Received: 12 April 2024 | Revised: 27 May 2024 | Accepted: 31 May 2024
DOI: 10.1111/jfpe.14668

ORIGINAL ARTICLE

Journal of Food Process Engineering WILEY

Infrared-aided hot-air drying of coconut: Impact on drying kinetics and quality metrics

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Funding information
ICAR AICRP on PHET, India

Abstract

This study explored various drying techniques and temperatures to analyze their effects on the drying kinetics and quality of copra. The initial moisture content of coconut kernels was 50%–55% (w.b.), which decreased to 6%–8% (w.b.) as a result of the drying process. This study focuses on evaluating the individual and hybrid effects of infrared drying (IRD) and hot-air drying (HAD) techniques to enhance the quality of copra. Three drying methods were used: IRD, HAD, and infrared-assisted hot-air drying (IRAHAD). Coconut pieces were subjected to different drying temperatures (50, 60, and 70°C) with a constant air speed of 2 m/s. Optimal results were achieved by employing the IRAHAD method at 60°C, preserving a crucial fat content of 68.4% essential for increased extraction of oil from copra and comparatively high drying rates. In particular, the drying rates in IRAHAD were twice as high as those in IRD and HAD. At a drying temperature of 60°C, the logarithmic model and the diffusion approximation model were deemed the best fit for HAD and IRAHAD, respectively.

Practical applications

This study demonstrates the efficacy of infrared-assisted hot-air drying (IRAHAD) at 60°C in preserving copra's crucial fat content of 68.4% for optimal oil extraction. By implementing IRAHAD, producers can efficiently dry coconut kernels while maintaining quality, enhancing extraction yields, and improving overall profitability in the coconut processing industry.

KEYWORDS
fat content, heat transfer, moisture reduction, Page model

1 | INTRODUCTION

Coconut (*Cocos nucifera* L.) is an important economic crop in more than 93 countries (Ng et al., 2021). The important products derived from coconut are coconut milk, coconut oil, virgin coconut oil, desiccated coconut powder, neera, and neera sugar (Patil & Benjakul, 2018). Technically it is a fibrous fruit with a thick mesocarp and a thin endocarp covering the meat. Coconut meat or kernel is rich in fat that is highly nutritious and has been associated with great health benefits.

The dried coconut kernel is called copra; the main procedure for the production of copra is to reduce the moisture content of the kernel (wet and fresh) from 50%–55% (w.b.) to 6%–8% (w.b.). The majority of coconut production in the world is used for the production of copra and oil. Copra, which contains 65%–70% of oil, is the richest source of fat (Manikantan et al., 2018). On average, 5–7 coconuts are required to produce 1 kg of copra, although this depends on the variety and location (Waidyarathne et al., 2022). Copra contains the highest percentage of oil compared to other oil seeds. It contains 15%–20% carbohydrates, 9% protein, and 4.10% crude fiber in addition to

https://doi.org/10.1111/jfpe.14668

65%–68% fat. Lauric acid is a major fatty acid present in oil derived from copra. As an edible oil, lauric acid enriched coconut oil is an important component of the diet (Dorni et al., 2018).

Processing of coconut into copra commands a premium price due to its prolonged shelf life and versatility in further processing into oil, butter, cheese, and soap (Newport, 2018). Traditionally, copra drying has relied on two primary methods: sun drying in the field and the use of heating stoves fueled by wood or coconut shells for direct heating (Pramono and Arifin, 2020). However, sun drying exposes copra to dust and microbes, leading to moldy copra with elevated moisture levels. Moreover, this method typically takes 5–7 days at temperatures ranging from 25 to 40°C (Sai Krishna and Mathew, 2017). Conversely, employing heating stoves often results in uncontrolled temperatures, causing inadequate and over-drying of the copra (Pramono and Arifin, 2020). Hence, there is a pressing need for innovative technologies to produce high-quality copra in a shorter timeframe. Remarkably, there is a scarcity of research exploring novel approaches to copra drying.

Jeevarathinam et al. (2021) investigated the use of an infrared (IR) dryer to dry turmeric slices and reported that the drying process required only 5 min at a temperature of 60°C. In recent years, IR heating has gained popularity in thermal food processing operations like drying and dehydration operations (Manyatsi et al., 2023). During IR heating, food material absorbs IR and generates thermal energy through molecular vibration. Due to rapid and volumetric heating, IR drying has gained immense popularity in the food processing industry compared to conventional drying methods (Pawar & Pratape, 2017).

IR heating allows for more uniform heating and gives better quality of dried products. The hybrid method of drying, mainly the IR-assisted hot-air process, improves the drying characteristics. Most IR and IR combined drying methods are widely used for drying process. In a study, infrared-assisted hot-air drying (IRAHAD) of carrot slices was carried out and the results were compared with hot-air-dried samples (Wu et al., 2018). The drying rate of the hot-air-dried samples was less compared to that of the IRAHAD samples. IRAHAD reduces the processing time around 48% when compared to hot-air drying (HAD). Hence, IR and IRAHAD recorded advantages, such as reduced drying time and higher drying rate compared to sun drying, solar drying, and tray drying.

The primary objectives of the study are to assess how different drying techniques (infrared drying [IRD], HAD, and IRAHAD) and temperature (50, 60, and 70°C) combinations impact the biochemical quality of copra. Additionally, the study aims to investigate the drying characteristics of copra produced using different drying methods at various temperatures and to determine the optimal drying technique and temperature for producing high-quality copra.

2 | MATERIALS AND METHODS

2.1 | Materials

The 12-month-old mature coconut (Var. WCT) was taken from the Farm Section of the ICAR Central Plantation Crop Research Institute, Kasaragod for the production of copra.

2.2 | Sample preparation

The collected coconuts were dehusked using a dehusker (350 coconuts per hour) and then cut into two halves. Drying experiments were conducted in IRD, IRAHAD, and HAD at 55, 65, and 75°C. The average of 1 kg of copra was obtained from three full coconut (six pieces); this value varies with the (±30%) variety of coconut.

2.3 | Drying of copra

The different drying techniques, namely the HAD, IRD, and IRAHAD, were employed to perform the drying process of copra. Drying temperatures of 50, 60, and 70°C were selected according to the previous study (Deepa et al., 2015). The drying was continued until it reaches the required moisture content.

The IR dryer (M/S NP Technology, Maharashtra, India) powered with 415 v 3 phase AC supply and stainless steel (SS) 304 tubular air heaters placed on both sides. The cross-flow air circulation with 1/2 hp three-phase AC motor with variable speed controller is attached with dryer to adjust the hot-air velocity. An air velocity of 2 m/s was used during HAD. In the present study, the drying was carried out in three modes of operation such as HAD, IRD, and IRAHAD. The IRAHAD includes the option to adjust temperature up to 150°C and six perforated trays of size 17″ × 22″ × 1″. Three IR bulbs were placed in the dryer. The dryer was provided with the ability to operate in individual and combined modes of drying.

2.4 | Drying kinetics

Drying kinetics refers to mass and heat transfer during the drying of a sample; it mainly depends on drying temperature, type of dryer used, and the characteristic feature of the sample being dried. The drying curve was obtained by measuring the moisture content and weight of the samples at 1-h intervals. The drying process continued until the samples reached a constant weight. Seven kinds of mathematical models were used to fit the drying curve of the experimental data to describe the changes in moisture in materials under different drying conditions. The types and formulae of the models are shown in Table 1. The best model with high R^2 value with low Root Mean Square Error, χ^2, and parameters was obtained.

2.5 | Physicochemical characteristics

All the physicochemical characteristics of sample were carried out in triplicates.

2.5.1 | Moisture content

The moisture content was determined using IR moisture analyzer (A&D brand, MX-50, the capacity of 51 g; 0.01% accuracy over 1 g).

TABLE 1 Mathematical modeling.

Model	Equation	Reference
Newton	$MR = e^{-kt}$	Motevali et al. (2013)
Page	$MR = e^{-kt^n}$	Doymaz and İsmail (2011)
Modified Page	$MR = e^{(-kt)^n}$	Overhults et al. (1973)
Diffusion approximation	$MR = ae^{(-kt)} + (1-a)e^{(-kbt)}$	Islam et al. (2005)
Henderson–Pabis	$MR = ae^{-kt}$	Abbaspour-Gilandeh et al. (2020)
Logarithmic	$MR = ae^{-kt} + c$	Darvishi et al. (2014)
Wang and Singh	$MR = 1 + at + bt^2$	Manikantan et al. (2014)

Three grams of sample was placed on the analyzer and moisture content was shown digitally in wet basis (% w.b.).

2.5.2 | Ash content

Muffle furnace was used for determining the ash content by incinerating the sample at 550°C for 5 h. After 5 h, the muffle furnace was switched off and kept overnight for cooling. Then, the crucible was weighed to get the percentage of ash in the sample (AOAC: 938.08, 2005).

$$\text{Total ash content} = \frac{\text{weight of ash}}{\text{weight of sample}} \times 100. \qquad (1)$$

2.5.3 | Total protein content

The sample is digested with mixed catalyst and concentrated H_2SO_4 to convert nitrogen in protein to ammonium sulfate in a micro-Kjeldahl flask. In steam distillation, in presence of strong alkali, ammonia liberated is converted into ammonium borate by combining with boric acid solution which is estimated by titrating against any standard acid (AOAC 955.04).

$$\%\text{protein} = \frac{[\text{titre value} - \text{blank value}] \times 0.096 \times 0.014 \times 100}{\text{weight of sample}} \times 6.25. \qquad (2)$$

2.5.4 | Total carbohydrate content

Total carbohydrate was estimated using phenol–sulfuric acid method (AOAC 44.1305). In hot acidic medium, glucose is dehydrated to hydroxylmethyl furfural. This forms an orange-yellow colored product with phenol and has absorption maximum at 490 nm.

2.5.5 | Fat content

Completely dried Soxhlet beakers are weighed and finely ground 3–5 g samples are kept in the thimbles. Beakers are filled with 90 mL petroleum ether and the whole beaker with thimble is placed in the Soxhlet apparatus. It is allowed to boil at 100°C in the first phase and fat is extracted in this phase to the solvents in 1 hr. In the second condensation phase at 180°C, petroleum ether is evaporated to leave the fat in the beaker. Extraction was repeated three times for maximum extraction of fat. Beaker is then cooled in desiccator and weighed (AOAC 920.58).

$$\text{Fat}\% = \frac{\text{final weight} - \text{initial weight}}{\text{weight of sample}} \times 100. \qquad (3)$$

2.6 | Statistical analysis

All experiments were conducted in three replicas; all data were expressed in mean ± standard deviation (SD). The influence of using IR and IRAHAD was analyzed in two factorial and completely randomized designs using ICAR statistical analysis Web Agri Stat Package 2.0.

3 | RESULTS AND DISCUSSION

3.1 | Drying characteristics

Figure 1 clearly illustrates the relationship between drying time and moisture ratio, as well as drying time and drying rate, at three different temperatures: 50, 60, and 70°C. The IRAHAD method showed much higher drying rates compared to other methods. Rapid drying rates in IRAHAD are mainly due to the combined heating effects of hot-air and IR radiation, which synergistically accelerate moisture removal from the material's surface and interior (Delfiya et al., 2022). However, a low drying rate was observed in the HAD method compared to other methods. The slower drying rate in conventional HAD can be attributed to its reliance solely on hot air for the drying process. This method might take longer because it primarily heats the surface and leading to slower moisture transfer from the material's interior to its surface for evaporation. Table 2 shows the initial and final moisture content of each dried sample and the drying time.

The slow drying rate was observed after the first falling rate period (Jeevarathinam et al., 2021). The decrease in the moisture ratio with a shorter drying time of 720 min can be observed at 70°C of IRAHAD, followed by an IRD of 960 min and an HAD of 1320 min (Figure 1e). In all drying methods and temperatures, there was initially a more pronounced decrease in the moisture ratio and an increase in the drying rate. During the initial stages of drying, factors such as efficient surface moisture evaporation, high temperature gradient, strong driving force for moisture transfer, low

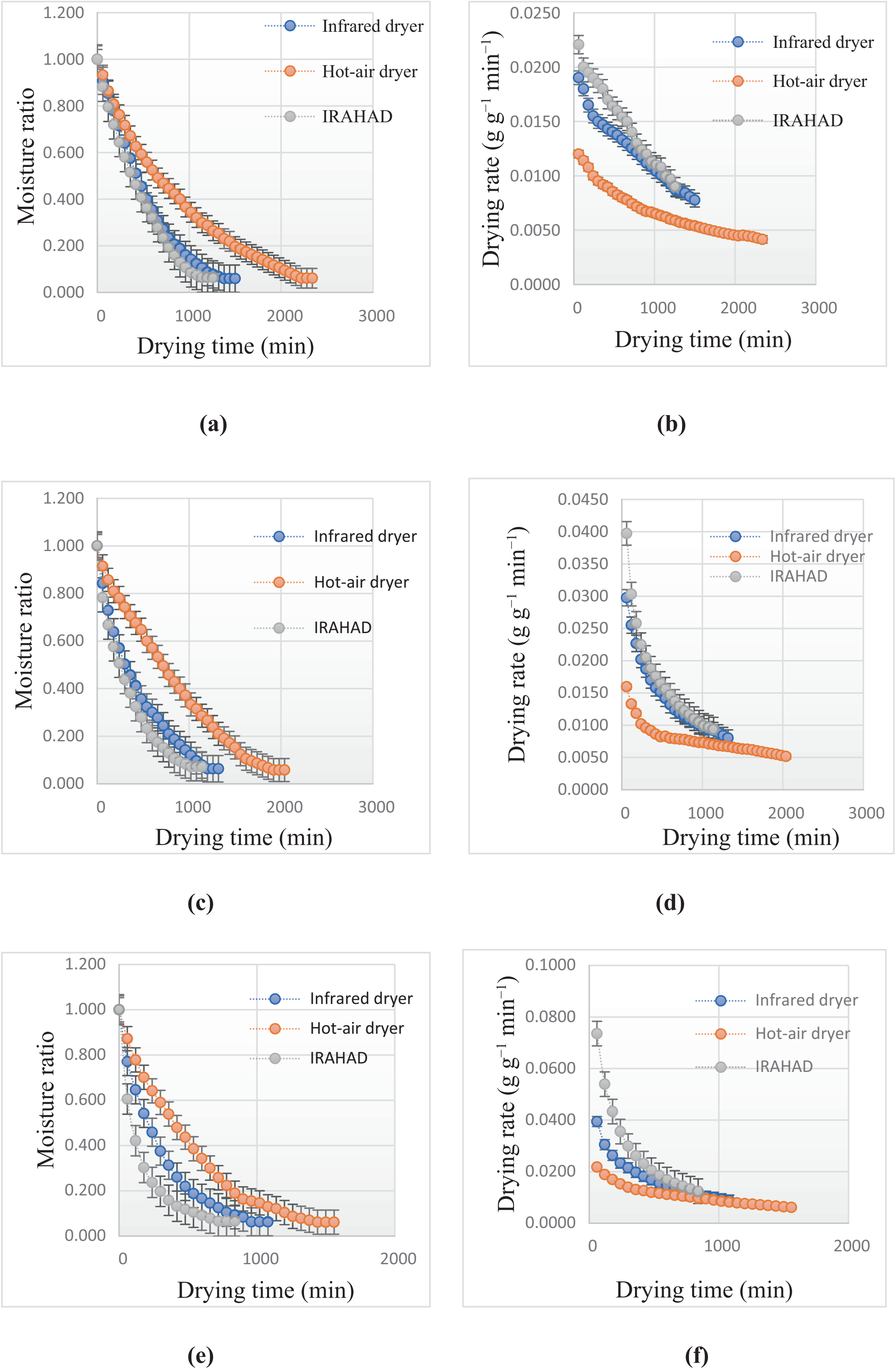

FIGURE 1 (a) Effect of drying time on the moisture ratio of copra for infrared drying (IRD), hot-air drying (HAD), and infrared-assisted hot-air drying (IRAHAD) at 50°C. (b) Effect of drying time on the drying rate of copra for IRD, HAD, and IRAHAD at 50°C. (c) Effect of drying time on the moisture ratio of copra for IRD, HAD, and IRAHAD at 60°C. (d) Effect of drying time on the drying rate of copra for IRD, HAD, and IRAHAD at 60°C. (e) Effect of drying time on the moisture ratio of copra for IRD, HAD, and IRAHAD at 70°C. (f) Effect of drying time on the drying rate of copra for IRD, HAD, and IRAHAD at 70°C.

TABLE 2 Moisture content (drying data) of samples that underwent different drying and temperature systems.

Sample ID	Temperature (°C)	Initial moisture content (w.b.) %	Final moisture content (w.b.) %	Drying time (h)
HAD	50	50.20 ± 0.01	5.98 ± 0.13	37
	60	52.80 ± 0.02	5.92 ± 0.02	32
	70	50.52 ± 0.12	5.8 ± 0.05	24
IRD	50	55.30 ± 0.05	6.9 ± 0.13	23
	60	53.02 ± 0.03	5.92 ± 0.02	20
	70	50.82 ± 0.04	6.5 ± 0.05	16
IRAHAD	50	52.80 ± 0.01	6.52 ± 0.01	19
	60	52.28 ± 0.02	5.52 ± 0.02	17
	70	52.80 ± 0.06	5.5 ± 0.05	12

Abbreviations: HAD, hot-air drying; IRAHAD, infrared-assisted hot-air drying; IRD, infrared drying.

resistance to moisture transfer in the material, and effective heat transfer collectively contribute to a more pronounced decrease in moisture ratio and an increase in drying rate. However, this effect faded off over time as the copra had reduced moisture content. As drying continues, the air used for drying absorbs moisture from the copra, which increases its humidity and makes removing moisture less effective. The initial drying rate of the copra sample was high due to the presence of high moisture content (initial) in the coconut kernel. Copra has initial moisture content about 55% moisture content (w.b.), so that it has the ability to absorb the radiation of different wavelengths. Due to the decrease in the moisture content of copra over time, IR energy absorption also decreased gradually (Aktaş et al., 2016). As a result, this leads to a decrease in the moisture ratio and drying rate since moisture moves slowly from the product's inner layers to its surface. Temperature significantly influences moisture removal, rate of drying, and duration of drying (Izli et al., 2017).

3.2 | Modeling of drying kinetics

Modeling serves as an effective tool that explains the kinetics, moisture, and temperature in a food material. Table 3 explains each drying method with seven mathematical models. Each drying method was fitted into a specific model; the best model was obtained with a high R^2 value with low Root Mean Square Error (RMSE), χ^2, and parameters. The table shows the best model for IRD 50°C was Wang and Singh with an R^2 value of 0.9991, IRD 60°C the Page model was the best fit with the highest R^2 (0.998), and IRD 70°C diffusion approximation was the best model with R^2 value of 0.9993. The best model for HAD at 50 and 60°C was the logarithmic method with R^2 0.9999 and 0.9974, respectively and for HAD 70°C the best model was Page with R^2 value 0.9973. For IRAHAD 50°C, the best model was the logarithmic method with R^2 0.9981 and for 60 and 70°C the best model was diffusion approximation with R^2 values 0.9994 and 0.9995, respectively. Furthermore, several investigations (Agarry, 2016; Nag & Dash, 2016; Torres-Ossandón et al., 2018) have indicated that drying models offer valuable information for assessing the most effective drying parameters, including temperature and duration, to achieve the desired moisture content in diverse food items.

3.3 | Drying techniques and temperature impact on copra moisture content

Monitoring and controlling the moisture content are critical to ensuring high-quality copra and subsequent oil production (Lakshmanan et al., 2020). The moisture content of the copra samples obtained by different drying methods is shown in Table 4. To improve oil extraction efficiency and extended shelf life, the initial moisture level of fresh coconuts, which is around 52% on a wet basis, must be reduced to 7% through the drying process (Deepa et al., 2015). By controlling moisture levels, the risk of spoilage is minimized, allowing copra to be stored for longer periods without deterioration.

The moisture content of the copra dried under different methods was recorded in the range of 6%–7% (w.b.) (Table 4). The IRAHAD sample at 70°C showed a lower moisture content of 5.88% and the HAD sample at 50°C was observed to have a higher moisture content of 7%. The uneven distribution of hot air within the dryer can create pockets where moisture remains trapped, leading to incomplete drying and higher moisture retention in specific areas of the material (Pu & Sun, 2017). IRAHAD often effectively removes moisture as a result of the intense and focused heat generated by IR radiation. Jeevarathinam et al. (2021) conducted a study on effect of different drying methods such HAD, IRD, and IRAHAD on turmeric quality. The IRAHAD method showed a more efficient reduction in moisture content of turmeric with a shorter drying duration compared to both the IRD and HAD methods. This could be attributed to greater mass and heat transfer processes in IRAHAD drying method compared to other methods. The absorption of IR radiation by the food sample leads to an increased pressure difference between the inner and outer layers. This, in turn, accelerates the diffusion of moisture and creates rapid molecular friction within the food material. In all modes of drying, it was noticed that as the temperature increases, the moisture content decreases. Copra having a moisture content of 7% or less is consistently sold on the market at profitable rates, while those with a higher moisture content are typically sold at a lower price (Ghosh, 2015).

A similar value for copra moisture content was obtained by Deepa et al. (2015). Asgar et al. (2022) explained that, by increasing the drying temperature and extending the duration, drying improves the material's ability to expel water from its surface, leading to a lower water content. Su et al. (2020) conducted a study to explore the impact of microwave hot-air flow rolling dry-blanching on the drying characteristics and water migration of *Pleurotus eryngii*. Their conclusion suggests that the high temperature of the samples, along with the relatively low humidity in the environment, may be the factors responsible for the removal of binding water from the cell walls.

TABLE 3 Statistical parameters of the model obtained for infrared drying (IRD), hot-air drying (HAD), and infrared-assisted hot-air drying (IRAHAD).

Drying temperature (°C)	Models	Parameters					R^2	Root Mean Square Error (RMSE)	χ^2
		k	*n*	*a*	*b*	*c*			
IRD									
50	Newton	0.00175	-	-	-	-	0.9897	0.0302	0.0228
	Page	0.014	0.734	-	-	-	0.9303	0.0785	0.154
	Modified Page	0.03258	0.0539	-	-	-	0.9896	0.031	0.023
	Diffusion approximation	0.1739	-	0.01	0.0101	-	0.9886	0.0331	0.0253
	Henderson–Pabis	0.001851	-	1.053	-	-	0.9932	0.0249	0.0149
	Logarithmic	0.00153	-	1.109	-	−0.0817	0.9971	0.01663	0.00636
	Wang and Singh	-	-	−0.001354	4.898×10^{-7}	-	0.9991	0.0091	0.00198
60	Newton	0.00212	-	-	-	-	0.993	0.0222	0.0108
	Page	0.00385	0.906	-	-	-	0.9968	0.0155	0.005065
	Modified Page	−0.000236	−0.989	-	-	-	0.993	0.00228	0.01087
	Diffusion approximation	0.7948	-	0.7803	0.00224	-	0.9933	0.0023	0.0105
	Henderson–Pabis	0.00203	-	0.9579	-	-	0.9958	0.01764	0.0065
	Logarithmic	0.00203	-	0.958	-	−0.00013	0.9958	0.0065	0.018
	Wang and Singh	-	-	−0.00163	7.328×10^{-7}	-	0.9672	0.0493	0.0511
70	Newton	0.00316	-	-	-	-	0.9923	0.0237	0.0101
	Page	0.007028	0.8658	-	-	-	0.9989	0.00739	0.00093
	Modified Page	0.0084	0.3769	-	-	-	0.9918	0.02441	0.01
	Diffusion approximation	0.1375	-	0.1301	0.02	-	0.9993	0.00969	0.00150
	Henderson–Pabis	0.00287	-	0.95	-	-	0.9949	0.0185	0.00616
	Logarithmic	0.003	-	0.9541	-	0.015	0.9952	0.019	0.00627
	Wang and Singh	-	-	−0.0023	1.395×10^{-6}	-	0.9546	0.05917	0.0595
HAD									
50	Newton	0.00108	-	-	-	-	0.9978	0.01253	0.00613
	Page	0.02	0.582	-	-	-	0.9976	0.085	0.282
	Modified Page	0.02438	0.044	-	-	-	0.9978	0.00127	0.0061
	Diffusion approximation	0.8967	-	−1.449	0.0014	-	0.9981	0.01207	0.00539
	Henderson–Pabis	0.00107	-	0.9948	-	-	0.9978	0.0125	0.00601
	Logarithmic	0.000945	-	1.03	-	−0.0524	0.9992	0.0078	0.00225
	Wang and Singh	-	-	−0.00084	1.986×10^{-7}	-	0.9883	0.0292	0.0324
60	Newton	0.00111	-	-	-	-	0.979	0.041	0.0572
	Page	0.01	0.6829	-	-	-	0.8947	0.0927	0.2925
	Modified Page	0.02601	0.0426	-	-	-	0.9788	0.0416	0.0571
	Diffusion approximation	0.4911	-	0.0006106	0.002258	-	0.9794	0.0423	0.05725

TABLE 3 (Continued)

Drying temperature (°C)	Models	Parameters							
		k	*n*	*a*	*b*	*c*	R^2	Root Mean Square Error (RMSE)	χ^2
	Henderson–Pabis	0.00115	-	1.035	-	-	0.9812	0.03977	0.0522
	Logarithmic	0.0006769	-	1.28	-	−0.3003	0.9974	0.0150	0.00722
	Wang and Singh	-	-	−0.00084	1.829×10^{-7}	-	0.997	0.0158	0.00824
70	Newton	0.0185	-	-	-	-	0.9971	0.0148	0.00569
	Page	0.00163	1.019	-	-	-	0.9973	0.0147	0.00544
	Modified Page	0.01549	0.1196	-	-	-	0.9969	0.01509	0.00569
	Diffusion approximation	0.01749	-	0.0152	0.1042	-	0.9972	0.01538	0.00568
	Henderson–Pabis	0.00184	-	0.9949	-	-	0.997	0.015	0.00562
	Logarithmic	0.0019	-	0.9887	-	0.01	0.9966	0.0167	0.00673
	Wang and Singh	-	-	−0.0014	5.42×10^{-7}	-	0.9895	0.0289	0.021
IRAHAD									
50	Newton	0.02	-	-	-	-	0.9911	0.02751	0.0159
	Page	0.00084	1.136	-	-	-	0.9964	0.0180	0.0065
	Modified Page	0.1141	0.017	-	-	-	0.9911	0.0282	0.0162
	Diffusion approximation	0.9109	-	−4.892	0.0032	-	0.9971	0.0164	0.00514
	Henderson–Pabis	0.002054	-	1.026	-	-	0.9921	0.0265	0.0141
	Logarithmic	0.001583	-	1.115	-	−0.1197	0.9981	0.0133	0.00336
	Wang and Singh	-	-	−0.001538	6.338×10^{-7}	-	0.9977	0.0145	0.004205
60	Newton	0.002736	-	-	-	-	0.9921	0.02374	0.01071
	Page	0.005753	0.878	-	-	-	0.9981	0.01189	0.00254
	Modified Page	0.0458	0.059	-	-	-	0.9921	0.0244	0.0107
	Diffusion approximation	27.66	-	0.9043	0.00246	-	0.9994	0.00692	0.00081
	Henderson–Pabis	0.00259	-	0.9499	-	-	0.9959	0.0176	0.00559
	Logarithmic	0.00281	-	0.9348	-	0.0268	0.9968	0.01568	0.001474
	Wang and Singh	-	-	−0.00206	1.144×10^{-6}	-	0.965	0.05147	0.04769
70	Newton	0.00591	-	-	-	-	0.9516	0.05695	0.0454
	Page	0.0372	0.657	-	-	-	0.997	0.0142	0.00264
	Modified Page	0.2543	0.591	-	-	-	0.964	0.0375	0.047
	Diffusion approximation	0.1768	-	0.6648	0.0122	-	0.9995	0.00604	0.00043
	Henderson–Pabis	0.00535	-	0.9207	-	-	0.9596	0.0539	0.03789
	Logarithmic	0.00779	-	0.8935	-	0.0838	0.9942	0.0212	0.0054
	Wang and Singh	-	-	−0.0034	2.974×10^{-6}	-	0.809	0.1175	0.1794

TABLE 4 Proximate analysis of the copra sample dried at different temperatures and methods.

Treatment	Sample ID	Temperature (°C)	Moisture (w.b.) (%)	Ash (%)	Protein (%)	Carbohydrate (glucose eq/100 g)	Fat (%)
T1	HAD	50	7.00 ± 0.03^{a}	0.28 ± 0.09^{g}	6.50 ± 0.01^{g}	15.42 ± 0.19^{c}	66.5 ± 1.0^{ab}
T2		60	6.96 ± 0.03^{a}	0.68 ± 0.07^{ef}	7.36 ± 0.04^{e}	13.37 ± 0.17^{f}	67.1 ± 1.4^{ab}
T3		70	6.50 ± 0.01^{b}	0.02 ± 0.02^{h}	6.34 ± 0.06^{g}	13.32 ± 0.14^{f}	58.9 ± 1.0^{c}
T4	IRD	50	6.03 ± 0.06^{e}	0.32 ± 0.05^{g}	7.51 ± 0.02^{de}	16.75 ± 0.24^{ab}	66.8 ± 2.4^{ab}
T5		60	6.50 ± 0.01^{b}	0.90 ± 0.02^{d}	7.75 ± 0.02^{bc}	14.26 ± 0.10^{e}	65.5 ± 1.8^{bc}
T6		70	5.97 ± 0.07^{de}	1.07 ± 0.03^{c}	6.98 ± 0.04^{f}	14.73 ± 0.28^{d}	62.0 ± 1.1^{d}
T7	IRAHAD	50	6.96 ± 0.08^{a}	0.59 ± 0.13^{f}	8.60 ± 0.24^{a}	16.98 ± 0.18^{a}	66.5 ± 0.9^{ab}
T8		60	6.19 ± 0.01^{c}	1.12 ± 0.04^{c}	8.56 ± 0.04^{a}	16.34 ± 0.23^{b}	68.4 ± 0.7^{a}
T9		70	5.88 ± 0.11^{e}	0.77 ± 0.13^{e}	6.47 ± 0.07^{g}	15.73 ± 0.10^{c}	66.5 ± 1.6^{ab}

Note: The different letters in the columns indicate a significant effect at the level of .05.
Abbreviations: HAD, hot-air drying; IRAHAD, infrared-assisted hot-air drying; IRD, infrared drying.

3.4 | Drying techniques and temperature impact on copra ash content

Determining the ash content of dried food products is vital for assessing quality, nutritional value, process control, regulatory compliance, and estimating shelf life of dried products (Patel & Panwar, 2022; Yusufe et al., 2017). This ensures the safety of foods and there are no toxic minerals in it. In copra, the ash content was 1.59%.

Table 4 represents the ash content of the copra sample obtained by different drying methods and the temperatures ranged from 0.02% to 1.12%. The lowest ash content (0.02%) was obtained for the hot-air-dried sample at 70°C. Conventional hot-air dryers often operate at moderate temperatures, which can help preserve the organic components of food while removing moisture. Lower temperatures may lead to less combustion of organic matter, resulting in lower ash content. The highest ash content was observed for the IRAHAD sample at 60°C (1.12%). The ash content in a food sample serves as an indicator of the degree of processing it has undergone. Natural foods generally exhibit lower ash content in contrast to the processed ones. Oil and fat have 0% ash content, but processed dried meat can contain up to 12% ash (Harris & Marshall, 2017; Soren & Biswas, 2020).

Ho et al. (2016) found that the freeze-dried powder derived from the red-fleshed watermelon rind showed a higher ash content (19.13%) compared to the powder produced by drying in a hot-air oven. Agoreyo et al. (2011) suggest that the application of heat to food can have both positive and negative effects on nutrients. Heat improves food digestibility, increases taste, and extends food shelf life, ensuring safer consumption. On the contrary, the heating process can cause nutrient losses by causing biochemical and nutritional changes in the food composition. The high temperatures involved in the processing and instability of mineral elements during smoking result in a high ash value in *Corbicula fluminea*; it was concluded that the extreme temperature in the modern oven method affects ash content in *C. fluminea* (Zaki et al., 2020).

3.5 | Drying techniques and temperature impact on copra protein content

The protein content of the copra sample mentioned in Table 4 was between 6.3% and 7.92%. The protein content of the copra sample was high (8.6%) for IRAHAD at 50°C and a low protein content (6.34%) was obtained for HAD at 70°C. Seifu et al. (2018) investigated that the degradation of nutritional quality of onion powder such as vitamin C, pyruvic acid, and desired sensory attributes increased with increasing oven drying temperature. The greater degradation of protein in a hot-air dryer compared to an IR-assisted hot-air dryer could be attributed to differences in drying mechanisms and temperatures. IRAHAD usually requires less processing time compared to conventional HAD methods. This shorter duration of exposure to heat can aid in maintaining the protein content by reducing the risk of heat-induced changes or damage to the protein structure. Hot-air dryers use only convective heat transfer, while IR-assisted dryers combine convection with IR radiation (Rao & Najam, 2016). IR radiation can penetrate the surface of the material, promoting a more gentle and uniform heating compared to pure convection, which could subject the protein to less degradation. The decrease in protein content might be due to the nature of the food. Most food experiences denaturation when exposed to temperatures exceeding 60°C (Liu et al., 2016). A study done in soybeans by Zhang et al. (2022) found that heating will lower the nitrogen fraction of nano-protein such as the soluble and rapidly degrade fraction, and also heating tends to decrease the true protein, one fraction that is rapidly degradable. Mondal et al. (2019) found that oven-dried samples are prone to have lower values in soluble protein content along with moisture content. Protein denaturation is the process where a protein's structure undergoes changes, often leading to a reduction in its functional abilities. Atuonwu et al. (2017) concluded that protein denaturation rates of heated whey protein increase with moisture content, as well as temperature.

3.6 | Drying methods and temperature impact on copra carbohydrates

Table 4 provides the carbohydrate content of copra samples, ranging from 16.9% to 13.32%. The drying temperature and drying time significantly influenced the carbohydrate content in a copra sample. IRAHAD at 50°C showed a high carbohydrate (16.98 glucose eq/100 g) and a low value of 13.32 glucose eq/100 g of carbohydrate was observed for HAD at 70°C. In a study on the drying of turmeric slices showed a comparable result of more retention of starch content in turmeric slices dried using the IRAHAD method compared to those dried using IRD and HAD dryers (Jeevarathinam et al., 2021).

IRAHAD dryers probably preserve more carbohydrates in dried foods because of the effective drying mechanism. IR-assisted dryers utilize both convection and radiation modes of drying. Thus, volumetric heating results in the penetration of IR radiation into the surface of the food material, causing gentle and more uniform heating. This gentle heating can help preserve the structure and integrity of carbohydrates better than the higher and less evenly distributed heat in standard hot-air dryers. To conclude, the controlled temperature, uniform heating, minimized oxidative reactions, and improved moisture removal inherent in IRAHAD collectively play a role in better preserving carbohydrates compared to alternative drying techniques. Zhang et al. (2020) noted that, IRAHAD provided many advantages in minimizing the drying time and better preserving the quality over HAD under the same conditions. Generally, food products dried in hot-air dryers show quality degradation. In some cases, hot-air dryers may not distribute heat uniformly, resulting in localized hot spots. This uneven heating can cause varying moisture removal rates, leading to uneven drying, which affects the texture and quality of the final product.

3.7 | Drying techniques and temperature impact on copra fat content

Fat content in dried foods is crucial for both nutritional quality and sensory appeal. The fat content in the copra from different treatments is given in Table 4. It shows variation in the fat content of samples dried at different temperatures. Fat content is vital for maintaining the distinctive flavor and texture of dried copra, enhancing its taste and overall appeal to consumers (Samuel, 2018). While higher fat content can render copra more susceptible to oxidation and rancidity, resulting in a reduced shelf life (Seneviratne & Jayathilaka, 2015). The IRAHAD sample at 60°C was found to have a higher amount of fat 68.4% and the low fat value represents the HAD sample (58.9%). The values obtained are in the range of 58%–68% and are consistent with the results obtained by Deepa et al. (2015). The above mentioned fat content complies with Codex standards for coconut oil. IRAHAD often requires shorter drying times compared to conventional methods. The decreased duration of exposure to heat can limit the potential degradation or loss of fats, leading to higher retention. Surendar et al. (2018) studied the effect of different drying techniques on the quality parameters of tomato powder. The investigation showed that the fat content in foam-mat-dried powder was a little higher than in cabinet-dried powder, but low compared to spray-dried tomato powder. The increase in fat content in the spray-dried powder was attributed to its lower moisture content compared to both the cabinet- and foam-mat-dried powders.

4 | CONCLUSIONS

IRAHAD, an energy-efficient dryer, employs volumetric heating and preserves copra quality. The study delves into the impact of three drying temperatures (50, 60, and 70°C) and three drying methods (IRD, HAD, and IRAHAD) on the drying rate and nutritional quality of copra slices. In comparison to conventional methods like sun drying and solar drying, both IRD and IRAHAD exhibit a two-fold reduction in drying time compared to HAD. Optimal drying rates were achieved at a temperature of 70°C across all drying methods. Notably, employing the IRAHAD technique at 60°C is considered optimal, as it significantly preserves the high fat content (68.4%), crucial for extracting premium-quality oil from copra. The IRAHAD method outperformed IRD and HAD in terms of shorter drying times, attributed to enhanced mass and heat transfer within the IRAHAD drying process. This underscores the efficiency of IRAHAD as a method that not only accelerates drying but also ensures the retention of key nutritional components in copra. Investigating the scalability of optimized drying methods for large-scale copra production or exploring novel processing techniques to further enhance copra quality and functionality, are future line of research. Further the effects of other novel drying technique or hybrid technique such as heat pump dryer, radiofrequency dryer, and rotary dryer on the quality of copra are warranted.

FUNDING INFORMATION

The authors would like to thank ICAR All India Coordinated Research Project on Post Harvest Engineering & Technology (AICRP on PHET), Ludhiana, India for funding.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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How to cite this article: Pandiselvam, R., Davison, S., Manikantan, M. R., Jeevarathinam, G., Jacob, A., Ramesh, S. V., & Shameena Beegum, P. P. (2024). Infrared-aided hot-air drying of coconut: Impact on drying kinetics and quality metrics. *Journal of Food Process Engineering*, *47*(6), e14668. https://doi.org/10.1111/jfpe.14668