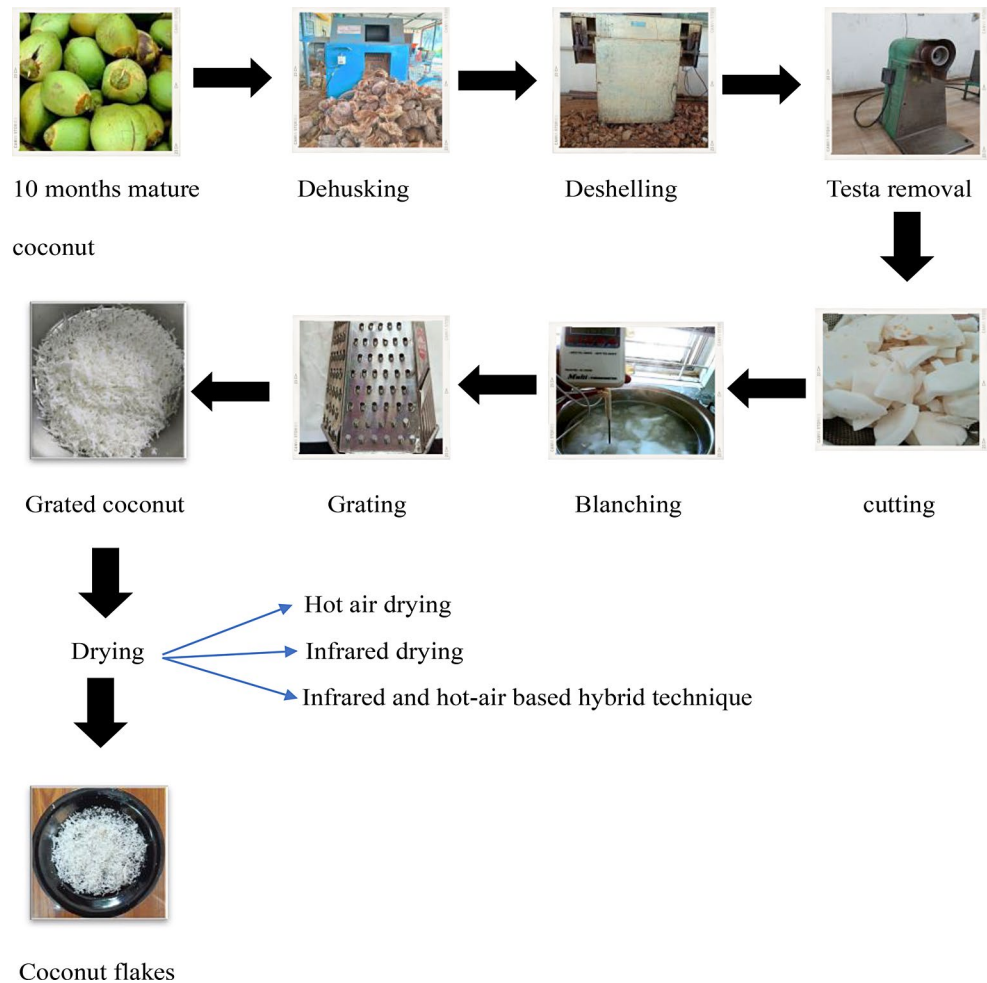


Fig. 2 Process involved in the preparation of coconut flakes



sample's weight was measured at 10-minute intervals until a consistent weight was achieved.

Physical properties

Rehydration ratio

The rehydration capacity of the final dried coconut flakes was measured. Five gram sample was rehydrated for 3 h in 250 mL water. Then the rehydrated samples were taken and weighed [20].

$$\text{Rehydration ratio (RR)} = \frac{M_r}{M_d} \quad (1)$$

M_r - mass after rehydration (g).

M_d - mass before rehydration (g).

Hygroscopicity

Five grams of samples were placed at controlled temperature and relative humidity of 25°C and 75% respectively.

The humidity condition was maintained by placing the sample in a desiccator containing saturated NaCl solution. The weight of the sample was noted after one week and the weight gained was calculated [21].

Bulk density (BD)

Bulk density represents the bulk volume of flakes. It was measured by weighing the sample completely filled in a beaker and the volume of the beaker was measured [22].

$$BD \left(\frac{g}{ml} \right) = \frac{\text{Weight of sample (g)}}{\text{Volume of sample (mL)}} \quad (2)$$

Tapped bulk density (TD)

A beaker of known volume was filled with samples and tapped 50 times to fill it completely [23].

$$TD \left(\frac{g}{ml} \right)$$

$$\frac{\text{Final weight of sample after tapping (g)}}{\text{Volume of sample (mL)}} \quad (3)$$

Compressibility index (C) and Hausner ratio (H) were also calculated from the above data. Hausner ratio is used as an internal friction index for cohesive powders and is the ratio between tapped and bulk density [24].

$$C = \frac{T - B}{T} \times 100 \quad (4)$$

$$H = \frac{T}{B} \quad (5)$$

where T- Tapped density (g/mL) and B- Bulk density (g/mL).

Biochemical analysis

Proximate composition The proximate composition analysis of coconut flakes included the determination of moisture (AOAC 934), ash (AOAC 938.08), and total protein using the Kjeldahl method (AOAC 978.02). It also involved measuring total carbohydrates using the phenol sulfuric acid method (AOAC 44.1305) and fat content using the Soxhlet method (AOAC 920.58).

Total phenol content (TPC) The assessment of total phenolic content utilized the Folin–Ciocalteu (FC) reagent through a spectrophotometric method. This procedure followed the method outlined by Seneviratne and Kotuwegedara [25].

The results were expressed as milligrams of Gallic acid equivalent phenolics per gram of extract (mg GAE/100 g).

Antioxidant potential by FRAP and DPPH methods FRAP was performed according to Benzie and Strain [26] and 2,2-diphenylpicrylhydrazyl (DPPH) assay was carried out according to the method of Brand-Williams et al. [27].

Statistical analysis

All the experiment results including physical, biochemical, and proximate analysis were evaluated using ICAR statistical analysis -Web Agri Stat package 2.0. Experiments were conducted in three replicates and data were given as mean \pm standard deviation. Confidence level was set at a probability value of 0.05 [21].

Results and discussion

Effect of processing on rehydration ratio (RR) of dried coconut flakes

Rehydration properties play a crucial role in dried materials, influencing the water adsorption quality of dried food materials. A higher rehydration rate indicates minimal tissue damage or slight changes occurred to them during the drying process [28]. Table 1 shows rehydration ratio of dried samples at different drying methods and temperatures significantly affects the RR ($p < 0.05$). The lowest RR (1.57) was observed for osmotically dehydrated coconut flakes in HAD at 75 °C followed by IRD at 75 °C and then IRHAD at 75 °C. The uneven heat distribution, potential for structural damage, and nutrient loss associated with conventional HAD methods can collectively contribute to lower rehydration

Table 1 Evaluation of physical properties of coconut flakes prepared with osmotic dehydration and other drying techniques

Treatment	Sample code	Temperature (°C)	Physical properties					
			Rehydration Ratio	Hygroscopicity (%)	Bulk Density(g/mL)	Tapped density (g/mL)	Compressibility index	Hausner ratio
T 1	IRD	75	1.61 \pm 0.03 ^d	4.06 \pm 0.02 ^a	0.534 \pm 0.04 ^f	0.624 \pm 0.01 ^{de}	6.62 \pm 0.02 ^f	1.06 \pm 0.12 ^f
T 2	IRD	65	2.13 \pm 0.03 ^b	1.42 \pm 0.04 ^d	0.576 \pm 0.04 ^c	0.627 \pm 0.02 ^d	5.57 \pm 0.01 ^g	1.07 \pm 0.03 ^e
T 3	IRD	55	2.11 \pm 0.14 ^b	0.96 \pm 0.01 ^{fg}	0.604 \pm 0.06 ^{bc}	0.671 \pm 0.03 ^{ab}	7.21 \pm 0.01 ^e	1.08 \pm 0.04 ^d
T 4	IRHAD	75	1.81 \pm 0.03 ^c	4.06 \pm 0.02 ^a	0.534 \pm 0.03 ^f	0.580 \pm 0.12 ^f	7.45 \pm 0.03 ^d	1.04 \pm 0.03 ^g
T 5	IRHAD	65	2.37 \pm 0.06 ^a	1.68 \pm 0.01 ^c	0.552 \pm 0.02 ^e	0.610 \pm 0.02 ^e	7.22 \pm 0.13 ^e	1.04 \pm 0.02 ^g
T 6	IRHAD	55	2.11 \pm 0.03 ^b	1.12 \pm 0.04 ^{ef}	0.573 \pm 0.01 ^{cd}	0.662 \pm 0.04 ^{bc}	8.13 \pm 0.02 ^b	1.09 \pm 0.02 ^{bc}
T 7	HAD	75	1.57 \pm 0.11 ^d	2.17 \pm 0.03 ^b	0.576 \pm 0.03 ^c	0.610 \pm 0.03 ^e	9.50 \pm 0.04 ^a	1.08 \pm 0.03 ^d
T 8	HAD	65	1.90 \pm 0.11 ^c	1.23 \pm 0.06 ^{de}	0.621 \pm 0.01 ^{ab}	0.651 \pm 0.01 ^{bc}	7.93 \pm 0.04 ^c	1.09 \pm 0.01 ^b
T 9	HAD	55	1.91 \pm 0.08 ^c	0.72 \pm 0.01 ^g	0.634 \pm 0.07 ^a	0.679 \pm 0.01 ^a	8.17 \pm 0.01 ^b	1.10 \pm 0.03 ^a

*(IR-Infrared; HAD- Hot air dryer; IRHAD-Infrared assisted hot air dryer; (The different letters in the columns indicates a significant effect at level of 0.05.)

ratios in food samples compared to more advanced drying techniques [29]. The rehydration ratio declined as the drying temperature was elevated, possibly due to the temperature's adverse impact causing sugar caramelization and the internal structure may be damaged [30]. Consequently, pores on the surface became obstructed, leading to reduced water diffusion during rehydration [31]. Zalpouri et al. [30] observed that prolonged drying periods and excessive heat exposure during convective tray drying can create an impermeable layer on potato flakes, impeding the rehydration process and preventing the dried product from regaining its original volume and shape.

While the rehydration ratio was higher for samples dried on IRHAD at 65 °C. A higher rehydration rate indicates minimal tissue damage or slight changes occurred to them during the drying process [28]. The higher rehydration ratio observed with an IRHAD is likely due to several factors including reduced drying time, the consistent and controlled heating minimizes physical and chemical alterations in the food. This preserves the food's cellular structure, making it more receptive to reabsorbing water during rehydration [32]. Some research results explained that the food matrix having less deformation due to moderate drying temperature and drying time has greater RR [33].

Effect of processing on the hygroscopicity of dried coconut flakes

Hygroscopicity plays a vital role in dried snack products, influencing the ultimate crispiness of the final item [34]. Hygroscopicity is the ability of food to absorb water in a humid environment or release water in a dry environment. Reduced drying duration results in decreased shrinkage and enhances the rehydration as well as the hygroscopic characteristics [35]. Similar to the above observation, coconut flakes samples dried using IRD and IRHAD at 75 °C observed to be increased hygroscopicity values (4.06%). The explanation could be attributed to the ability of IRD and IRHAD methods to maintain the surface qualities of food due to its volumetric heating [19]. This retention of surface characteristics can enhance the food's ability to attract and retain moisture from the surrounding environment, leading to a higher hygroscopicity value. Glucose and fructose in fruit powders exhibit robust bonding with water molecules because of the polar ends found in these molecules, fostering a robust interaction [36]. The reduced moisture content of coconut flakes through IR and IRHAD also resulted in a higher hygroscopicity value. Tonon et al. [37] indicated that the reduced moisture content in acai powder resulted in an increased hygroscopic property. While the higher final moisture content in HAD led to a lower hygroscopicity value at 55 °C. Ferrari et al. [38] suggested that food items

with elevated moisture levels had a reduced ability to take in moisture from their surroundings.

Effect of processing on bulk density and tapped density of dried coconut flakes

Bulk density refers to the mass of a bulk solid occupying a unit volume of space, encompassing the volume of all inter-particle voids. Tapped bulk density is the maximum bulk density that can be achieved without the deformation of the particles. The greater the compressibility index of a product less flowable it is and the Hausner ratio is used to measure the internal friction index for cohesive products [39]. The osmotically dehydrated flakes exhibited higher bulk density and tapped density in the HAD samples at 55 °C, along comparatively increased with compressibility index and Hausner ratio than other treatments. Non-uniform drying in HAD can lead to uneven moisture removal, causing certain parts of the food to be over dried while others remain moist [40]. This non-uniform drying can lead to extreme shrinkage and inner destruction of cells which results in inconsistent bulk density within the food sample [41]. Mirhosseini and Amid [42] also reported similar findings of higher bulk density for durian seed gum samples dried under a hot air oven than other novel drying methods. In addition, as the drying temperature decreased from 75 °C to 55 °C, bulk and tapped density increased.

IRHAD sample at 75 °C exhibited the lowest values for both densities, as well as the compressibility index and Hausner ratio. IRHAD often heats the surface of the food material more rapidly, allowing moisture to escape quickly. This can result in less shrinkage compared to conventional hot air dryers, leading to a lower bulk density as the volume reduction due to moisture loss is minimized [43]. The lower bulk density of dried products is often preferred as it enhances sensory qualities and increases consumer approval [44]. The compressibility index and Hausner ratio values for each treatment were observed under the excellent flowability category according to the classification of the European Pharmacopoeia (Powder flow, European Pharmacopoeia, 2011).

Effect of different dryers and drying temperature on the moisture content of dried coconut flakes

Moisture content is an important parameter to be considered for the dried snacks as it affects shelf life along with its crispiness [45]. If moisture content is increased, the water activity also increases which leads to the deterioration of the product due to microbial action [46]. By analyzing moisture ratio v/s drying time isotherm it is evident that at high temperature, there is a rapid decline in moisture content. Table 2

shows the significant effect of different drying methods and drying temperatures on moisture content ($p < 0.05$).

Osmosis is a pre-treatment that reduces some percentage of moisture content along with migration of some solutes to the product. IRHAD sample at 75 °C (2.36%) observed the lowest moisture content due to the specific heating mechanism they employ. The synergy between infrared radiation and hot air allows for faster and more efficient drying. Infrared radiation directly heats the water molecules within the material, causing them to evaporate quickly. Hot air, on the other hand, helps in carrying away the moisture released by the infrared heating, expediting the overall drying process [47]. Jeevarathinam et al. [19] reported less drying time for turmeric slices dried under the IRHAD method compared to IRD and HAD. This may be due to more mass and heat transfer processes involved in the IRHAD drying method than in other methods.

HAD samples at 55 °C were found to be high moisture content compared to other treatments. This method may not penetrate deeply into the material to efficiently remove moisture within the sample [48]. As a result, moisture can remain trapped deeper in the material and leading to higher retention. Studies have revealed that agricultural products such as apples, strawberries, tomatoes, and mushrooms dried with a microwave-assisted hot air dryer exhibit a greater reduction in water content compared to those dried by HAD methods [49].

Effect of different dryers and drying temperature on ash content of dried coconut flakes

Ash refers to the inorganic residue remaining after either ignition or complete oxidation of organic matter in a foodstuff [50]. Ash content signifies the cumulative mineral composition within foods [51]. Table 2 shows the variation in ash content according to different drying methods and temperatures. It was noticed that the drying methods significantly affected the ash content in coconut flakes ($p < 0.05$).

Osmotically dehydrated coconut flakes preserved a higher amount of volatile and inorganic substances in the sequence of IRHAD > IRD > HAD. Differences in the methodology of IRHAD such as the duration and intensity of infrared radiation, the temperature gradient, and the overall drying process, can significantly affect the preservation of volatile and inorganic substances. Vega-Galvez et al. [52] has mentioned the variation of ash content of papaya with different drying techniques. According to their findings, papaya dried through infrared techniques showed a slight increase in ash content, whereas convective drying, freeze drying, and vacuum drying displayed a considerable reduction in ash content. The higher ash content in coconut flakes was observed at 65 °C for all the treatments. Typically, the ash content in a food sample increases with temperature. However, excessively high temperatures might also lead to the loss of certain volatile minerals or alter the composition of the ash, affecting the accuracy of the measurement [53]. The temperature and duration of ashing need to be carefully controlled to obtain precise and reliable ash content measurements.

The hot air-dried coconut flakes were noted as reduced ash content (0.76%). Some minerals, especially volatile ones like certain trace elements (e.g., potassium, sodium, zinc), might be lost during the non-uniform HAD process at high temperatures. These minerals can evaporate and escape as gases, resulting in a reduction of the overall ash content. This result is consistent with the results of Isik et al. [54] who also found that the ash content of the bee pollen was slightly reduced under HAD as compared to the fresh sample.

Effect of different dryers and drying temperature on the carbohydrate of dried coconut flakes

Carbohydrate content is important in the case of snacks as it is the source of energy. Coconut contains high amounts of carbohydrates, in the forms of total sugar, reducing and

Table 2 Proximate analysis of coconut flakes prepared with osmotic dehydration and other drying techniques

Treatment	Sample code	Temperature (°C)	Moisture content (% w.b)	Ash content (%)	Carbohydrate (glucose eq/100 g)	Fat content (%)	Protein (%)
T 1	IRD	75	2.62 ± 0.01 ^{cd}	0.69 ± 0.14 ^d	26.43 ± 1.12 ^{cd}	34.75 ± 1.66 ^{bc}	3.72 ± 0.08 ^{ab}
T 2	IRD	65	2.68 ± 0.04 ^{cd}	1.46 ± 0.03 ^b	33.52 ± 2.14 ^a	35.11 ± 2.10 ^{bc}	3.85 ± 0.05 ^a
T 3	IRD	55	2.90 ± 0.04 ^c	0.85 ± 0.24 ^{cd}	30.90 ± 0.99 ^b	40.71 ± 0.34 ^{ab}	3.64 ± 0.05 ^{-bc}
T 4	IRHAD	75	2.36 ± 0.01 ^d	1.43 ± 0.02 ^b	29.25 ± 1.27 ^{bc}	32.57 ± 1.32 ^{cd}	3.91 ± 0.15 ^a
T 5	IRHAD	65	2.52 ± 0.08 ^{cd}	1.92 ± 0.35 ^a	33.86 ± 3.21 ^a	34.29 ± 2.88 ^{bcd}	3.92 ± 0.03 ^a
T 6	IRHAD	55	3.83 ± 0.09 ^b	1.9 ± 0.08 ^a	30.28 ± 1.79 ^b	44.69 ± 0.51 ^a	3.76 ± 0.03 ^{ab}
T 7	HAD	75	3.65 ± 0.11 ^b	0.76 ± 0.02 ^d	26.38 ± 0.66 ^{cd}	29.21 ± 2.50 ^e	3.11 ± 0.18 ^e
T 8	HAD	65	3.93 ± 0.11 ^b	1.25 ± 0.08 ^{bc}	27.50 ± 1.13 ^c	29.86 ± 2.22 ^e	3.25 ± 0.03 ^d
T 9	HAD	55	4.60 ± 0.43 ^a	1.23 ± 0.06 ^{bc}	25.56 ± 1.18 ^e	30.79 ± 1.22 ^{cde}	3.23 ± 0.03 ^d

*(IR-Infrared; HAD - Hot air dryer; IRHAD-Infrared assisted hot air dryer ; (The different letters in the columns indicates a significant effect at level of 0.05)

non-reducing sugars, and dietary fiber. Most of these will be lost during the processing but it can be preserved using novel processing techniques. During slow drying these carbohydrates may be subjected to deterioration and at high temperatures the sugar reacts with amino acids to form Maillard reaction products [55].

Osmotically dehydrated coconut flakes contained about 28–33% carbohydrates (Table 2). High-temperature drying caused a reduction in carbohydrate content as compared to other drying temperatures [56]. HAD at 75 °C showed a significant reduction ($p < 0.05$) in carbohydrate content due to the Maillard reaction and caramelization of sugar which also imparts some color and flavor to the product. It is also observed that drying with IRHAD at 65 °C significantly retained more carbohydrate content compared to drying at 55 °C, while the lowest carbohydrate content was observed at 75 °C. Initially, during the drying process, carbohydrates may concentrate due to the loss of water content. However, if the temperature becomes too high or the drying process is prolonged, there's a risk of chemical changes occurring in carbohydrates. For instance, at very high temperatures, some carbohydrates can undergo degradation or caramelization, leading to a decrease in their overall content. As per the information from Yusufe et al. [57], the carbohydrate content of tomatoes was higher after oven drying at 60 °C compared to the carbohydrate content in the fresh sample. It has been also shown that the content of sucrose increases in cell sap during osmotic dehydration [58].

Effect of different dryers and drying temperature on fat content of dried coconut flakes

Coconut is high in fat and falls under the category of medium saturated fats, recommended for limited consumption to lower the risk of heart disease [59]. Its predominant medium-chain fatty acids are absorbed uniquely and have been linked to various health advantages, such as enhanced cognitive function and a more favorable lipid profile compared to longer-chain fatty acids [60].

The fat content of coconut flakes dried with osmotic pretreatment was in a range of 24–44% (Table 2). The HAD sample at 75 °C observed less fat content (24.21%) ($p < 0.05$) while the IRHAD sample at 55 °C was found to retain high fat content (44.69%). It was suggested that lower-fat versions of foods contain more sugar [61]. Osmotic dehydration in neera syrup increases the sugar content of the product, hence fat content is reduced to a considerable range. The further decrease in fat content during HAD might be caused by the higher temperatures, which can accelerate the oxidation of fats, leading to their degradation and eventual loss [62]. This process can result in the breakdown of fatty acids, causing a reduction in overall fat content. A similar result

was also reported by Bhat et al. [63]. They observed that in hybrid drying the loss of fats was lesser than in individual drying.

Effect of different dryers and drying temperature on protein content of dried coconut flakes

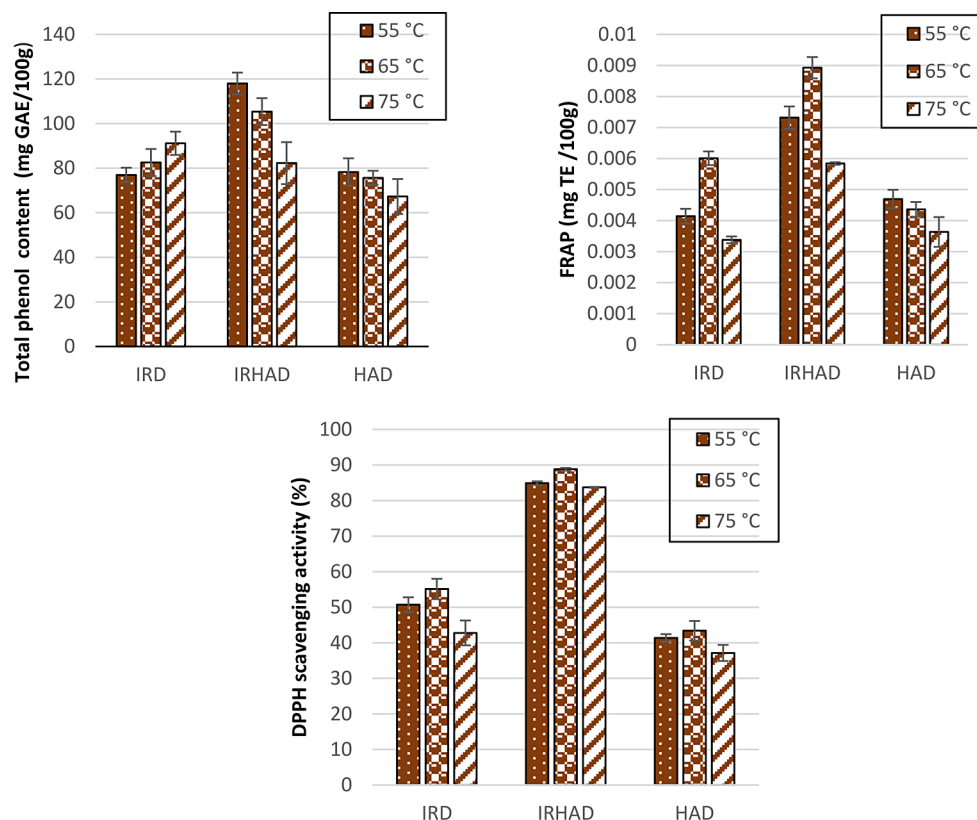
Different drying methods have significantly ($p < 0.05$) affected the protein content (Table 2). IRHAD drying at 65 °C was observed to preserve a high amount of protein (3.92%) while HAD at 75 °C was found to have the least protein content (3.11%). The reduction in protein content could be due to increased drying time at high temperatures of HAD. Here it is evident that protein content also leaches out during prolonged osmosis along with water and solutes. As water is removed from a protein structure, it can cause denaturation, altering its conformation and potentially leading to protein precipitation. In a study [64], it was observed that the application of elevated temperatures during the frying process resulted in a considerable reduction in protein content. In contrast, the lower temperatures associated with drying using microwaves, infrared, or other hybrid drying technology did not affect the protein loss and thereby retained more nutrients [64]. The retention of protein in IRHAD could be resulted from its volumetric heating and the shorter exposure to heat helps preserve the structure of proteins and reduces the extent of denaturation or degradation. Zhao et al. [65] also found a significantly higher retention of protein content in mushrooms when dried by far infrared drying.

Effect of different dryers and drying temperature on total phenolic content (TPC) of dried coconut flakes

According to previous reports, phenolic compounds exhibit free radical inhibition, peroxide decomposition, metal inactivation, or oxygen scavenging in biological systems and prevent oxidative disease burden [66]. It is evident that (Fig. 3) different drying methods and drying temperatures significantly affected the total phenolic content ($p < 0.05$).

In that, the lowest value of TPC (67.28 mg GAE/100 g), was recorded with HAD at 75 °C, while the highest value (118 mg GAE/100 g) was observed with IRHAD at 55 °C. Variations in phenolic compounds might arise from the energy needed for activation, thermal treatments, and the breakdown of enzymes like polyphenol oxidase during drying processes. This suggests that alternative drying techniques could potentially diminish or reduce the presence of certain phenolic compounds identified in this study [67]. According to Jihène et al. [68], it can be observed that an elevation in IR drying temperature significantly impacted the overall phenolic content, causing a substantial decrease

Fig. 3 Biochemical analysis of coconut flakes prepared with osmotic dehydration and other drying techniques



in these elements, particularly at elevated temperatures (60 and 70 °C). Decreases in TPC during dehydration were described as the binding of polyphenols with other compounds or the variations caused in the chemical structure of polyphenols, which cannot be extracted and determined by available methods [69].

The high preservation of TPC in IRHAD might be attributed to minimal alteration or harm to the cellular structure following the drying procedure. According to Zalpour et al. [30], the drying of black raspberry powder using an IRHAD dryer, also indicated a substantial increase in the preservation of polyphenol content.

10 Effect of different dryers and drying temperature on antioxidant activity of dried coconut flakes

The phenolic compounds present in coconut meat, functioning as antioxidants, serve to safeguard cells against oxidative damage, potentially aiding in the prevention of chronic diseases [70]. Results depicted in Fig. 3 show that the IRHAD sample at 65 °C had the highest antioxidant activity in the DPPH assay (88–81%). In the FRAP assay also IRHAD at 65 °C was found to have the highest value (0.00893TE/100G), while in both assays HAD at 75 °C was observed to have the lowest value. IRHAD can sometimes help to retain more antioxidants compared to traditional HAD alone. This method might preserve certain

heat-sensitive antioxidants better due to the reduced drying time and lower overall heat exposure.

Antioxidants have an optimal range of temperatures at which they remain stable and active. Beyond this range, they might degrade or become less effective. The optimum temperature for the coconut flakes was found to be at 65 °C where maximum antioxidant activity was observed. The antioxidant value of the final product could change considerably with the solute used in the osmotic dehydration process [21]. Similarly, within coconut sugar, the by-products resulting from the Maillard reaction are recognized as a significant contributor to antioxidant activity [71]. The antioxidant capacity can be affected by chemical changes, leaching losses, reduced moisture, and solid gain as well as the present bioactive in the profile of the analysis method [71, 72].

Conclusion

The present study is conducted to optimize the processing parameters for sweetened coconut flakes. The uniqueness of the coconut flakes production is attributed to the utilization of distinct drying methods and processes, distinguishing it from conventional approaches. Based on the physical properties and biochemical analysis, IRHAD samples at 65 °C exhibited a strong nutritional profile, with a protein content of 3.92% and a carbohydrate content of 33.86%.

The reduced drying time and potentially lower heat exposure of IRHAD helped to maintain the nutritional quality. The hot air-dried sample was found to exhibit a greater degradation of nutrients and other sensitive compounds in the coconut flakes. It might be due to its longer drying times or higher temperatures. In conclusion, based on the observed outcomes, the IRHAD method appears to be a more favorable technique for drying coconut flakes, preserving overall quality better than traditional HAD. Furthermore, the outcomes of this study may benefit coconut industries in developing countries by enhancing the value of coconut-derived products and promoting sustainable economic growth.

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Data availability Data will be made available on request from corresponding author.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication All authors agreed on the publication of this research work.

Competing interests The authors declare no competing interests.

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