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Formulation, Physicochemical, and Sensory Evaluation of Cookies Prepared from Sacha Inchi Oil Meal (SIOM)

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ABSTRACT

Due to its substantial amounts of essential amino acids and protein, sacha inchi oil meal (SIOM) is ideal for producing protein-rich food. This study developed the cookies by blending SIOM with wheat flour at 5, 10, 20, and 30% (w/w), respectively. Physical properties, proximate composition, and sensory study were evaluated on the cookies. Data showed that 10% of wheat flour-SIOM cookies had the highest protein content (13.03%) compared to wheat flour cookies (4.89%). Cookies made with 20 and 30% SIOM were also feasible as the crude fiber content was high (48%). The hardness of wheat flour-SIOM incorporated cookies was lower (2.52–3.22 N) than wheat flour cookies (3.30 N). The water activity value of all the cookie samples during the 30-day storage was less than 0.6, indicating that the product was stable. Sensory analysis showed that the panelists preferred 10% SIOM-blend cookies over commercial cookies because of their better color, sweetness, texture, and appearance. Moreover, the overall acceptability of SIOM cookies was greater than 6 on a 9-point hedonic scale. This study concludes that SIOM can be a functional food ingredient that can help develop healthier bakery products.

Keywords: Cookies, flour blends, protein-rich food, sacha inchi oil meal, sensory analysis

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INTRODUCTION

In recent years, there has been a rise in global acceptance and preference for emerging plant-based alternatives like almonds, chickpeas, soybeans, and lupins due to their rich nutrient content, including proteins, essential fatty acids, and fiber. These foods hold the potential for development into functional foods, dietary supplements, and pharmaceutical products, offering preventive benefits for conditions such as metabolic syndrome, diabetes, and lactose intolerance (Kotecka-Majchrzak et al., 2020; Rizzello et al., 2016). Additionally, the use of oil seeds has gained traction in both pharmaceutical and food research, with extracted oils being rich in polyunsaturated fatty acids, bioactive components, and vitamins essential for neuroendocrine system health (Hidalgo & Zamora, 2006; Kotecka-Majchrzak et al., 2020). The byproducts of oil extraction, oil cake/oil meal, are valuable sources of phytochemical compounds, antioxidants, and dietary fibers, making them useful functional ingredients contributing to overall health (Belghith-Fendri et al., 2016; Jeddou et al., 2017). The high protein content in oil meal, resulting from the removal or reduction of fat during oil extraction, presents an opportunity to develop functional foods (Kotecka-Majchrzak et al., 2020).

A few examples of oil meals with health benefits are okara, sesame seed meal, chia seed meal, SIOM, and hemp seed meal (Manikantan et al., 2015; Radočaj et al., 2014; Sánchez et al., 2021; Souza et al., 2015; Swallah et al., 2021). Valorization of agro-industrial byproducts has grown significantly in recent decades due to their presence of essential nutrients while benefiting the environment and economy (de Pilar Sánchez-Camargo et al., 2019).

Sacha inchi seeds (*Plukenetia* spp.) are known globally as a "superfood" due to their excellent nutritional value. The seeds are mainly used to extract the oil as they are enriched with polyunsaturated fatty acids (PUFAs) (α-linolenic acid ~50%, and linoleic acid ~35%) (Gutiérrez et al., 2011, 2019). Due to the presence of PUFAs in the oil, the oil has wide application in nutraceutical, food and pharmaceutical markets (Sánchez et al., 2021). The protein content in the seed varies between 22–30% and has essential amino acids (EAA) higher than other oil seeds (Čepková et al., 2019; Kodahl, 2020). In general, the amino acid composition of the seeds is consistent with dietary guidelines and may represent a valuable source of amino acids, particularly in malnourished and undernourished populations (Sathe et al., 2012).

SIOM, a byproduct of Sacha inchi oil processing, is rich in protein (32 to 62%), and this concentration of protein is generally higher in *Plukenetia volubilis* (59%) as compared to *Plukenetia huayllabambana* (46%) (Ruiz et al., 2013). Nevertheless, regardless of the variety, the protein content in SIOM is similar to the soybean mean (42–50%) (Ibáñez et al., 2020). SIOM also contains important minerals such as potassium, magnesium, calcium, and phosphorus. The investigation by Rawdkuen et al. (2016) on the mineral content in SIOM showed the presence of calcium (7,616 ppm), magnesium (8,922 ppm), phosphorus (13,125 ppm), and potassium (13,935 ppm), wherein the amount of phosphorus and calcium were similar to soybean meal. SIOM is also rich in amino acids. SIOM is comparable to soy protein in terms of total EAA concentration, making it a rich source of protein. The SIOM has been used as a functional food ingredient and a non-conventional source of protein isolate and hydrolysates (Chirinos et al., 2017; Rawdkuen et al., 2018; Rodríguez et al., 2018).

The development of foods high in fiber, fatty acids, and protein fiber is a prominent trend that meets the current needs of the population and certain consumer groups such as individuals with insufficient dietary fiber intake, weight management and vegans. Due to its high nutritional value, SIOM is suitable for fortifying foods with proteins, fiber, and essential fatty acids (Sánchez et al., 2021).

Cookies are popular bakery products that all age groups prefer. Due to their ease of availability, taste, and longer shelf life, cookies represent a valuable carrier of nutrient supplementation (Machado et al., 2021). Research studies on incorporating oil meal as fortificants have been reported by earlier studies (Shabeer et al., 2016). Thus, this study was undertaken to develop cookies by incorporating SIOM and to investigate the effect of the addition of SIOM on the nutritional and overall acceptability of the formulated cookies.

MATERIALS AND METHODS

Materials

The ingredients, such as whole wheat flour (Pillsbury, India), sugar (CSR Sugar, Malaysia), salt (Double Swallow, Malaysia), margarine (Planta, Malaysia), and vanilla essence (STAR BRAND, Malaysia) were purchased from a local hypermarket (Lulu hypermarket, Malaysia). SIOM was obtained after processing sacha inchi oil seed procured from Myanmar (Wusang Group Sdn. Bhd., Malaysia).

Preparation of Flour Blends

Four flour blends were prepared by blending SIOM with wheat flour at 5, 10, 20, and 30%. The flour blends were designated samples F5, F10, F20, and F30, respectively.

Functional Properties of Flour Blends

Water Absorption Capacity (WAC)

One gram of the sample was mixed with 10 ml distilled water. The solution was centrifuged for 30 min at 1,196 × *g*. The supernatant was discarded, and the sample was weighed again. The results were expressed as g water/g flour.

Oil Absorption Capacity (OAC)

The water was replaced by soybean oil, and the results were expressed as g oil/g flour to determine the OAC (Ghoshal & Kaushik, 2020).

Bulk Density (ρ_B)

A 2 g sample was taken in a measuring cylinder to calculate the bulk density. The cylinder was gently tapped to dislodge any powder adhering to its inner surface. The bulk density was calculated using Equation 1:

$$\rho_B = \frac{M}{V} \quad [1]$$

where, M = mass of the sample; V = volume of the powder.

Tapped Density (ρ_T)

The measuring cylinder was manually tapped 50 times to ascertain the compact volume (V_T) to calculate the tapped density. The tapped density was then determined using Equation 2:

$$\rho_T = \frac{M}{V_T} \quad [2]$$

where, M = mass of the sample; V_T = compact volume after tapping. The results were expressed as g/ml (Lavanya et al., 2020; Shafi et al., 2016).

Preparation of Cookies

Margarine, powdered sugar, and flavor (vanilla) were creamed in a mixer (Kenwood Chef Classic KM 336, Malaysia) with salt and water. The contents were further mixed for 2 min. The flour blend (5, 10, 20, and 30%) was gradually added, and the contents were kneaded for 2 min to make the dough. The dough sheet was sheeted using a rolling pin and cut into a round shape with a diameter of 4.80 cm using a cookie cutter. The cookies were baked in a baking oven (Elba electric oven, EEO-A2815 (SV), Malaysia) at 160°C for 15–20 min. The products were cooled completely at room temperature (28 ± 1°C). The formulation of the cookies is shown in Table 1.

Proximate Analyses

The proximate analyses of cookies were evaluated following the Association of Official Analytical Chemists (AOAC) method (Horwitz & Latimer, 2005). The calorific value was calculated using 4, 9, and 4 factors for protein, fat, and carbohydrate and was expressed as kcal/100 g (Rai et al., 2014).

Physical Parameters

The physical parameters of the cookies were measured by the method proposed

Table 1
Formulation of cookies

Ingredients	**Incorporation of sacha inchi oil meal (SIOM) at different levels in cookies**				
	F0	**F5**	**F10**	**F20**	**F30**
Wheat flour (g)	100	95	90	80	70
SIOM (g)	0	5	10	20	30
Margarine (g)	60	60	60	60	60
Sugar (g)	35	35	35	35	35
Vanilla essence (tsp)	¼	¼	¼	¼	¼
Water (ml)	10	10	10	10	10

Note. F0 = Control; F5 = 5% replacement with SIOM; F10 = 10% replacement with SIOM; F20 = 20% replacement with SIOM; F30 = 30% replacement with SIOM by Chauhan et al. (2016). The spread ratio was calculated as the diameter-to-thickness ratio, as shown in Equation 3. The cookies' weight was determined using a digital electronic balance (A&D, HR-60, Japan).

$$\text{Spread ratio} = \frac{\text{Diameter (mm)}}{\text{Thickness (mm)}} \quad [3]$$

Color and Hardness of Cookies

The cookies' color was measured using a Chroma Meter CR-400 (Konica Minolta, Inc. Japan). L* indicates lightness, and its values from 0 (black) to 100 (white), a* (±indicates red/green), and b* (± indicates yellow /blue) were used to determine the cookies' color.

The hardness, which represents the maximum force (N) that the cookies could withstand before breaking, was analyzed using a texture analyzer (Stable Micro Systems, United Kingdom) with a shape blade-cutting probe. The analyzer was maintained at pre-test speed =1 mm/s, test speed = 0.5 mm/s, and post-test speed = 10 mm/s.

Microstructural Analysis

Scanning electron microscopy (SEM) (JSM 5800, JEOL Ltd., Japan) was used to investigate the morphology of the cookies. The samples were affixed to a specimen stub with double-sided adhesive tape and then coated with gold using a magnetron sputter coater. The coated samples were examined in SEM at 15 kV at a magnification level of 1,000×.

Moisture Stability of Cookies

The cookies were packed in low-density polyethylene (LDPE) pouches, stored at ambient temperature for a month and analyzed for changes in water activity and moisture content. Moisture content was assessed by calculating the loss on drying at 105°C. The cookies' water activity (a_w) was determined using a water activity meter (AQUALAB Pre Water Activity Analyzer, Decagon Devices Inc., USA). It determines the viable water molecules present in the food system. Lower water activity lowers microbial growth (Theagarajan et al., 2019).

Sensory Analyses

Sixty non-trained panelists over 65 years old performed sensory analyses of the cookies. The panelists were provided with cookie samples, and the objective of the sensory evaluation was presented to them. The sensory attributes of the cookies were evaluated using a 9-point hedonic scale ranging from 1 (strong dislike) to 9 (like to maximum).

Statistical Analysis

A significant difference between the mean values was determined by one-way analysis of variance (ANOVA) and Tukey's range test using Minitab (version 17).

RESULTS AND DISCUSSION

Functional Properties of Flour Blends

Functional properties are the inherent physicochemical characteristics that reflect the intricate interaction between the composition, structure, physico-chemical properties of proteins, and the type of environment in which these are measured (Kinsella & Melachouris, 1976). These characteristics can ultimately influence the overall quality of the food, specifically concerning its sensory and physicochemical properties. A basic understanding of the functional properties helps to improve processing requirements and optimize their use to develop various food products (Eltayeb et al., 2011).

The effect of incorporating SIOM at various levels on the functional properties such as water holding capacity, oil holding capacity, bulk density, and true density were analyzed, and the results are presented in Table 2.

Water holding capacity is desirable in food processing as it provides the essential organoleptic qualities that make the food acceptable to consumers. In this study, the WAC of the samples varied from 1.45 g/g (F0) to 1.75 g/g (F30). Overall, F0 had the lowest WAC. Germination, fermentation, soaking, or thermal treatments (toasting/autoclaving) considerably improve the water absorption capacity of the meals (Moure et al., 2006). Studies by Iyenagbe et al. (2017) on defatted conophor nuts in raw and toasted oil meal flour showed the highest WAC (1.36 g/g) for toasted flour as compared to untoasted flour (1.18 g/g). The increase in WAC could be due to the partial denaturation of proteins during thermal pre-treatment as during the process, major proteins can break into subunits with more water binding sites than native oligomeric proteins, and this, along with gelatinization of carbohydrates, results in an overall increase in WAC. Variations in WAC between the samples could be attributed to protein structure and various hydrophilic carbohydrates (Sarabhai & Prabhasankar, 2015).

OAC is an important feature for food products, as lipids often improve the flavor and texture of food products. In this study, the OAC decreased with an increase in SIOM addition. Sarabhai and Prabhasankar (2015) reported a similar result when replacing wheat flour with chestnut flour and potato starch. The high OAC value of wheat

Table 2
Functional properties of composite flour blends

Samples	WAC (g water /g flour)	OAC (g oil/g flour)	Bulk density (g/ml)	Tapped density (g/ml)
F0	1.45 ± 0.06[c]	1.56 ± 0.24[a]	0.50 ± 0.003[a]	0.63 ± 0.02[a]
F5	1.55 ± 0.06b[c]	1.53 ± 0.05[a]	0.52 ± 0.006[a]	0.65 ± 0.01[a]
F10	1.54 ± 0.03[bc]	1.53 ± 0.03[a]	0.53 ± 0.003[a]	0.66 ± 0.01[a]
F20	1.61 ± 0.04[b]	1.53 ± 0.06[a]	0.54 ± 0.008[a]	0.66 ± 0.01[a]
F30	1.75 ± 0.06[a]	1.53 ± 0.14[a]	0.54 ± 0.005[a]	0.67 ± 0.01[a]

Note. F0 = Control; F5 = 5% replacement with sacha inchi oil meal (SIOM); F10 = 10% replacement with SIOM; F20 = 20% replacement with SIOM; F30 = 30% replacement with SIOM. The values represented by different letters in the same column differ significantly (p<0.05). WAC = Water absorption capacity; OAC = Oil absorption capacity flour is due to low hydrophobic proteins in wheat flour that exhibit better binding towards lipids (David et al., 2015).

The bulk density of the flour increased with the level of incorporation of SIOM. Similar consistent results were reported by Ndife et al. (2014) on wheat soy flour blends. Likewise, studies by Marak et al. (2019) also reported increased bulk density by replacing wheat flour with foxtail millet and ginger millet powder at increasing proportions. Generally, low bulk density is required for products such as geriatric foods and weaning foods and high bulk density is required for specialty foods to satisfy consumers (Nikitha & Natarajan, 2020). The tapped density measures random dense packing related to the increased bulk density obtained after mechanically tapping the container (Saw et al., 2013). Mechanically tapping a container rearranges the powder particles, lowering the volume of the interparticle gaps, and hence, the tapped density is greater than the bulk density. The tapped density of the samples was between 0.63–0.67 g/ml, and there was no significant difference between the samples.

Proximate Composition of Cookies

The cookies' proximate analyses, including moisture, ash, crude protein, crude fiber, and fat, were studied. The results are shown in Table 3.

The moisture content of cookies with SIOM had higher moisture content as compared to wheat flour cookies, and there was a significant difference ($p<0.05$). The increase in moisture content could be due to the WAC of the composite flours, wherein the WAC was higher in composite flour than wheat flour (Raihan & Saini, 2017). The study results for moisture content agree with cookies developed using carrot pomace, germinated wheat flour, and coffee silver skin, respectively (Baljeet et al., 2014). The protein content of the

Table 3
Proximate composition of cookies

Samples	Moisture (%)	Ash (%)	Crude protein (%)	Crude fat (%)	Crude fiber (%)	Carbohydrate (%)	Calorific value (kcal/100 g)
F0	4.76 $\pm$ 0.06^{b}	1.93 $\pm$ 0.25^{bc}	4.89 $\pm$ 0.67^{c}	28.17 $\pm$ 0.04^{a}	46.63 $\pm$ 0.29^{b}	13.61 $\pm$ 0.56^{a}	327.53
F5	5.34 $\pm$ 0.08^{a}	1.82 $\pm$ 0.11^{c}	9.88 $\pm$ 0.42^{b}	27.33 $\pm$ 0.21^{b}	46.82 $\pm$ 0.12^{b}	8.82 $\pm$ 0.72^{b}	320.77
F10	5.36 $\pm$ 0.01^{a}	2.03 $\pm$ 0.07^{bc}	13.03 $\pm$ 1.79^{a}	28.15 $\pm$ 0.21^{a}	47.46 $\pm$ 0.18^{b}	3.88 $\pm$ 1.92^{c}	320.99
F20	5.38 $\pm$ 0.08^{b}	2.21 $\pm$ 0.08^{ab}	11.83 $\pm$ 0.50^{ab}	27.79 $\pm$ 0.13^{ab}	48.05 $\pm$ 1.29^{ab}	4.73 $\pm$ 0.96^{c}	316.35
F30	5.46 $\pm$ 0.15^{c}	2.41 $\pm$ 0.12^{a}	11.55 $\pm$ 0.72^{ab}	27.75 $\pm$ 0.43^{ab}	48.06 $\pm$ 0.17^{a}	4.80 $\pm$ 1.2^{c}	315.15

Note. F0 = Control; F5 = 5% replacement with sacha inchi oil meal (SIOM); F10 = 10% replacement with SIOM; F20 = 20% replacement with SIOM; F30 = 30% replacement with SIOM. The values represented by different letters in the same column differ significantly ($p<0.05$). WAC = Water absorption capacity; OAC = Oil absorption capacity

cookies decreased as the level of SIOM incorporation increased. A similar result was reported by Arun et al. (2015) on cookies developed by replacing wheat flour with plantain peel flour. A small but statistically significant difference was observed for crude fat. The crude fiber content significantly increased when SIOM replaced wheat flour. Fiber helps in healthy bowel movements and reduces the risk of obesity and colon cancer (Papathanasopoulos & Camilleri, 2010). The data for calorific value shows a reduction in calorific value for cookies. The reduction in calorific value in SIOM cookies could be due to low carbohydrate and high fiber content. Hence, SIOM can be used to develop high-fiber and low-calorie foods to improve health. Yashini et al. (2021) reported a similar reduction in calorific value on cookies developed using defatted tomato seed flour.

Physical Parameters of Cookies

The changes in physical parameters of the cookies, which include weight, diameter, thickness and spread ratio, were analyzed, and the results are presented in Table 4.

The data showed a statistically significant difference ($p<0.05$) in the thickness, diameter, spread ratio, and weight of each sample. The weight of the cookies varied from 13.68 g (F0) to 11.61 g (F30), respectively. The diameter of the cookies varied from 45.43 to 47 mm. The diameter of the cookies developed with SIOM gradually reduced as the level of incorporation of SIOM increased. Studies by Pawde et al. (2020) on biscuits developed using dragon fruit powder reported a similar trend in reduction in diameter of biscuits as the refined wheat flour was replaced by dragon fruit powder (30–60%). Likewise, studies by Ghoshal and Kaushik (2020) also reported a decreasing trend in the diameter of the cookies developed using soy meal flour. The decrease in diameter could be because a higher protein or carbohydrate content in the dough improves its ability to bind water, which promotes the formation of an elastic network and causes the network to shrink after baking (Yashini et al., 2021). However, studies by Guyih et al. (2020) on cookies developed using almond seed and carrot flour reported an increase in

Table 4
Physical parameters of cookies

Samples	Weight (g)	Thickness (mm)	Diameter (mm)	Spread ratio
F0	13.68 ± 1.02^{a}	8.51 ± 0.16^{a}	47.00 ± 0.40^{a}	5.52 ± 0.08^{d}
F5	12.97 ± 0.18^{bc}	8.62 ± 0.06^{b}	46.11 ± 0.52^{b}	5.35 ± 0.11^{bc}
F10	12.57 ± 0.46^{ab}	9.06 ± 0.19^{b}	46.07 ± 0.41^{b}	5.08 ± 0.07^{cd}
F20	11.80 ± 0.63^{c}	9.39 ± 0.09^{c}	45.85 ± 0.39^{b}	4.88 ± 0.10^{a}
F30	11.61 ± 0.28^{c}	9.50 ± 0.12^{c}	45.43 ± 0.40^{b}	4.78 ± 0.06^{ab}

Note. F0 = Control; F5 = 5% replacement with sacha inchi oil meal (SIOM); F10 = 10% replacement with SIOM; F20 = 20% replacement with SIOM; F30 = 30% replacement with SIOM. The values represented by different letters in the same column differ significantly ($p<0.05$). WAC = Water absorption capacity; OAC = Oil absorption capacity

the diameter value as the wheat flour was replaced by almond and carrot flour.

Likewise, the thickness of the cookies gradually increased as the SIOM was incorporated at various levels. Thickness and diameter are inversely related, while the spread ratio depends on the proportion between diameter and thickness (Srivastava et al., 2014). In the present study, the spread ratio of the cookies varied from 5.52 (F0) to 4.78 (F30) respectively. The spread ratio decreased as the level of SIOM addition increased. The decrease in the spread ratio of SIOM cookies can be explained by the fact that wheat and SIOM flour form a higher number of hydrophilic sites for a limited amount of free water in cookie dough. Rapid moments of free water to this hydrophilic region occur during dough blending, which limits the cookie's spread during baking. A similar result was reported by Ghoshal and Kaushik (2020) on soy meal-fortified cookies.

Color and Hardness of Cookies

The effect of the incorporation of SIOM on the color and hardness of cookies was evaluated, and the results are summarized in Table 5. The color values of the freshly baked cookies for lightness (L*) were between 53.05 and 56.00. The value of a* (redness) followed a decreasing pattern with an increase in the level of incorporation of SIOM, and the value of b* for the cookies did not differ much. No significant difference ($p<0.05$) was observed in the L* and b* values. Incorporation of SIOM at the highest level (30%) resulted in a low value of L* (53.05) when compared to the control (53.28), indicating that SIOM cookies are darker in color. Studies by Chauhan et al. (2016) also reported a low value of L* (59.01) on cookies developed by completely replacing wheat flour with amaranth flour. Studies by Ghoshal and Kaushik (2020) on cookies developed using defatted soymeal flour (15–25%) reported that the lightness of cookies (L*) followed an increasing pattern with the level of defatted soymeal flour. During baking, a brown color is formed due to the caramelization of sugar and the Maillard reaction, which are influenced by various factors such as water activity, sugars, and temperature. The lighter color

Table 5
Effect of incorporation of SIOM on color and hardness of cookies

Samples	L*	a*	b*	Hardness (N)
F0	53.28 ± 1.22[a]	5.68 ± 0.37[a]	18.88 ± 1.21[a]	3.30 ± 1.26[a]
F5	56.00 ± 1.30[a]	5.67 ± 0.42[ab]	19.38 ± 1.82[a]	2.52 ± 0.58[a]
F10	55.26 ± 1.46[a]	5.54 ± 0.49[a]	19.84 ± 1.25[a]	2.64 ± 1.14[a]
F20	55.84 ± 0.48[a]	5.53 ± 0.17[b]	18.54 ± 0.72[a]	2.87 ± 0.4[a]
F30	53.05 ± 1.46[a]	5.33 ± 0.4[a]	18.90 ± 1.02[a]	3.22 ± 0.4[a]

Note. F0 = Control; F5 = 5% replacement with sacha inchi oil meal (SIOM); F10 = 10% replacement with SIOM; F20 = 20% replacement with SIOM; F30 = 30% replacement with SIOM. The values represented by different letters in the same column differ significantly ($p<0.05$). WAC = Water absorption capacity; OAC = Oil absorption capacity

of cookies may be owing to a lower protein content, which results in less Maillard compound production (Shafi et al., 2016).

Texture, like color, is an important sensory parameter that determines the acceptability of the product. Hardness is one of the texture parameters for cookies (Cheng & Bhat, 2016). The maximum force that the cookies could withstand before breaking was determined using a texture analyzer. Replacement of wheat flour with SIOM to develop cookies changed the breaking strength of the cookies (Table 5). The data reports that the breaking strength of the cookies did not vary significantly ($p<0.05$). The hardness of cookies is due to the formation of a gluten network, which is caused by the absorption of water molecules by gluten (Aslam et al., 2014). The hardness of the cookies gradually increased with the addition of SIOM (5–30%). The increase in hardness could be due to the fiber and protein content in the SIOM, which has a very good WAC, thus making the dough very sticky. A similar result was reported by Kaur et al. (2019) on cookies developed using flax seed powder. The addition of SIOM at 30% caused an increase in the hardness of cookies, and eventually, a rise in breaking strength was noted. Studies by Ghoshal and Kaushik (2020) also reported that cookies developed with a 25% level of defatted soy meal flour had higher breaking strength when compared to 15 and 20%, respectively. Likewise, studies by Shafi et al. (2016) reported that with an increase in the level of replacement of water chestnut flour (20, 40, 60, 80, and 100%), a gradual increase in the force required to break the cookies was observed.

Microstructural Analysis

The microstructure of the cookies was analyzed using SEM, and the results are shown in Figures 1A-1E. SEM images of control cookies (Figure 1A) showed the presence of large and small gelatinized wheat starch granules embedded in a protein matrix. The matrix is a network enveloping the starch granules (Rao et al., 2022). Figures 1B-1E show the micrograph of wheat flour-SIOM cookies. As the level of SIOM increased from 5 to 30%, the structure appeared loose and open with gaps. This difference was particularly noticeable in the 30% wheat flour- SIOM cookie sample because a lesser amount of starch granules is enclosed in the protein matrix as the gluten in wheat flour is replaced by the proteins in SIOM. Moreover, the presence of fiber and other components of SIOM can affect the starch gluten matrix. It was also evident in the cookie texture, as the spread ratio decreased with the increase in the hardness of cookies (McWatters, 1978).

Moisture Stabilities of Cookies

The cookies prepared using wheat flour and SIOM were stored at ambient temperature for 30 days, and the changes in moisture content and water activity were analyzed; the study results are shown in Figures 2 and 3. The initial moisture content of the cookies was between 4% (F0) and 5.46% (F20). During storage, moisture content increased for all the cookie samples was observed until day 15 and then decreased till day 30 of storage for SIOM cookies. However, an increase in the moisture content of the F0

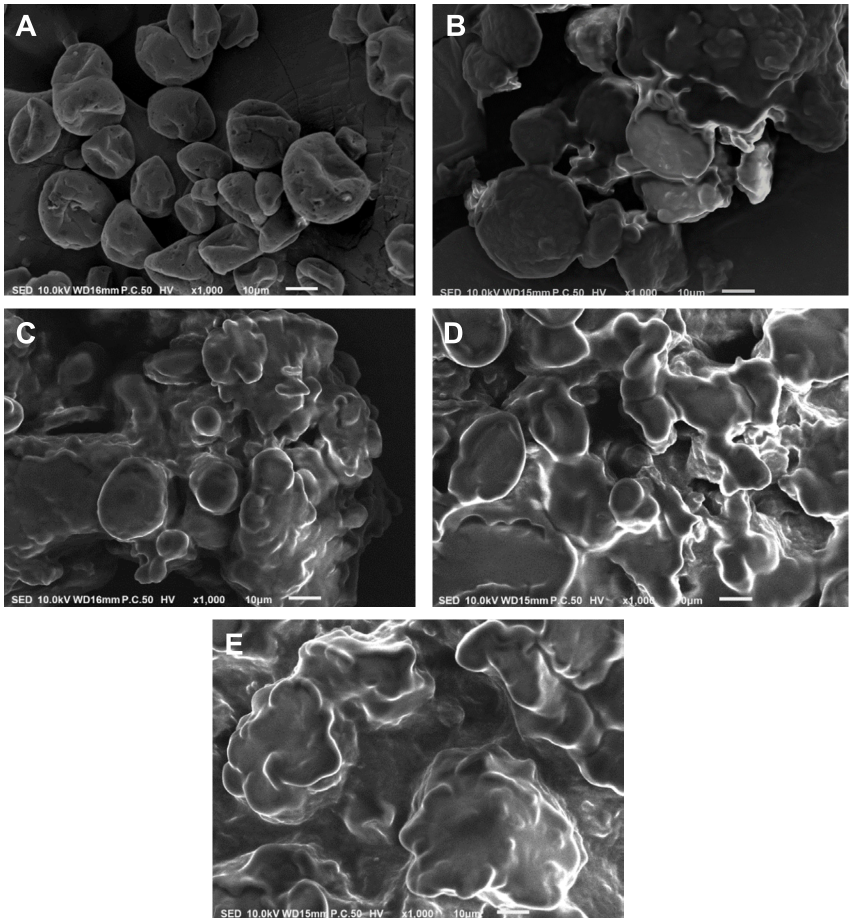

Figure 1. Microstructural analysis of cookies
Note. A = Control; B = 5% replacement with sacha inchi oil meal (SIOM); C = 10% replacement with SIOM; D = 20% replacement with SIOM; E = 30% replacement with SIOM

sample was observed till day 30 of storage, indicating that the F0 sample absorbed moisture from the environment. A similar observation was reported by Chung et al. (2014) on wheat flour cookies during a 7-day storage study.

The loss or gain of moisture in the food component from one place to another continues until thermodynamic equilibrium is attained with the food and the environment (Vasanthakumari & Jaganmohan, 2018). Water activity directly impacts a product's shelf life since most spoilage microbes require specific water activity. In general, the value of water activity close to one indicates that the product is unstable, as most microbes, such as fungi, yeast, and bacteria, require minimum water activity closer to one for their growth. The product's shelf life is acceptable within a water activity range of < 0.6 (Vadukapuram et al., 2014).

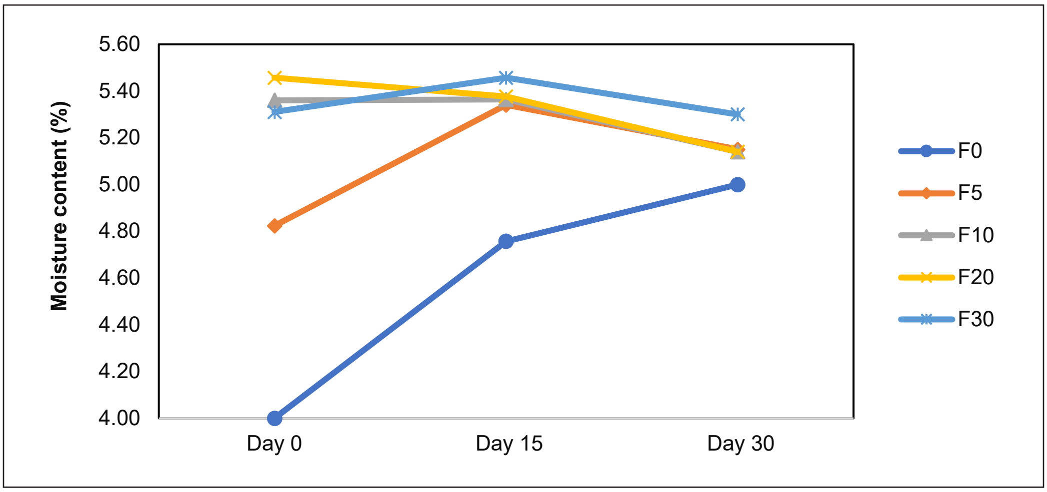

Figure 2. Changes in moisture content of the cookies during 30-day storage
Note. F0 = Control; F5 = 5% replacement with sacha inchi oil meal (SIOM); F10 = 10% replacement with SIOM; F20 = 20% replacement with SIOM; F30 = 30% replacement with SIOM

The water activity of the cookies during the 30-day storage is shown in Figure 3. The F30 cookie sample had the lowest water activity (0.426) compared to the control (0.472) on day 0. The study showed that the water activity of the cookie samples increased during storage. The obtained values were <0.6, indicating that the products were stable during storage. These results were similar to the previously reported studies (Park et al., 2015; Secchi et al., 2011). The increase in water activity during storage is due to the crystallization of sugars (Shafi et al., 2016).

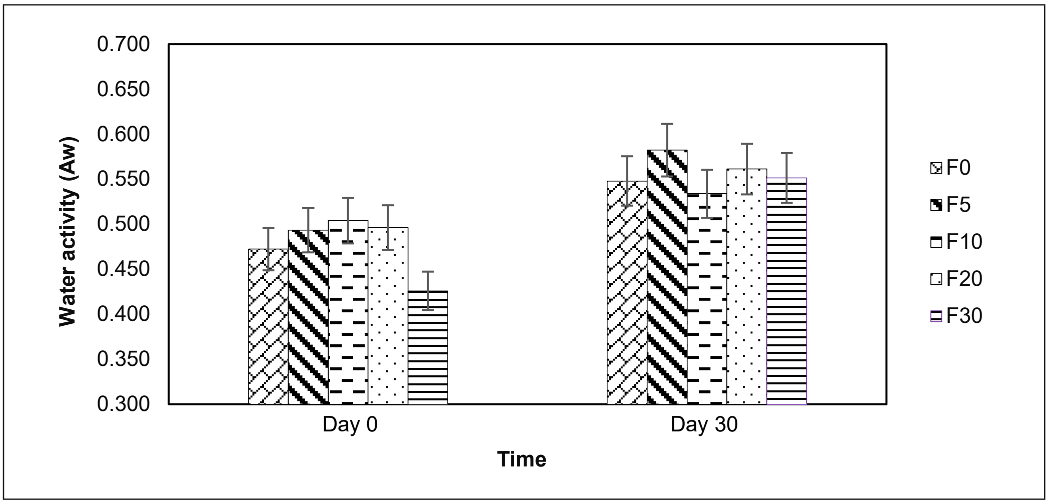

Figure 3. Changes in moisture content of the cookies during 30-day storage
Note. F0 = Control; F5 = 5% replacement with sacha inchi oil meal (SIOM); F10 = 10% replacement with SIOM; F20 = 20% replacement with SIOM; F30 = 30% replacement with SIOM

Sensory Evaluation of Cookies

Sensory evaluation is the simplest and easiest method for consumers to evaluate the acceptability of the product. The results of sensory evaluation are presented in Table 6. The average scores showed a reduction in sensory attributes with increasing levels of SIOM in cookie formulation. Commercial cookies received the lowest score in all the attributes. Among the SIOM cookies, the panelist commented that cookies made from wheat flour blended with 30% SIOM had a nutty taste compared to 5, 10, and 20%. Shafi et al. (2016) reported a similar nutty taste on cookies developed with 100% water chestnut flour. The nutty taste of the wheat flour blended with 30% SIOM reduced the overall acceptability of the cookies. The color of the cookies did not vary across all the cookies. The overall acceptability results showed that SIOM cookies were preferred over commercial cookies. Panelists preferred the sweetness of SIOM cookies more than commercial cookies. Among all the samples, cookies containing 10% SIOM were deemed the best, achieving the highest possible score regarding overall acceptability. Thus, the sensory evaluation results based on the overall acceptability score showed that SIOM could be incorporated as a functional ingredient to develop cookies as healthy snacks for the elderly to promote healthy aging.

CONCLUSION

The study results show that SIOM can be used to develop nutritionally enriched cookies. There was marginal improvement in protein content in SIOM cookies compared to wheat flour cookies. By analyzing the sensory evaluation results, the oil meal can be incorporated up to 10% in the cookies for better acceptability. Further studies can be done to determine the *in-vitro* protein digestibility and minerals in cookies to determine the bio-accessibility of proteins.

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Table 6
Sensory evaluation of cookies

Samples	Color	Texture	Sweetness	Taste	Overall acceptability
A	6.77 ± 1.42^{a}	6.47 ± 1.43^{b}	6.66 ± 1.28^{b}	6.48 ± 1.21^{b}	6.45 ± 1.40^{b}
B	6.87 ± 1.32^{a}	7.17 ± 1.08^{a}	7.26 ± 1.06^{a}	7.05 ± 1.02^{ab}	7.15 ± 0.86^{a}
C	7.05 ± 1.25^{a}	7.35 ± 0.99^{a}	7.16 ± 0.94^{ab}	7.33 ± 0.95^{ab}	7.41 ± 0.85^{a}
D	7.17 ± 1.25^{a}	7.38 ± 1.11^{a}	7.20 ± 1.02^{ab}	7.40 ± 1.06^{ab}	7.48 ± 1.08^{a}
E	7.08 ± 1.31^{a}	7.23 ± 1.13^{a}	7.18 ± 0.97^{ab}	7.03 ± 1.15^{ab}	7.20 ± 1.01^{a}
F	7.17 ± 1.45^{a}	6.95 ± 1.46^{ab}	7.06 ± 1.09^{ab}	6.73 ± 1.33^{b}	7.03 ± 1.30^{a}

Note. A = Commercial cookie; B = Control cookie; C = 5% replacement with sacha inchi oil meal (SIOM); D = 10% replacement with SIOM; E = 20% replacement with SIOM; F = 30% replacement with SIOM. The values represented by different letters in the same column differ significantly (p<0.05)

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