Journal of Food Measurement and Characterization (2024) 18:10102–10108
https://doi.org/10.1007/s11694-024-02945-5

ORIGINAL PAPER

Comparative analysis of biochemical composition of fried coconut chips: influence of thickness and oil type on nutritional attributes

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Received: 19 August 2024 / Accepted: 14 October 2024 / Published online: 4 November 2024

Abstract

In recent years, there has been a noticeable rise in the importance of snack items in diets, particularly among children and adolescents who enjoy them socially with friends. Chips, commonly produced through frying, have garnered significant popularity. This study aimed to assess the quality of fried coconut chips of thickness 0.5 mm and 1.4 mm, made using both sunflower oil and coconut oil. Deep frying was conducted at 160 °C for both types of oil. The findings indicated that coconut oil-fried chips, regardless of thickness, exhibited superior sensory attributes (i.e. appearance, colour, crispiness and flavour). All sensory attributes (except appearance) were rated the highest for coconut oil fried chips. The biochemical properties of chips fried in both oils were largely similar, yet coconut oil-fried chips displayed slightly better characteristics compared to their counterparts. For instance, the 0.5 mm thick coconut oil-fried chips were noted for their improved protein content and fat content, leading to a higher overall acceptability of the 0.5 mm thickness.

Keywords Deep fat frying · Coconut oil · Sunflower oil · Coconut chips · Proximate composition · Snacks

Introduction

Deep frying, a widely adopted culinary technique, is commonly used to prepare fried foods such as potato chips, French fries, and extruded snacks [1, 2]. Known for its simplicity and distinct sensory qualities, such as flavour and texture, deep frying relies on high temperature and swift heat transfer, making it effective in both domestic and industrial settings. Fats and oils play essential roles in food preparation, enhancing flavour, texture, and mouthfeel [3]. Many investigations ([4, 5]) have focused on developing novel technologies to reduce the oil content in fried foods in order to produce healthier and safer fried foods. Thus, emerging alternative frying technologies, including microwave frying, vacuum frying, microwave-assisted vacuum frying, and pulsed-spouted microwave vacuum frying, have garnered significant attention in the domain of food processing [6]. Moreover, deep frying aids in food safety by eliminating harmful bacteria and enzymes and reducing water content, thus prolonging food preservation [7]. Typically conducted at temperatures ranging from 150 to 200 °C, deep frying is a vital aspect of culinary practices worldwide [8].

Coconut trees, often termed "Tree of Life," are highly valued for their versatility [9]. Coconut consists of approximately 28% inedible shell and 72% edible flesh or endosperm or kernel. The coconut flesh is rich in fat, carbohydrates, and moderate protein contents [10]. Across various cultures, fresh coconut kernel is utilized in diverse culinary uses, specifically, coconut is widely used for its oil, which is significant in various recipes and industrial applications. Whether grated, processed into paste, or used to extract coconut milk, the kernel finds its way into a multitude of dishes, including curries, chutneys, sweets, and more [11]. In addition to these traditional uses, coconut can be processed into coconut flour, which is derived from the residue remaining after coconut milk extraction. This flour is widely recognized for its high fiber and protein content, making it a valuable nutritional ingredient. It contains approximately 600 g of total

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dietary fiber per kilogram, with around 560 g being insoluble fiber and 40 g being soluble fiber per kilogram [12].

Several research studies have been conducted to investigate the production processes and quality analysis of chips derived from coconut, sweet potato, and other similar ingredients. Choosuk et al. [13] have studied the quality changes of coconut chips during storage at different temperatures of 35, 45 and 55 °C. Drying of the coconut chips was done using the tray drying method at 60 °C for 20 h [13]. According to the study, coconut chips stored at 55 °C for a prolonged period turned brown and had a higher peroxide value, as well as showed less crispiness [13]. In this study, rancidity was found to be one of the first characteristics that are noticeable when dried coconut chips start to lose their quality [13]. Caetano et al. [14] examined and compared the physicochemical and sensory attributes of sweet potato chips subjected to various cooking techniques such as oven-baking, air frying and deep frying methods. They concluded that oven-baked and air-fried chips exhibited the lowest levels of fat and moisture, which contributed to an extended shelf life. Moreover, deep-fried sweet potato chips demonstrated the highest sensory acceptance and purchase intent among the evaluators.

Nevertheless, the coconut chips sold in markets undergo a procedure involving osmotic dehydration facilitated by sucrose, followed by convective drying. The coconut slices, once osmotically dehydrated, can be dried in a forced hot air electric dryer at temperatures ranging from 70 to 80 °C for a duration of 5 to 6 h [15]. The prolonged production time and the uneven colour on the surface of the chips are significant drawbacks of the current coconut chips production method. Our study introduces an innovative approach by employing a frying method for the preparation of coconut chips, an area which has not been previously explored in research.

In many regions, the growing consumption of snacks has integrated fried food into daily diets, particularly among children and adolescents who enjoy them socially. This study aims to assess the quality attributes of fried coconut chips of varying thickness using different frying oils, such as sunflower oil and coconut oil, contributing to the ongoing exploration of optimal frying practices. By analysing how different frying oils affect the sensory qualities of coconut chips, such as taste and texture, the study could reveal new opportunities for product differentiation in the market.

Materials and methods

Experimental materials

The experiment utilized mature coconuts, aged 9-10 months, from West Coast Tall variety sourced from the ICAR-Central Plantation Crops Research Institute (ICAR-CPCRI) Farm in Kasaragod, India. Table sugar, Sodium chloride (NaCl), and concentrated vanilla essence were procured from the local market in Kasaragod, Kerala, India. All analyses in the study were performed using analytical reagent (AR) grade chemicals.

Preparation of fried coconut chips sample

The freshly harvested coconuts underwent a series of processing steps utilizing machineries developed at ICAR-CPCRI. Initially, the dehusker, with a capacity of processing 350 coconuts per hour at 2 horsepower, removed the husk. The desheller, operating at 0.5 horsepower and capable of processing up to 150 coconuts per hour, first removed the shells. This was followed by the testa removal machine, also operating at 0.5 horsepower, which could handle 100 coconuts per hour to remove the testa. The kernels were then sliced using an in-house developed multi-commodity slicer, which could process 60 coconuts per hour with a power input of 0.5 horsepower. This slicer allowed for slicing the kernels into 0.5 mm and 1.4 mm thicknesses. After slicing, the coconut kernels were blanched in hot water at 90–95 °C for 2 min and carefully patted with tissue paper to remove any excess water from the surface [16]. Finally, the coconut slices were subjected to frying.

Frying

Sunflower and coconut oils are commonly used among various cooking oils because of their favorable characteristics on final products [17]. Sharanke and Sivakanthan [18] also noted that coconut oil underwent fewer positive changes in the measured parameters during continuous deep frying. Therefore, coconut chip frying was conducted using coconut oil and sunflower oil. The coconut chip samples were fully submerged in separate pans, each filled with the corresponding oils (coconut oil and sunflower oil). The frying temperature was maintained at 160 °C, with approximately 500 g of chips fried in 1 L of oil.

Physical analysis

Rehydration ratio

The rehydration ability of coconut chips was evaluated using a modified version of the method described by Zou et al. [19]. Around 5 g of fried coconut chip samples were submerged in 250 ml of water in a beaker and allowed to rehydrate for 3 h. Once the time elapsed, the rehydrated samples were removed from the water. Any surface moisture on the coconut chips was removed by softly patting them with filter paper, and then the weight of the samples was measured.

$$Rehydration\ ratio(RR) = Mr/Md \tag{1}$$

where: *Mr* is rehydrated chips mass (g), *Md* is chip mass before rehydration (g).

Hygroscopicity

The moisture absorption capability of coconut chip samples was examined by analysing their hygroscopic characteristics, as per the procedure outlined by Tonon et al. [20]. Five grams of coconut chips were accurately measured and placed in a controlled environment set at 25 °C temperature and 75.2% humidity. The sample was then sealed within a desiccator alongside a saturated sodium chloride (NaCl) solution, which was kept in an incubator to ensure consistent temperature and humidity levels. After a week, the chips were weighed again, and the results were expressed as grams of water absorbed per 100 g of dry weight.

Biochemical analysis

Proximate composition

The proximate composition of coconut chips prepared with various frying oils was analyzed using standard methods outlined in the official AOAC (2005) protocols, including determination of moisture content (method AOAC 925.09), ash content (method AOAC 938.08), total carbohydrate content (method AOAC 44.130), protein content (method AOAC 955.04), and fat content (method AOAC 920.58).

Total phenol content (TPC)

Based on the methodology described by Seneviratne et al. [21] the total phenolic content was determined using the Folin–Ciocalteau (FC) reagent using a spectrophotometric technique and the results were presented in milligrams of gallic acid equivalent phenol per 100 gram of extract (mg GAE/100 g).

Antioxidant potential by Ferric reducing antioxidant power (FRAP) and 2,2-diphenyl-1-picryl-hydrazyl-hydrate (DPPH) methods

FRAP was conducted following the methodology outlined by Benzie and Strain, while the DPPH assay was performed as per the procedure detailed by Brand-Williams et al. [22]

Sensory evaluation

A sensory evaluation of the samples was conducted by 11 panelists. Standard sensory protocols were carried out. Samples quality attributes were appearance, colour, crispiness, flavor and overall acceptability as per 9 point Hedonic scale [23]. Each chip sample was stored individually in plastic dishes, labeled with a unique number for easy identification. Prior to tasting the next sample, panelists were given drinking water to cleanse their palates.

Statistical analysis

Three replicates were utilized for conducting all experiments, with all parameters expressed as average ± standard deviation (SD). The influence of different frying oil and slice thicknesses was analyzed using a two-factorial, completely randomized design, employing the ICAR statistical analysis Web Agri Stat Package 2.0.

Results and discussion

Physical properties

Table 1 presents the physical attributes of fried coconut chips manufactured using coconut oil and sunflower oil at two distinct thicknesses. Maintaining an appropriate rehydration ratio and hygroscopicity is crucial for the longevity of fried food products [24]. Our study findings indicate that fried coconut chips produced using both coconut oil and sunflower oil demonstrated similar physical characteristics. However, despite their comparable physical attributes, coconut oil-fried chips exhibited superior rehydration ratio and hygroscopicity. The rehydration ratio of a dehydrated product assesses its ability to regain its original moisture content after rehydration [25]. The 0.5 mm and 1.4 mm

Table 1 Physical properties of coconut chips using different frying oils

*CO-Coconut oil & SO-Sunflower oil ; The different letters in the columns indicates a significant effect at level of 0.05

Treatment	Sample ID	Physical properties			
		0.5 mm		1.4 mm	
		Rehydration ratio (%)	Hygroscopicity (%)	Rehydration ratio (%)	Hygroscopicity (%)
T1	CO	1.57 ± 0.00^{ef}	3.25 ± 0.06^{b}	1.56 ± 0.01^{cd}	2.36 ± 0.29^{def}
T2	SO	1.51 ± 0.02^{fg}	5.54 ± 0.14^{b}	1.40 ± 0.00^{f}	2.71 ± 0.04^{cde}

Table 2 Proximate composition of fried coconut chips using different frying oils -0.5 mm thickness

Treatment	Sample ID (°C)	Biochemical analysis				
		Moisture (w.b., %)	Ash (%)	Total carbohydrate (%)	Protein (%)	Fat (%)
T1	CO	2.72 ± 0.10^{ab}	0.71 ± 0.02^{e}	28.55 ± 1.00^{d}	3.62 ± 0.04^{b}	45.73 ± 1.23^{b}
T2	SO	2.73 ± 0.15^{abc}	0.78 ± 0.02^{e}	23.24 ± 0.16^{g}	3.01 ± 0.13^{c}	44.80 ± 0.22^{c}

*CO-Coconut oil & SO-Sunflower oil; The different letters in the columns indicates a significant effect at level of 0.05

Table 3 Proximate composition of fried coconut chips using different frying oils -1.4 mm thickness

Treatment	Sample ID (°C)	Biochemical analysis				
		Moisture (w.b. %)	Ash (%)	Total carbohydrate (%)	Protein (%)	Fat (%)
T1	CO	3.37 ± 0.22^{bc}	0.94 ± 0.07^{bcd}	25.94 ± 1^{def}	5.05 ± 0.9^{a}	47.75 ± 1.23^{b}
T2	SO	3.56 ± 0.12^{ab}	0.96 ± 0.02^{def}	22.92 ± 0.52^{bcd}	4.87 ± 0.9^{a}	44.57 ± 0.50^{c}

*CO-Coconut oil & SO-Sunflower oil; The different letters in the columns indicates a significant effect at level of 0.05

thick samples fried in coconut oil displayed the highest rehydration ratio (1.57% and 1.56%). Dewada et al. [26] noted a negative correlation between the rehydration ratio of dried potato slices and the dehydration ratio of the dried sample, along with a positive correlation with the oil content of deep-fried chips. It is presumed that reduced rehydration ratios may be the result of structural damages that occurr during the dehydration process.

The chip samples fried in sunflower oil demonstrated the highest levels of hygroscopicity among all samples, regardless of thickness, registering at 5.54% for the 0.5 mm thickness and 2.71% for the 1.4 mm thickness. Excessive hygroscopicity can result in issues such as clumping, stickiness, and accelerated spoilage due to excessive moisture absorption, thus compromising the product's quality and appeal [27]. In contrast, the hygroscopicity value of samples prepared using coconut oil was significantly lower ($p < 0.05$) compared to that of the sunflower oil-fried samples. A low hygroscopicity in dried food products indicates their ability to resist moisture absorption from the surrounding environment. Pravitha et al. [28] compared the hygroscopicity of dehydrated coconut chips sample treated with different osmotic agents such as coconut sugar, jaggery and sucrose. Jaggery-treated samples exhibited the highest hygroscopicity, followed by those treated with coconut sugar, while the samples treated with sucrose showed the lowest value. Jaggery's hygroscopic characteristics are largely due to the presence of reducing sugars, dextrose, and minerals.

Proximate composition

Tables 2 and 3 display the proximate composition of fried coconut chips at thicknesses of 0.5 mm and 1.4 mm, respectively. The moisture content of fried coconut chip samples showed similar ranges for both those fried in sunflower oil and coconut oil. This suggests that moisture from the food, combined with high frying temperatures, accelerates the hydrolysis process of oils [29]. Prolonged exposure of oil to high temperatures promotes the modification of polyunsaturated fatty acids, particularly those containing two or three double bonds. Free fatty acids, along with low molecular weight acidic byproducts generated from fat oxidation, facilitate the hydrolysis process, particularly in the presence of steam during frying [30]. Specifically, the moisture content of coconut oil-fried and sunflower oil-fried samples at a thickness of 0.5 mm was approximately 2.72% and 2.73%, respectively. The presence of steam during frying contributes to the formation of free fatty acids and low molecular weight acidic compounds through lipid oxidation, thereby enhancing the hydrolysis process [31]. Additionally, the 1.4 mm sample exhibited slightly higher moisture retention compared to the 0.5 mm sample (3.37% for coconut oil-fried samples and 3.56% for sunflower oil-fried samples). Yang et al. [32] investigated the microstructure and water absorption capacity of three types of fried potato chips to elucidate their structure, texture, and shelf life. They concluded that higher porosity correlates with increased moisture absorption capacity in potato chips.

Ash content in food refers to the residue left behind after burning off the organic components [33]. Assessing ash content is crucial in food analysis as it helps to evaluate nutritional composition and overall quality [34]. High ash content may suggest the presence of mineral-rich ingredients or contamination, while low ash content could be attributed to the reduction caused by the evaporation of volatile compounds from the food products [35]. In this study, the ash content of 0.5 mm coconut chip samples fried in coconut oil and sunflower oil exhibited similar values with no significant difference, at 0.71% and 0.78%, respectively. Conversely, the ash content of the 1.4 mm samples showed slightly higher levels (0.94% for coconut oil-fried samples and 0.96% for sunflower oil-fried samples). Yaseen et al. [36] conducted a study on the chemical composition of fried potato chips and observed the highest ash content (3.11%) at 180 °C for 4 min. Pravitha et al. [37] investigated the quality of jaggery infused osmo-dehydrated coconut chips. The study revealed that jaggery chips displayed a higher ash content compared to the sugar-osmosed chips.

Carbohydrates serve as the body's primary energy source [38]. With their rich carbohydrate content, coconut chips offer a quick energy boost, making them ideal for pre- or post-workout snacks or for refueling during physical activity. Samples of coconut chips, fried in coconut oil at thicknesses of 0.5 mm and 1.4 mm, showed the highest total carbohydrate content (28.55% and 25.94%, respectively). Conversely, the high unsaturated fatty acid content in sunflower oil leads to hydrolysis and oxidation under moisture and heat, diminishing the nutritional quality of fried chips [39]. Elmoneim et al. [40] conducted a study on banana chips and noted a substantial increase in carbohydrate content during frying and baking, by approximately 500% and 400%, respectively. In a study [37], coconut chips osmosed with jaggery and refined sugar showed an increase in carbohydrate content as compared to dry kernels. The increased carbohydrate level was predominantly a result of the osmotic dehydration process.

Coconut chips with elevated protein levels can enhance the overall nutritional value of the snack, rendering it a more balanced food choice. Samples of thicknesses 0.5 mm and 1.4 mm fried in coconut oil exhibited the highest protein content (3.62% and 5.05%, respectively). Coconut oil has higher saturated fat content and a lower proportion of polyunsaturated fats compared to sunflower oil. Saturated fats are less prone to oxidation during high-temperature frying, which may contribute to better preservation of protein content [41]. Nunes and Tavares [42] noted that thermal treatment of protein can reduce its quality and lead to the degradation of certain amino acids. Conversely, samples of thicknesses 0.5 mm and 1.4 mm fried in sunflower oil displayed the lowest protein content (3.01% and 4.87%). Mohammed et al. [43] suggested coating chips with protein and investigating the type of protein and storage duration's impact on the final product's quality. Potato slices were blanched, dipped in solutions containing sodium caseinate, whey protein concentrate, or egg white, and deep-fried in corn oil and hydrogenated oil. The study found that protein-coated chips exhibited reduced oil absorption and increased protein content.

Fat plays a vital role in shaping the flavor and texture of coconut chips. Coconut itself is renowned for being a rich source of healthy fats, primarily medium-chain triglycerides (MCTs), which are associated with various health benefits such as improved heart health and enhanced metabolism [44]. The fat content of coconut chip samples fried in both coconut oil and sunflower oil fell within a comparable range. It may be due to the comparable capacity of both oils to absorb into the coconut chips during frying. Specifically, samples fried at thicknesses of 0.5 mm and 1.4 mm in coconut oil exhibited fat contents of 45.73% and 47.75%, respectively, while those fried in sunflower oil displayed fat contents of 44.8% and 44.57%, respectively. Aida et al. [45] conducted a study aiming to reduce the fat content of fried banana chips using a sugar solution. Banana slices were dipped in sugar solutions of varying concentrations (4 g, 8 g, and 12 g) and then fried at 180 °C for 5 min. The study found that as the sugar concentration increased, the fat percentage decreased to 0.66%, 0.63%, and 0.54%, respectively.

Table 4 Biochemical parameters of fried coconut chips using different frying oils (0.5 mm thickness) – phenol and antioxidant

Treatment	Sample ID	Total phenol (mg gallic acid equivalent / 100 g)	Antioxidant	
			DPPH (%)	FRAP (mg trolox equivalent /100 g)
T1	CO	0.043 ± 7.07^{a}	63.35 ± 0.00^{bc}	0.001 ± 0.00^{a}
T2	SO	0.04 ± 0.00^{b}	64.7 ± 0.59^{a}	0.002 ± 3.53^{b}

*CO-Coconut oil & SO-Sunflower oil ; The different letters in the columns indicates a significant effect at level of 0.05

Table 5 Biochemical parameters of fried coconut chips using different frying oils (1.4 mm thickness) – phenol and antioxidantf

Treatment	Sample ID	Total phenol (mg gallic acid equivalent / 100 g)	Antioxidant	
			DPPH (%)	FRAP (mg trolox equivalent /100 g)
T1	CO	0.04 ± 7.1^{b}	63.35 ± 0.0^{c}	0.001 ± 0.0^{d}
T2	SO	0.045 ± 0.0^{b}	64.7 ± 0.6^{ab}	0.002 ± 3.5^{c}

*CO-Coconut oil & SO-Sunflower oil ; The different letters in the columns indicates a significant effect at level of 0.05

Total polyphenolic content and antioxidant activity

The results of the total phenolic content and antioxidant activity for fried coconut chip samples at two different thicknesses (0.5 mm and 1.4 mm) are outlined in Tables 4 and 5. The polyphenolic content of all samples fell within a similar range. Specifically, the polyphenolic content of the 0.5 mm samples fried in both coconut oil and sunflower oil was observed to be 0.043 mg gallic acid/100 g and 0.04 mg gallic acid/100 g, respectively. In a study by Habarakada et al. [39], it was found that the polyphenolic content of coconut and palm oil used for frying potatoes slightly increased, while that of sunflower oil decreased. Similarly, the 1.4 mm samples fried in coconut oil and sunflower oil exhibited a phenolic content of 0.04 mg gallic acid/100 g and 0.045 mg gallic acid/100 g, respectively. Karakaya and Simsek [46] investigated changes in total polyphenol content during deep fat frying using different oils and found that the total polyphenol content remained unchanged in corn oil, soybean oil, and olive oil. It is noted that thermal processing may cause polyphenol losses due to oxidation and leaching of water-soluble phenolics. However, high temperatures can

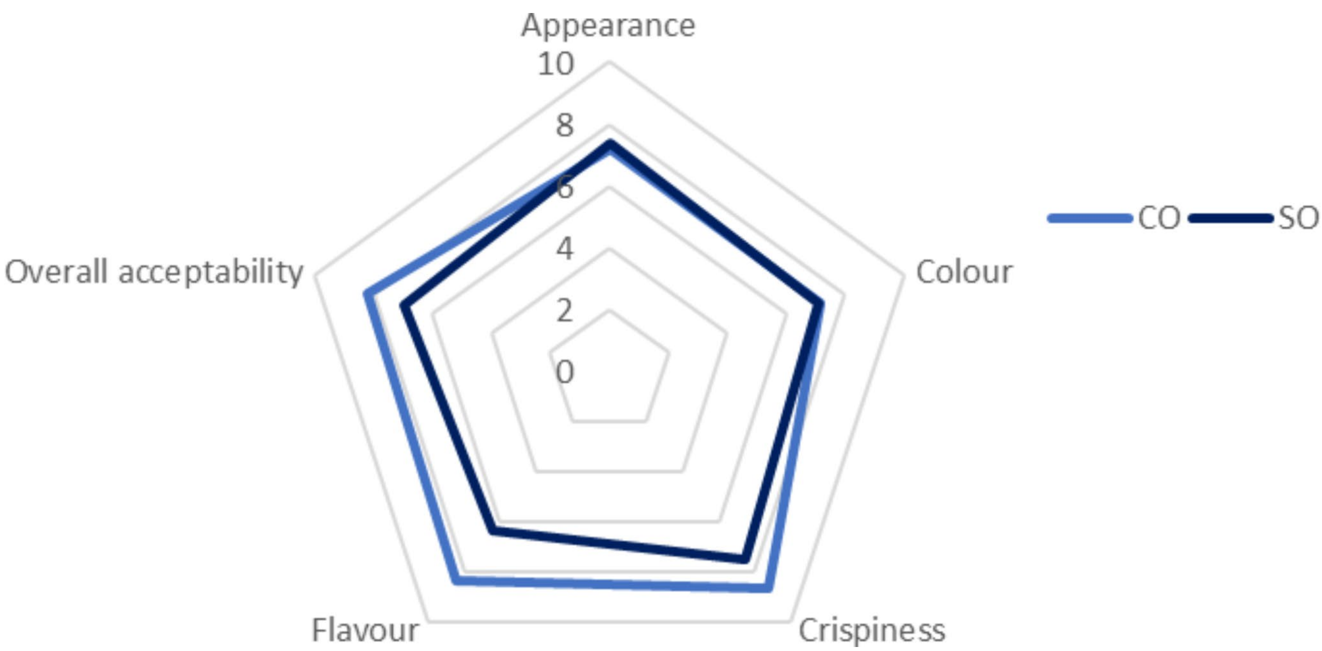

Fig. 1 Sensory scores of coconut chips sample prepared from coconut oil (CO) and sunflower oil (SO)

deactivate peroxidases, which have pro-oxidant properties, potentially enhancing antioxidant activity [47]. However, in a study by Alonso et al. [48] reported that repeated frying operations in virgin olive oil for the preparation of French fries resulted in a significant reduction in the total antioxidant activity of the extracted phenolic compounds.

The 0.5 mm and 1.4 mm samples fried in sunflower oil exhibited the highest DPPH scavenging activity (64.7%). Yu et al. [49] examined the physicochemical and oxidative stability of frying oils during the frying of potato chips and observed a decrease in DPPH scavenging activity in pure olive oil and vegetable shortening after frying. Additionally, Liu and Lin [50] noted a significant decrease in DPPH radical scavenging activity during boiling. It was observed that there was very slight variation in FRAP value between the 0.5 mm and 1.4 mm samples fried in both sunflower oil and coconut oil, with the FRAP value ranging from 0.001 to 0.002 mg trolox/100 g. Pravitha et al. [16] found that coconut chips treated with various osmotic agents differed in product quality. Notably, samples containing coconut sugar exhibited the highest DPPH scavenging activity (26.20%), followed closely by those treated with jaggery (24.49%).

Sensory analysis

All samples were considered acceptable because each attribute score for the individual samples was above six (Fig. 1). Coconut chips prepared from sunflower oil were observed to be more visually appealing than those from coconut oil. However, coconut chips samples fried in coconut oil were highly appreciated for their colour, crispness, and flavour. The overall acceptability (including all sensory parameters) was maximum for coconut chips fried in coconut oil with a mean value of 8.2 (liked very much) and the minimum for coconut chips fried in sunflower oil with a mean value of 7. So, coconut chips prepared from coconut oil offered a nutritional and organoleptically acceptable product.

Conclusion

Based on the results obtained, both coconut oil and sunflower oil demonstrate suitability for the preparation of coconut chip samples. However, it's noteworthy that the biochemical composition of the fried samples varies depending on the type of oil used for frying. The biochemical properties of the chips fried in both oils were generally comparable; however, the chips fried in coconut oil exhibited slightly superior biochemical characteristics compared to those fried in sunflower oil. A slightly higher content of carbohydrates, proteins, and fats was observed in the samples prepared using coconut oil. Sensory evaluation showed that, the overall acceptability (including all sensory parameters) was maximum for coconut chips prepared from coconut oil with a mean value of 8.2 (liked very much). Based on this finding, it can be concluded that coconut oil is more suitable than sunflower oil for the preparation of coconut chips. Nevertheless, future research could include a storage study on fried coconut chips samples to determine their shelf life when using different frying oils.

Acknowledgements This research was supported by the Indian Council of Agricultural Research-All India Coordinated Research Project on

Post-Harvest Engineering and Technology (ICAR-AICRP on PHET), Ludhiana, India. The authors express their sincere gratitude for the financial and technical support provided by ICAR-AICRP on PHET Team during the course of this study.

Declarations

Conflict of interest The authors declare that the research was conducted in the absence of any commercial or financial relationshipsthat could be construed as a potential conflict of interest.

References

1. M.D. Erickson, *Deep Frying: Chemistry, Nutrition, and Practical Applications* (Elsevier, 2015)
2. F. Yuksel, S. Karaman, M. Gurbuz, M. Hayta, H. Yalcin, M. Dogan, A. Kayacier, LWT-Food Sci. Technol. **83**, 235 (2017)
3. M. Ngadi, J. Xue, Nov. Food process. Eff. Rheol Funct. Prop. 437 (2016)
4. Y. Su, M. Zhang, Z. Fang, W. Zhang, Food Res. Int. **101**, 188 (2017)
5. A.H.A. Tarmizi, K. Niranjan, J. Food Sci. **75**, E572 (2010)
6. X. Zhang, M. Zhang, B. Adhikari, Trends Food Sci. Technol. **98**, 68 (2020)
7. K. Bordin, M. Tomihe Kunitake, Kazue Aracava, and C. Silvia Favaro Trindade. Arch. Latinoam. Nutr. **63**, 5 (2013)
8. E.A.A. Sanibal, Food Ingred. South. Am. **18**, 64 (n.d.).
9. M. Haseena, K.V. Kasturi Bai, S. Padmanabhan, J. Food Sci. Technol. **47**, 686 (2010)
10. O.C. Onwudike, *Food Feed from Legum. Oilseeds* (Springer, 1996), pp. 306–317
11. M. DebMandal, S. Mandal, Asian Pac. J. Trop. Med. **4**, 241 (2011)
12. A. Mithra, G.J. Swamy, V. Chandrasekar, S. Shanmgam, J. Indian Food Ind. Mag. **32**, 29 (2013)
13. N. Choosuk, P. Meesuk, P. Renumarn, C. Phungamngoen, N. Jakkranuhwat, Processes. **10**, 1392 (2022)
14. P.K. Caetano, F.A.D.C. Mariano-nasser, V.Z. De MendonÇa, K.A. Furlaneto, E.R. Daiuto, R.L. Vieites, Food Sci. Technol. **38**, 434 (2017)
15. M.R. Manikantan, (2016)
16. M. Pravitha, M.R. Manikantan, V. Ajesh Kumar, P.P. Shameena, Beegum, R. Pandiselvam, LWT 162, (2022)
17. D.D. Jayasena, K. Fernando, T. Awanthika, J. Adv. Agric. Technol. **5**, (2018)
18. K. Sharanke, S. Sivakanthan, (2022)
19. K. Zou, J. Teng, L. Huang, X. Dai, B. Wei, LWT - Food Sci. Technol. **51**, 253 (2013)
20. R.V. Tonon, C. Brabet, M.D. Hubinger, J. Food Eng. **88**, 411 (2008)
21. K.N. Seneviratne, R.T. Kotuwegedara, Food Sci. Technol. Int. **15**, 419 (2009)
22. W. Brand-Williams, M.E. Cuvelier, C. Berset, LWT - Food Sci. Technol. **28**, 25 (1995)
23. J.R. Piggott, *Sensory Analysis of Foods.* (1984)
24. P.P. Lewicki, Trends Food Sci. Technol. **17**, 153 (2006)
25. L. Hu, J. Bi, X. Jin, Y. Qiu, R G M Van Der Sman Foods. **10**, 769 (2021)
26. M. Dewada, R. Ranawat, B.S. Deora, Ann. Agri-Bio Rescarch. **23**, 99 (2018)
27. R. Wang, R.W. Hartel, Compr. Rev. Food Sci. Food Saf. **20**, 5901 (2021)
28. M. Pravitha, M.R. Manikantan, V.A. Kumar, P.P.S. Beegum, R. Pandiselvam, Lwt. **162**, 113432 (2022)
29. Y. Liu, J. Tian, T. Zhang, L. Fan, Food Chem. **345**, 128832 (2021)
30. N. Jorge, G. Márquez-Ruiz, M. Martín-Polvillo, M.V. Ruiz-Méndez, M.C. Dobarganes, Grasas Y Aceites. **47**, 20 (1996)
31. P.K. Nayak, U.M.A. Dash, K. Rayaguru, K.R. Krishnan, J. Food Biochem. **40**, 371 (2016)
32. J. Yang, A. Martin, S. Richardson, C.-H. Wu, J. Food Eng. **214**, 117 (2017)
33. J. Adamczyk, D. Smołka-Danielowska, A. Krzątała, T. Krzykawski, Int. J. Environ. Sci. Technol. **21**, 4025 (2024)
34. G.K. Harris, M.R. Marshall, Food Anal. 287 (2017)
35. R.N. Olusanya, U. Kolanisi, N.Z. Ngobese, Foods. **12**, 2182 (2023)
36. S.S. Yaseen, A.A. Khalf, and Y. I. AI-Hadidy, in *IOP Conf. Ser. Mater. Sci. Eng.*IOP Publishing, (2020), p. 52002
37. M. Pravitha, M.R. Manikantan, V. Ajesh Kumar, S. Beegum, R. Pandiselvam, LWT 146, (2021)
38. P. Singh, R.K. Kesharwani, R.K. Keservani, in *Sustain. Energy Enhanc. Hum. Funct. Act.*Elsevier, (2017), pp. 103–115
39. A. Habarakada, P. Perumpuli, W. T., Wanninaika, (2021)
40. O. Abd Elmoneim, A.M. Hassan, M.E. Abu, J. Hum. Nutr. Food Sci. **2**, 1052 (2014)
41. A.H. Khattab, A.H. El Tinay, H.A. Khalifa, S. Mirghani, J. Sci. Food Agric. **25**, 689 (1974)
42. L. Nunes, G.M. Tavares, Trends Food Sci. Technol. **90**, 88 (2019)
43. N.R. Mohammed, J.M.S. Al-Saadi, and A. M. A. O. Aljabary, in *IOP Conf. Ser. Earth Environ. Sci.*IOP Publishing, (2021), p. 12108
44. P.T. Parmar, A.K. Singh, S.G. Borad, Oilseeds Heal Attrib Food Appl. 163 (2021)
45. S.A. Aida, A. Noriza, M.M. Haswani, S.M.Y. Mya, Int. Food Res. J. **23**, 68 (2016)
46. Karakaya Sibel, Ş. Şebnem, J. Am. Oil Chem. Soc. 1361 (2011)
47. B. Xu, S.K.C. Chang, J. Agric. Food Chem. **56**, 7165 (2008)
48. S. Gómez-Alonso, G. Fregapane, M.D. Salvador, M.H. Gordon, J. Agric. Food Chem. **51**, 667 (2003)
49. K.S. Yu, H. Cho, K.T. Hwang, Food Sci. Biotechnol. **27**, 651 (2018)
50. L. Y.-M. and L. K.-W., J. Food Sci. **74**, 118 (2009)

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