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Characterization and Evaluation of Modified Potato Peel Starch and Soy Protein Isolate for Formulation in Reduced-Fat Mayonnaise

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ABSTRACT

Low-fat or reduced-fat food products have received significant attention in recent years. In the present study, the physicochemical, nutritional, and functional properties of reduced fat mayonnaise were evaluated. This mayonnaise was formulated by partially substituting oil with modified potato peel starch and isolated soy protein. Oil substitution levels ranged from 5% to 15% using the modified starch gel. Reduced-fat mayonnaise samples were compared to full-fat mayonnaise (control) in terms of physicochemical properties and sensory attributes. The amylose content of potato peel starch before and after modification was approximately 24.01% and 33.01%, respectively. The water-holding capacity, oil-holding capacity, protein yield, and protein content of soy protein isolate were found to be 1.12 ml/g, 1.02 ml/g, 30.49%, and 86.85%, respectively values that were higher than those of the modified potato peel starch. At the beginning of cold storage (4°C), the pH values of the mayonnaise samples ranged from 3.62 to 3.94, increasing to 4.49–4.99 after 30 days. High emulsion stability was maintained with up to 10% oil replacement. The full-fat control sample showed the highest L* (brightness) and b* (yellowness) values, followed by the sample containing 5% modified starch gel throughout the storage period. The reduced-fat mayonnaise with 15% modified starch gel had a total calorie content 21.48% lower than the full-fat mayonnaise. Compared to the control, mayonnaise samples with 5% and 10% modified potato peel starch substitution demonstrated superior sensory characteristics. The co-addition of isolated soy protein and modified potato peel starch did not adversely affect the physicochemical or sensory properties of the reduced-fat mayonnaise, except for a reduction in viscosity due to starch gel addition, even after one month of storage. These results suggest that using modified potato peel starch as a value-added component of agro-industrial waste, in combination with soy protein isolate, offers a promising technological approach for developing reduced-fat mayonnaise with enhanced health benefits.

1. Introduction

Consumers have a rising demand for functional foods that promote health (Bulathgama et al., 2022). A notable trend in the food industry is the creation of low-fat products, which are becoming more popular than traditional diets. Fat content plays a crucial role in factors such as taste, flavor, appearance, texture, and shelf life, and it is a key source of essential fatty acids (Giglio et al., 2024). Mayonnaise is a semisolid oil-in-water emulsion that is commonly used as a condiment due to its creamy texture and distinctive flavor. Traditional mayonnaise typically contains 65-80% fat, which contributes significantly to its flavor and texture (Sun et al., 2018). Given its high calorie and oil content, reducing the fat in mayonnaise is essential. Reduced fat or low-fat mayonnaise is becoming more popular than traditional full-fat mayonnaise (Hayati et al., 2009).

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Finding an effective fat replacer is crucial for formulating low-fat products, as decreasing fat content can lead to quality issues, such as undesirable mouthfeel and flavor (Park et al., 2020). Industrial processing generates between 70 and 140 thousand tons of peels worldwide annually (Chang, 2019). Additionally, in the industrial processing of potato tubers, about 88.9% of the product is utilized, leaving the remainder as waste. Approximately 25% of the waste generated during potato processing is disposed of without being processed for added value (Calvache et al., 2022). Potato peel are a rich source of starch, which holds significant value both as a food ingredient and in various industrial sectors (Jagadeesan et al., 2020). Despite this, the direct use of native starch in industrial processes is limited due to its poor resistance to heat and mechanical stress, as well as its tendency to undergo retrogradation during storage under cold or frozen conditions, leading to undesirable changes in food texture and quality (Arocas et al., 2009). To overcome these drawbacks, starch is often subjected to modification processes that improve its structural and functional characteristics, thereby expanding its range of potential applications (Zhang et al., 2023). Many studies have focused on modified starch, which involves altering natural starch to improve functionality (Zia-ud-Din et al., 2017). These modifications can be categorized as physical, chemical, or enzymatic, depending on the techniques used and the properties being altered (Bajaj et al., 2019). In its modified form, starch helps maintain food texture, acts as a gelling agent in emulsions to enhance stability, and prevents separation of components, thereby improving the overall appearance and flavor of food products (Egharevba, 2019). Soy protein isolates are effective emulsifiers, demonstrating higher emulsifying activity than soy protein concentrates. Various factors, such as pH, influence the emulsifying properties of soy protein (Jideani, 2011). Moreover, plant-based protein isolates are recognized for their stabilizing capabilities in food emulsions, primarily due to their efficiency in lowering the interfacial tension between aqueous and lipid phases. Among these, soy and other vegetable-derived proteins have demonstrated effectiveness in stabilizing oil-in-water (o/w) emulsions (Abu Ghoush et al., 2008). In addition, soy protein has proven suitable for use in low-cholesterol salad-type products, exhibiting functional characteristics comparable to those found in mayonnaise and traditional salad dressings (Puppo et al., 2003). Soy protein serves as an effective emulsifier and an affordable fat substitute (Garcia, et al., 2009). A chemical-free and gentle method for enhancing protein functionality such as emulsifying, foaming, and gelling is protein-polysaccharide conjugation. This process occurs during the early stages of the Maillard reaction (Burger & Zhang, 2019). This study investigated the development of low-fat mayonnaise with isolated soy protein, as emulsifier and stabilizer, and modified potato peel starch, as a fat replacer. Also, evaluated the effect of the re-placement on the physicochemical, nutritional, and functional properties of mayonnaise. And increased value-added of agro-industrial waste such as potato peel.

2. Materials and Methods

Materials

The potato peel utilized in this research were sourced from a chips production factory located in the industrial area of 6th October City, Giza, Egypt. Soybean seeds, used for the extraction of soy protein isolate, were obtained from El-Eman Miller Company in Saqqara, Giza. Additional ingredients, including sunflower oil, eggs, mustard, vinegar, and salt, were procured from a local market. All chemicals applied throughout the experimental procedures were of analytical reagent grade and supplied by Sigma Aldrich Co. Ltd. (Dorset, UK).

The native and modified potato peel starch

Starch extraction

The starch from potato peel were extracted using the traditional method described by (Vargas et al., 2016) with some modification. The potato peel were washed, to remove the dirt then, dried at 60ºC for 12hr. in order to their size was reduced and a void to fermenting it, the peels were then milled in laboratory mill, the peels powder were then soaked for 30 min, and blended with water (1:5 w/v) using (standard electric blender, Moulinex®, France) to obtain a suspension this process was repeated three times which was filtered with muslin cloth allowed to sediment for four hrs. and then decanted. Fresh water was added to the starch and stirred very well to allow any foreign material still in the starch to be loosened and to float and subjected to two washes using distilled water. The slurry after being allowed to sediment for another four hours was decanted, dewatered and the starch gotten was dried using the hot air oven model BST/HAO-1122 (300×300× 300 mm) (70°C for 8 hours). After drying, the starch was milled to obtain a finer starch. Sieving process with 60 mesh size used to sieve the end starch which was stored properly in an airtight container prior to the mayonnaise production.

Starch Modification

The potato peel starch was modified using a combination of (acid hydrolysis) and heat treatment as described by Shrestha et al. (2018), with slight modifications. The starch recovery of modified starch was determined as follows:

$$\%\,Starch\,recovery\,after\,modification = \frac{Weight\,of\,modified\,starch\,in\,dry\,basis}{weight\,of\,native\,starch\,in\,dry\,basis} \times 100$$

Starch Paste Preparation

The starch slurry was prepared by adding 67.5 g of modified potato peel starch to 682.5ml of water. The starch paste was prepared by heating the slurry in an 85°C water bath for 10 min under manual stirring Lee et al. (2013).

Preparation of soy flour

An Insta-Pro International Model 2500 extruder and Model 1500 screw press were used to process the dehulled and cracked soybeans into flour; to avoid any further heat denaturation of the proteins, care was taken to minimize heat generation during milling. Flour was defatted and stored in sealed plastic bags at -20°C until use.

Extraction of Soy Protein isolate

The soluble matter was extracted from soybean flour according to the method by Bello et al., (2023). The extraction experiment was carried out in triplicate. Figure 1 shows a graphical illustration of the alkaline extraction of soybean protein isolate.

Soy protein isolate yield

Soy protein isolate yield was calculated using the following equation according to the method of Alu'datt et al. (2017)

$$Yield\ (\%) = \frac{W_{P1} \times P_{P1}}{W_s \times P_s} \times 100$$

where W_{PI} is the protein isolate's weight, P_{PI} is the protein content in the protein isolate, W_S is the weight of the sample =100 and P_S is the protein content in the sample.

Chemical Composition

The moisture, protein, fat, and ash contents of protein isolate, potato peel starch, and mayonnaise samples were determined according to AOAC (2019). The total carbohydrate content was calculated by difference. The oil content of the mayonnaise was determined according to Lagunes-Galvez et al. (2002). The energy value (Kcal) was calculated theoretically according to the following equation: Total Energy = [(protein×4)+(fat×9)+(total carbohydrate×4)]

Amylose content of potato peel starch

Amylose content was determined using the methodology of Hoover and Ratnayake (2001). The iodine calorimetric method was used to determine the amylose content of native and modified starches. Starch (100mg) was taken in volumetric flask and added with 1ml of 95% ethanol and 9ml of 1N NaOH. The mixture was heated at 100◦C for 10 min., and the final volume was adjusted to 100ml after cooling the reaction mixture to room temperature. An aliquot of 2.5ml was taken from reaction mixture in another volumetric flask and mixed with 1ml of 1N acetic acid and 1ml of iodine solution. The final volume was raised to 50ml using distilled water and after shaking sample was incubated for 20 min in dark. The absorbance was read at 620nm using UV–Visible spectrophotometer (UV-1900i, Shimadzu, Japan). The amylose content of the starch samples was determined using the amylose standard curve prepared at different concentrations (0–40%).

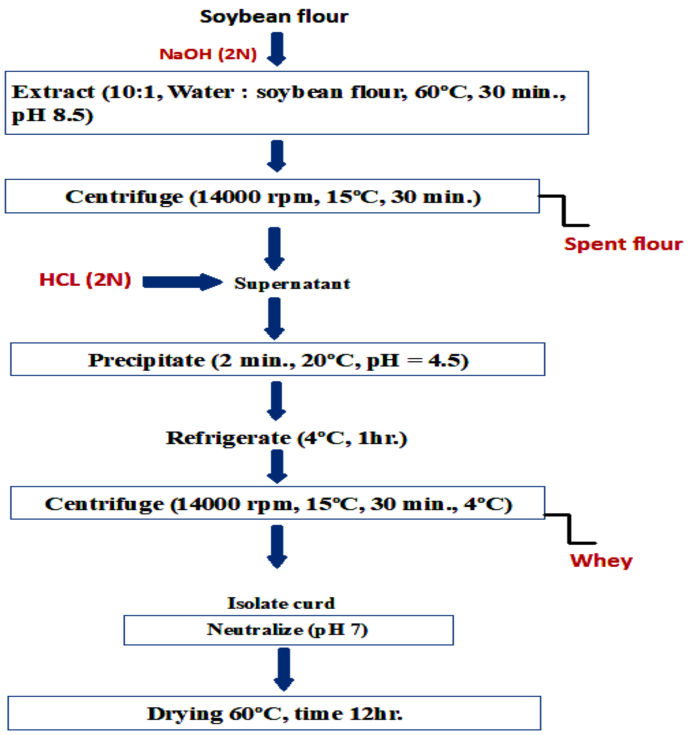

Figure 1. Preparation of soy protein isolate

Physical and functional Properties of modified potato peel starch and soy protein isolate (SPI)

pH: Values of pH were measured using a digital laboratory pH meter (HI931400 Hanna instruments) with glass electrode described by Su et al (2010).

The emulsion stability

The emulsion stability of modified potato peel starch and soy protein isolate (SPI) The Emulsification Activity Index (EAI) and the Emulsification Stability Index (ESI) were determined for modified starch according to (Shi et al., (2022) using the following equations:

$$T = 2.302\frac{A \times V}{0.01}$$

Where A is the absorbance measured by UV-V is spectrophotometer and V is the dilution factor.

$$Ke = \frac{A - A_0}{A} \times 100\%$$

Where A is the absorbance before centrifugation and A_0 is absorbance after centrifugation.

The emulsion was used to determine emulsification properties with slight modifications for soy protein isolate. The following formulas were used to calculate EAI and ESI. According to Zhang et al. (2022)

$$EAI\left(\frac{m^2}{g}\right) = \frac{T \times 2 \times N \times A_0}{10000 \times C \times \emptyset}$$

$$ESI(min.) = \frac{A_0 \times \Delta T}{A_0 - A_{10}}$$

Where: T = 2.303; N represents the dilution factor; A_0 denotes the initial absorbance before homogenization; C represents the concentration of soybean protein isolate (g/mL) before emulsion formation; ø represents the volume of the emulsion, which is equivalent to 1/4; A10 denotes the absorbance of the emulsion after 10 min of homogenization; ΔT is a time-varying value of 10min.

The emulsion stability of mayonnaise

The emulsion stability was measured following a method developed by Chun and Song (1995). The emulsion stability was calculated as follows:

% ES = $(F1/F_0) \times 100$

Where, F_0: sample and F1: precipitated fraction

Color measurement

Color values were measured at room temperature using a Minolta colorimeter CR-400 (Konica Minolta Business Technologies, Inc) (Puligundla, et al. 2015).

Water Holding Capacity (WHC) of soy protein isolate and modified starch.

Water Holding Capacity (WHC) of soy protein isolate and modified starch were determined using Liu, et al. (2022) and (Sindhu et al., 2019) methods with slight adjustments. The WHC is calculated using the following formula:

$$\%WHC = \frac{M_3 - M_2 - M_1}{M_1}$$

The test was performed in triplicate.

M1: weight the sample, M2: Weigh the centrifuge tube, M3: weight the centrifuge tube with the sample after centrifuged.

Oil Absorption Capacity of soy protein isolate and modified starch

The weight of oil absorbed by 1g of soy protein isolate and modified starch, was calculated and expressed as oil absorption capacity according to Neeraj and Bisht (2018) & Zhang and Zhao (2013).

Foaming properties

The foam capacity (FC) and foam stability (FS) of the soy protein isolate were based on this method (Zhang et al., 2022) with minor modifications. The FC and FS were calculated using the following method:

$$FC = V_1/V \times 100\% \qquad FS = V_{25}/V_1 \times 100\%$$

Where, V is the initial volume of the solution (mL); V1 is the volume of the foam after 1 min of homogenization (mL), V25 is the volume of the foam after 25 min of resting (mL).

Mayonnaise preparation

Table 1 shows the ingredients of reduced-fat mayonnaise. The egg yolk was first combined with a blender ball and swirled in a Kitchen Aid mixer for thirty seconds. After that, all other ingredients apart from sunflower oil were added and mixed for one and a half minutes. Lastly, 4 minutes of stirring with very slow additions of sunflower oil according to Puligundla, et al. (2015).

Table 1. Formulation of Reduced-Fat Mayonnaise

Ingredient (g)	Full-Fat Mayonnaise (CM)	Reduced-Fat Mayonnaise		
		5% (M1)	10% (M2)	15% (M3)
Sunflower Oil	50	45	40	35
Eggs	14	14	14	14
Salt	0.75	0.75	0.75	0.75
Vinegar	10	10	10	10
Modified Potato Peel Starch	0	5	10	15
Mustard	0.5	0.5	0.5	0.5
Isolated Soy Protein	0	1	1	1

(CM): control mayonnaise sample, (M1): mayonnaise sample substituted with 5% modified starch paste, (M2): mayonnaise sample substituted with 10% modified starch paste, (M3): mayonnaise sample substituted with 15% modified starch paste.

Sensory evaluation

Sensory evaluation was conducted according to Puligundla et al. (2015) after one day of storage at 4 °C. Taste, texture, mouthfeel, color, odor, acceptability, and overall quality (%) were evaluated by 10 trained panelists from the Food Science Department, Faculty of Agriculture, Cairo University.

Viscosity measurement

viscosity measurements of mayonnaise samples were performed with a Brookfield viscometer RVDV-II+ with cone and plates with a diameter of 25 mm (Puligundla et al., 2015).

Water Activity (a_w)

Water activity (a_w) was measured according to the method described by Hussien et al. (2018) using Hygro Lab EA10-SCS (Switzerland) a_w meter in triplicate.

Storage Stability Test

The physical and rheological characteristics of the mayonnaise samples were assessed after being stored for 30 days under refrigerated conditions at 4°C. In contrast, the attributes of commercial mayonnaise samples were evaluated after just one day of storage in a desiccator, as their properties typically remain stable throughout their shelf life, as noted by Lee et al. (2013).

Statistical analysis

All the tests were performed in triplicate, and results were expressed as mean standard deviation. A one-way analysis of variance (ANOVA) and Duncan's multiple range tests were used to establish the significance (p USA) (Steel et al., 1996).

3. Results and Discussion

Physico-chemical Properties of Modified Potato Peel Starch and Isolated Soy Protein

Chemical Composition

Soy protein isolate (SPI) represents the most refined form of soy protein, typically containing a minimum of 90% protein. It is widely used in food systems to improve both sensory properties and nutritional quality (Tseng et al., 2009). Table 2 outlines the chemical composition (g/100g, dry weight basis) of the modified potato peel starch and the isolated soy protein. The SPI sample showed notably high protein and ash contents, recorded at 86.85% and 4.7%, respectively. These values are consistent with the findings of Schmid et al. (2024), who confirmed that soy protein isolate is characterized by high levels of protein and ash, while containing negligible amounts of fat. In comparison, Codex Standard (1989) specifies that SPI should not exceed 10% moisture, 8% ash, and 0.05% crude fiber, with protein content not falling below 90%. On the other hand, the modified potato peel starch exhibited high total carbohydrate measured at 93.86%. These results align with data reported by Azima et al. (2020), who found that starches derived from tubers generally contain low protein levels, ranging from 0.14% to 0.16%. Higher protein levels in starch lead to decreased viscosity and lower starch quality. This occurs because proteins interact with the starch granules' surfaces, reducing viscosity and weakening gel strength (Richana & Sunarti, 2004).

Table 2. Chemical Composition of Modified Potato Peel Starch and Isolated Soy Protein

Composition	Modified Potato Peel Starch	Isolated Soy Protein
Moisture %	5.65±0.25	5.8±0.2
Ash %	0.25±0.02	4.7±0.2
Fat %	0.08±0.02	1.3±0.4
Protein %	0.17±0.02	86.85±0.55
Total Carbohydrates %	93.86±0.3	1.35±0.15

Values are mean ± standard deviation (n=3)

Table 3 displays the yield of native potato peel starch (%), the recovery percentage following modification, and the amylose content (%) before and after the modification process. The native starch yield and post-modification recovery were recorded at 12.3% and 10.43%, respectively. These values are closely associated with the carbohydrate content of the raw material, where a higher carbohydrate level typically results in greater starch yield. According to Camire et al. (1997), the method used for peeling potatoes significantly influences the chemical composition and usability of the resulting peel. For instance, the abrasion peeling technique, commonly applied in potato chips manufacturing, tends to preserve more starch, whereas steaming often used in producing dehydrated potatoes yields peels richer in dietary fiber but lower in starch. Potato peel is reported to contain approximately 25% starch on a dry weight basis (Liang & McDonald, 2014). However, factors such as geographical origin, cultivar type, and skin color can affect the starch content of potato peels, as noted by Javed et al. (2019). These variations extend to differences in extraction efficiency and starch yield based on the potato variety and cultivation region. The findings of this study are consistent with Azima et al. (2020), who reported a

A higher starch content typically indicates better purity, as it reflects minimal presence of interfering substances that could compromise starch functionality. Effective starch isolation methods result in a product with higher quality and fewer impurities.

Amylose content, a key contributor to starch viscosity (Arp et al., 2020), was found to be 24.01% before modification and increased to 33.01% after modification, as shown in Table 3. Similar trends were reported by Ali et al. (2023), who found native potato starches to contain 25.71–26.60% amylose, with significant increases observed after modification due to the transformation of amylopectin chains into amylose. The modified starches in their study exhibited amylose contents of 33.61%, 37.74%, and 37.64%. Shrestha et al. (2018) also demonstrated that treatments involving acid hydrolysis and heat led to pronounced increases in amylose levels, with combined treatments enhancing amylose content from 30.82% up to 55.79%.

Physical and Functional Properties

Table 4 displays the physical and functional properties, pH, emulsion stability, water holding capacity (WHC), and oil holding capacity (OHC) of modified potato peel starch and isolated soy protein.

Table 3. Native Starch Yield%, starch recovery after modification% and Amylose content% before & after modification of potato peel starch

Parameters	Potato Peel Starch
Native Starch Yield%	12.3±0.2
Starch recovery after Modification%	10.43±0.21
Amylose Content before Modification %	24.01±0.04
Amylose Content after Modification %	33.01±0.02

Values are mean ± standard deviation (n=3)

Table 4. Physical and Functional Properties of Modified Potato peel starch and Isolated Soy Protein

Parameters	Modified Potato peel starch	Isolated Soy Protein
pH	6.75±0.15	7.25±0.49
Emulsion Stability (m^2/g)	70.25±0.28	18.59±0.8
Water Holding Capacity (WHC ml/g)	1.09 ±0.34	1.12±0.33
Oil Holding Capacity (OHC ml/g)	1.02 ±0.22	1.02±0.11

Values are mean ± standard deviation (n=3)

Modified potato peel starch and isolated soy protein presented a pH value of 6.75 and 7.25, respectively (Table 4). The emulsion stability value of the modified potato peel starch was higher (70.25) than isolate soy protein. In comparison, Li et al. (2023) reported emulsion stability values of 19.62 to 25.28 m^2/g for soya bean protein isolate, Baranowska and Kowalczewski (2022) showed that modifications may improve the emulsifying capacity of starch, an example potato starch modified by chemical methods can be used as an emulsifier. Compared to physically modified starch, chemically modified starches have a much better water-binding capacity. The WHC and OHC for the modified potato peel starch and soy protein isolate ranged between (1.09 -1.12ml/g) (1.0933-1.1172%) and (1.02–1.02ml/g) (1.0151–1.0186%) respectively, this results higher than Neeraj and Bisht (2018) reported that significantly higher water absorption capacity (0.91ml/g) was recorded in modified potato starch than control starch (0.76ml/g). While Montoya-Anaya et al. (2023) stated that the obtained water absorption capacity (WAC) of potato starch was 1.0163gg-1 (101.63%). This behavior of oxidized starches could be due to introduction of functional groups on the starch molecules which facilitate a more enhanced binding capacity than the native starch. enhanced binding capacity than the native starch. Increase of water retention capacity of modified starches as compared to native starch could due to increase in the availability of water binding sites (Jyothi et al., 2005). Potato starch contains phosphate ester groups that provide a higher WAC and a faster rate of hydration compared to cereals starch, this property indicates the ability of starch to interact with water and to form pastes or gels; in addition, its use as WAC usually intended for this industrial sector (Solarte-Montufar et al., 2019).

Table 5 presents the foaming capacity, foaming stability, and yield values for the soy protein isolate.

Table 5. The Foaming capacity, foaming stability, and soy protein isolate yield for the soy protein isolate

Parameters	Soy Protein Isolate
Foaming Capacity FC (%)	1.41±0.06
Foaming stability FS (%)	0.31±0.03
Yield %	30.49±2.53

Values are mean ± standard deviation (n=3)

Soy protein isolate is commonly employed as a foaming agent in food formulations, attributed to its high nutritional profile and cost-effectiveness (Li et al., 2022). In this study, its foaming capacity (FC) and foaming stability (FS) were determined to be 1.41% and 0.31%, respectively. FC reflects the protein's ability to generate foam, whereas FS indicates the foam's resistance to collapse over time (Raikos et al., 2007). When compared with findings from Zhang et al. (2022), the foaming performance of soy protein isolate was found to be inferior to that of pea protein isolate, possibly due to differences in protein conformation and the behavior of protein complexes at the air–water interface (Damodaran, 2006). As for protein yield, the soy protein isolate extracted in this study had a yield of 30.49%. Abdolgader et al. (2007) reported that yields of soy protein isolate extracted from defatted soybean flour using different solutions at pH 8 ranged from 22% to 63%. Similarly, Zhu et al. (2024) noted a yield variation between 18.23% and 41.91% depending on extraction temperature. Chamba et al. (2015) also obtained yields ranging from 21.95% to 25.09% from soybean flour under varying processing conditions.

Chemical Composition of Full and Reduced-Fat Mayonnaise

Table 6 presents the chemical composition (g/100g) of both full-fat and reduced-fat mayonnaise formulations, based on fresh weight. Moisture content varied between 28.1% and 45.3% across the samples. These values were lower than those reported by Liu et al. (2007), who documented moisture levels ranging from 41.35% to 82.54% in formulations containing fat replacers. Protein content in the tested samples ranged from 4.5% to 7.3%, with higher values observed in the formulations containing soy protein isolate compared to the control. This increase is attributed to the naturally high protein concentration of soy protein isolate, as also indicated in Table 2. These results exceeded the protein levels reported by Alu'datt et al. (2017). Fat content showed a decreasing trend from 29.5% in the control sample to 25.4% in reduced-fat versions. The full-fat mayonnaise exhibited the highest fat level ($P \leq 0.05$), while formulations containing modified potato peel starch had significantly reduced fat content. An inverse relationship was observed between fat and moisture content across all samples. Notably, fat levels recorded in this study were lower than those reported by Abdel-Haleem et al. (2022), which ranged from 60% to 50.93%. Although all samples were prepared using equal weights of protein isolates, variations in protein concentration were evident, as detailed in Table 6. The ash samples were shown to increase from 1.7 to 2.3gm/100gm, this may be because soybean protein isolate is high in ash content (Table 2). Results are higher than work by Alu'datt et al. (2017), who reported only 1.15 -1.8% in vegan mayonnaise samples. Total carbohydrate contents of vegan mayonnaise samples were lower than control 19.67 and 36.08%, respectively. The values obtained in this study were higher than those obtained by Abdel-Haleem et al. (2022), they reported total carbohydrates to range between 1.51 to 2.5% for vegan mayonnaise samples and control. Figure 2. presents the total energy per 100g of each of the full and reduced-fat mayonnaise samples on a fresh weight basis. The results observed that the total energy of full and reduced-fat mayonnaises ranged from 336.48 to 428.46kcal/100g. Reduced-fat mayonnaise containing starch paste provided a lower calorie than full fat mayonnaise. The full-fat mayonnaise showed the highest value of total energy

(428.46kcal/100g) and decreased with adding modified potato peel starch as a fat replacer to (336.4kcal /100g). The percentage reduction in energy for reduced fat (M3) mayonnaise based on full fat mayonnaise was 21.48%. Song et al., (2007) reported that calories decreased by up to 44.7% by substituting 50% edible oil with modified potato peel starch in mayonnaise as shown in figure 2.

Table 6. Chemical Composition of Full and Reduced-Fat Mayonnaises

Samples	Full fat mayonnaise	Reduced fat mayonnaise		
	Control (CM)	M1	M2	M3
Moisture %	28.1±0.2[d]	32.1±0.1[c]	39.1±0.1[b]	45.3±0.1[a]
Protein %	4.5±0.1[c]	7.1±0.01[b]	7.2±0.1[ab]	7.3±0.01[a]
Fat %	29.5±0.4[a]	28.5±0.1[b]	27.3±0.2[c]	25.4±0.1[d]
Ash %	1.7±0.01[c]	1.9±0.03[b]	2.03±0.05[b]	2.3±0.1[a]
Total Carbohydrates %	36.08±0.4[a]	30.37±0.2[b]	24.33±0.12[c]	19.67±0.13[d]
Energy Values (Kcal)	428.46	406.38	371.82	336.48

Values are mean ± standard deviation (n=3) (CM): control mayonnaise sample, (M1): mayonnaise sample substituted with 5% modified starch paste, (M2): mayonnaise sample substituted with 10% modified starch paste, (M3): mayonnaise sample substituted with 15% modified starch paste.

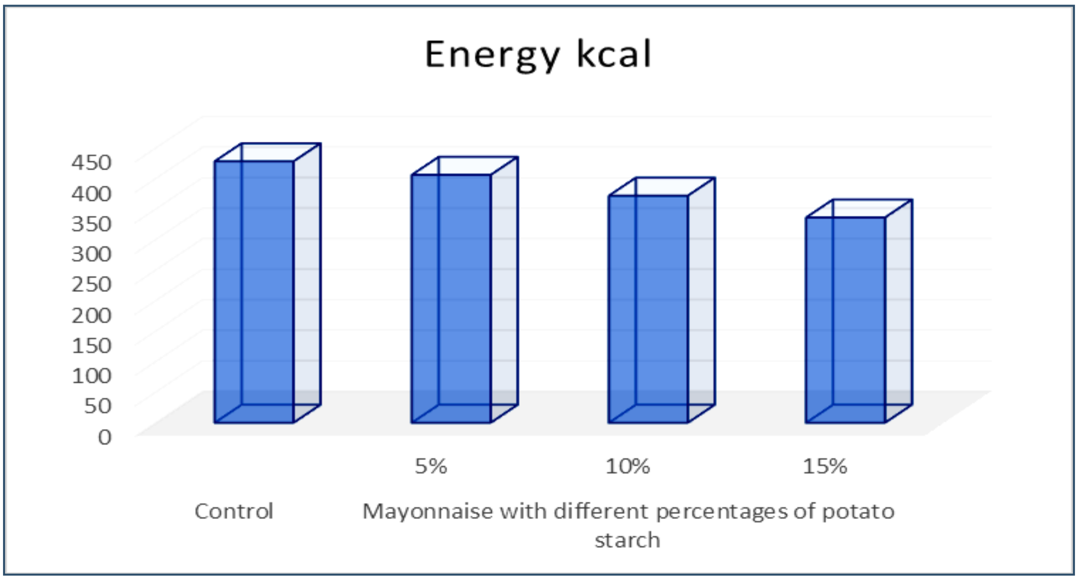

Figure 2. Energy values of control and reduced-fat mayonnaises with different levels of potato peel starch

Organoleptic Properties of Full and Reduced-Fat Mayonnaise

Table 7 shows the sensory acceptability scores of full and reduced-fat mayonnaise samples. The full fat mayonnaise had scores significantly (P>0.05) higher than reduced fat mayonnaise in all sensory characteristics. The sensory scores of M1 such as taste, texture, mouthfeel, color, odor, and acceptability were almost equal to the control, and these changes were insignificant. Results agree with Al-Sayed et al. (2012). The overall acceptability of reduced-fat mayonnaises was near the control except for M3, which had the lowest sensory score (78). Carcelli et al. (2020) reported that the formation of mayonnaise with a 25% fat reduction formulation obtained a good quality product without changing the mayonnaise's taste. Subroto et al. (2020) stated that starch modification can provide creaminess characteristics to the final product. These data agree with Karas et al. (2002) the standard mayonnaise containing high fat as opposed to low-fat mayonnaise gained higher grades for most sensory attributes, especially a shiny bright yellow color mainly due to fat replacers. containing high fat as opposed to low-fat mayonnaise gained higher grades for most sensory attributes, especially a shiny bright yellow color mainly due to fat replacers.

Table 7. Sensory acceptability scores for full and reduced-Fat mayonnaises with different levels of Potato peel starch

Composition (%)	Samples			
	CM	M1	M2	M3
Taste (10)	9.65±0.47[a]	9.85±0.34[a]	9.00±0.67[a]	8.05±0.68[b]
Texture (10)	9.8±0.34[a]	9.85±0.34[a]	9.35±0.47[b]	8.04±0.48[c]
Mouth Feel (10)	9.25±0.35[a]	8.97±0.78[a]	8.97±0.62[a]	7.7±0.67[b]
Color (10)	9.1±0.87[a]	9.17±1.0[a]	8.87±0.51[a]	7.5±0.70[b]
Odor (10)	9±0.47[a]	9.25±0.92[a]	9.17±0.76[a]	7.73±0.69[b]
Acceptability (10)	9.36±0.27[a]	9.42±0.54[a]	9.172±0.39[a]	7.80±0.48[b]
Overall Quality %	93	94	91	78

Values are mean ± standard deviation (n=3) (CM): control mayonnaise sample, (M1): mayonnaise sample substituted with 5% modified starch paste, (M2): mayonnaise sample substituted with 10% modified starch paste, (M3): mayonnaise sample substituted with 15% modified starch paste

Viscosity of Full and Reduced-Fat Mayonnaise

As shown in Figure 3 a remarkable decrease in viscosity after 30 day of refrigerator storage at 4ºC was noted in reduced-fat mayonnaises upon potato peel starch paste. Viscosity decreased linearly with increasing amount of starch substitution. In this study, the substitution of fat with modified potato peel starch resulted in a decrease in viscosity of resulting mayonnaise with M1 having the heights viscosity with a slight significant ($p>0.05$) change in viscosity compared to full-fat mayonnaise. However, the viscosity of M3 mayonnaise was significantly lower than the other samples. Compared to full fat the viscosity showed 2- and 3-fold reductions for M2 and M3, respectively. These trends were similar to the results of Puligundla, et al. (2015)

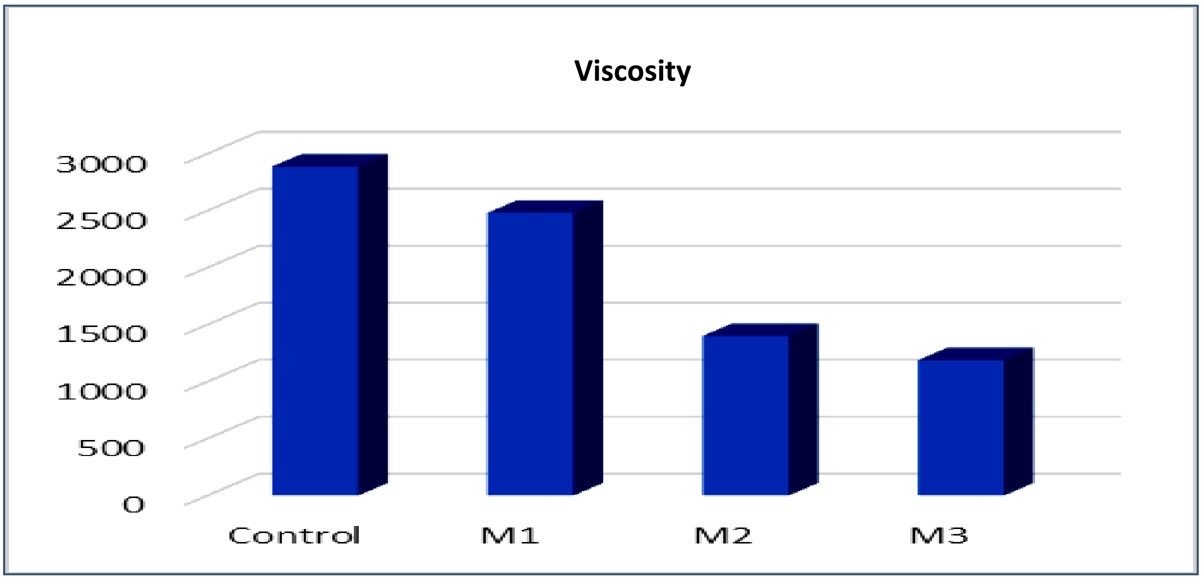

Figure 3. Viscosity of Full and Reduced-Fat Mayonnaises with Different Levels of Potato peels starch

Effect of Storage on Full- and Reduced-Fat Mayonnaises with Different Levels of Modified Potato Peel Starch

pH, water activity and emulsion stability values of full and reduced-fat mayonnaise samples replaced with modified potato peel starch and isolated soy protein at day 1 and after 30 days are shown in Table 8. Mayonnaise is generally an acidic product, the pH is the primary parameter that influences the shelf life and consumer acceptance of mayonnaise (Yolmeh et al., 2014). The pH values of mayonnaise samples at the beginning of cold storage (4ºC) ranged from 3.62 to 3.94 and after cold storage for 30 days, from 4.49 to 4.99 (Table 8).

A general trend was observed where the pH values increased as the fat content decreased, likely due to the relative increase in the hydrophilic phase, as noted by Carcelli et al. (2020). At the initial measurement, the water activity (aw) of all mayonnaise samples was high, ranging from 0.90 to 0.91. These values were slightly lower than those reported by Carcelli et al. (2020), who found aw levels between 0.95 and 0.98. They emphasized the importance of pH control and thermal treatment in maintaining microbiological safety due to the elevated water activity in such products. After one month of storage, the aw of the tested samples decreased, ranging between 0.877 and 0.894. Table 8 also summarizes the results related to the emulsion stability of both full-fat and reduced-fat mayonnaise. Since oil is the primary component in mayonnaise, it plays a key role in determining the emulsion's stability. A reduction in oil content generally leads to decreased stability and viscosity (Widerström & Öhman, 2017). The full-fat sample exhibited the highest emulsion stability at 97.7%, while the reduced-fat variants showed slightly lower stability, ranging from 88.6% to 97.5% at the time of production. These findings are consistent with those reported by El-Bostany et al. (2011). Following one month of refrigerated storage, the emulsion stability of the reduced-fat mayonnaise samples (M1, M2, and M3) declined significantly, with values falling between 86.7% and 89.8%. This decline aligns with the observations of Lee et al. (2013), who explained that such reduction is often caused by the breakdown of the starch gel network under acidic conditions found in mayonnaise. Prior studies on both full-fat and reduced-fat mayonnaise (Mun et al., 2009) described mayonnaise as exhibiting gel-like behavior typical of emulsified systems, which imparts desirable texture (Corradini & Peleg, 2005). However, fat reduction can lead to a transition from a gel-like structure to a thinner, more fluid consistency, which may negatively affect mouthfeel and consumer acceptance (McClements & Demetriades, 1998). In this study, the fat replacer contributed to maintaining a gel-like structure by reinforcing the continuous phase of the emulsion, allowing all formulations to retain a semi-solid, gel-like texture (Carcelli et al., 2020)

Table 8. pH, Water Activity and Emulsion Stability of Full and Reduced-Fat Mayonnaises with Different Levels of Modified Potato peel starch at zero time and after 30 days of storage at 4°C.

Samples	0 Time			30 Days		
	pH	a_w	Emulsion Stability	pH	a_w	Emulsion Stability
Control	3.62±0.02[d]	0.90±0.01[b]	97.7±0.03a	4.49±0.06[b]	0.894±0.001[a]	91.55±0.45[a]
Reduced fat mayonnaise						
M1	3.66±0.01[c]	0.90±0.02[b]	97.5±0.60[a]	4.99±0.002[a]	0.885±0.001[b]	89.80.51±0[b]
M2	3.79±0.01[b]	0.91±0.01[a]	97.1±0.80[a]	4.98±0.03[a]	0.878±0.001[c]	89.50.30±0[b]
M3	3.94±0.02[a]	0.91±0.01[a]	88.6±0.60[b]	4.98±0.01[a]	0.877±0.002[c]	86.79±0.70[c]

Values are mean ± standard deviation (n=3), (CM): control mayonnaise sample, (M1): mayonnaise sample substituted with 5% modified starch paste, (M2): mayonnaise sample substituted with 10% modified starch paste, (M3): mayonnaise sample substituted with 15% modified starch paste.

Table 9 presents the color characteristics of the prepared mayonnaise samples, evaluated using the Hunter Lab color scale. The analyzed parameters include lightness (L*), redness (a*), and yellowness (b*). Among these, lightness (L*) plays a critical role in visual appeal and consumer acceptability of mayonnaise. It has been observed that reducing fat content leads to a lower concentration of dispersed oil droplets, which in turn diminishes the L* value and potentially affects product acceptance. The control sample (full-fat mayonnaise) demonstrated the highest L* and b* values, recorded at 80.16 and 11.93 respectively, reflecting a bright and yellowish appearance. However, after one month of storage, these values declined, indicating reduced brightness and yellowness. According to Lee et al. (2013), the addition of starch paste contributes to such reductions in L* and b* values, while full-fat formulations typically maintain higher levels of both. This suggests that incorporating fat replacer gels alters the light-scattering properties of the emulsion, resulting in a paler visual appearance. Furthermore, replacing fat with starch led to a statistically significant increase in a* (redness) and a decrease in b* (yellowness) values ($p < 0.05$). Similar findings were reported by Park et al. (2020) and Thaiudom & Khantarat (2011), who noted that both fat content and droplet size impact brightness, with smaller fat droplets and higher fat levels enhancing light refraction (McClements, 2015). The L* value, in particular, was consistently higher in full-fat mayonnaise compared to low-fat formulations containing potato -based substitutes. El-Bostany et al. (2011) also confirmed that increasing the amount of potato powder in low-fat mayonnaise leads to a noticeable reduction in L* values. Typically, full-fat mayonnaise is characterized by a glossy, bright yellow color. Puligundla et al. (2015) suggested that adding fat replacers at around 20% can optimize appearance by enhancing shine and imparting a yellowish-white hue. During storage, all mayonnaise samples exhibited a gradual decline in L*, a*, and b* values. This change may be attributed to lipid oxidation, which can cause color darkening over time (Hakimian et al., 2022).

Table 9. Color of Full-Fat and Reduced-Fat Mayonnaises with Different Levels of modified of Potato peel starch

Samples	0 Time			30 day		
	L*	a*	b*	L*	a*	b*
Control (CM)	80.16±0.15[a]	-3.46±0.02[d]	11.93±0.01[a]	80.55±0.05[a]	-3.47±0.01[d]	11.99± 0.01[a]
M1	79.50±0.05[b]	-3.21±0.01[c]	11.33±0.04[b]	79.97±0.01[b]	-3.23±0.01[c]	11.40±0.05[b]
M2	79.29±0.07[c]	-3.18±0.02[b]	10.22±0.02[c]	79.96±0.02[b]	-3.20±0.01[b]	10.31±0.01[c]
M3	79.10±0.05[d]	-2.99±0.01[a]	9.94±0.03[d]	79.71±0.37[b]	-3.03±0.02[a]	10.03±0.05[d]

L* (Brightness; 100: white, 0: black), a* (+red, - green), and b* (+yellow, - blue). Values are means ± SD (n=3)
CM): control mayonnaise sample, (M1): mayonnaise sample substituted with 5% modified starch paste, (M2): mayonnaise sample substituted with 10% modified starch paste, (M3): mayonnaise sample substituted with 15% modified starch paste.

4. Conclusion

Based on the experimental results, it can be concluded that reduced-fat mayonnaise can be successfully produced using modified potato peel starch paste as a fat substitute, with the co-addition of isolated soy protein as an emulsifier and stabilizer. Excellent emulsion stability was maintained with up to 10% oil replacement using potato peel starch paste. The calorie content of mayonnaise prepared at this substitution level decreased by 21.48% compared to full-fat mayonnaise. Furthermore, extracting starch from potato peel byproducts of the chips industry in Egypt enhances the value-added utilization of agro-industrial waste. Additionally, modifying potato peel starch may reduce dependence on imported modified starch, lower costs, and decrease overall purchasing expenditures. It is recommended to implement techniques for recycling and valorizing agro-industrial waste to produce value-added products. Moreover, the development of efficient extraction techniques for obtaining valuable components, such as starch, from potato peels should be further explored.

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