

ASSESSING THE IMPACT OF POTATO PEEL POWDER FORTIFICATION ON THE PHYSICOCHEMICAL, ANTIOXIDANT, AND SENSORY QUALITIES OF FUNCTIONAL COOKIES

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Abstract

Agro-industrial waste contains a variety of essential nutrients, and a large amount of this waste material is being wasted or dumped intentionally due to a lack of awareness about nutrients. Current research aims to explore the nutritional and functional properties of potato peels, and the research was conducted in two different phases. In the 1st phase, potato peels were subjected to their proximate composition followed by their mineral profile. Then, peel powder was subjected to its phenolic content, and its activity was assessed using three commonly used antioxidant assays including DPPH and FRAP. In the 2nd phase of the study, potato peels were incorporated into cookie formulation for the development of functional cookies. The results regarding the proximate composition showed that moisture, ash, fat, fiber, and protein content were 65.23 ± 0.21 , 4.79 ± 0.31 , 2.79 ± 0.072 , 12.68 ± 1.17 , and 13.03 ± 0.010 . Further, the mineral profile showed that potato peels contain mineral content including sodium, magnesium, and calcium in major concentrations of 25.54 ± 0.67 , 132.77 ± 2.04 , and 22.78 ± 1.09 , whereas, iron, copper, and zinc were present in minute quantities of 0.92 ± 0.07 , 0.54 ± 0.02 , and 1.36 ± 0.05 respectively. Furthermore, the activity of polyphenols showed that peel powder showed good scavenging potential. Moreover, the incorporation of potato peel powder enhances the physicochemical profile of cookies, along with improved sensory scores. The current study showed that potato peels should be used as food additives and a new way towards the sustainable production of functional foods.

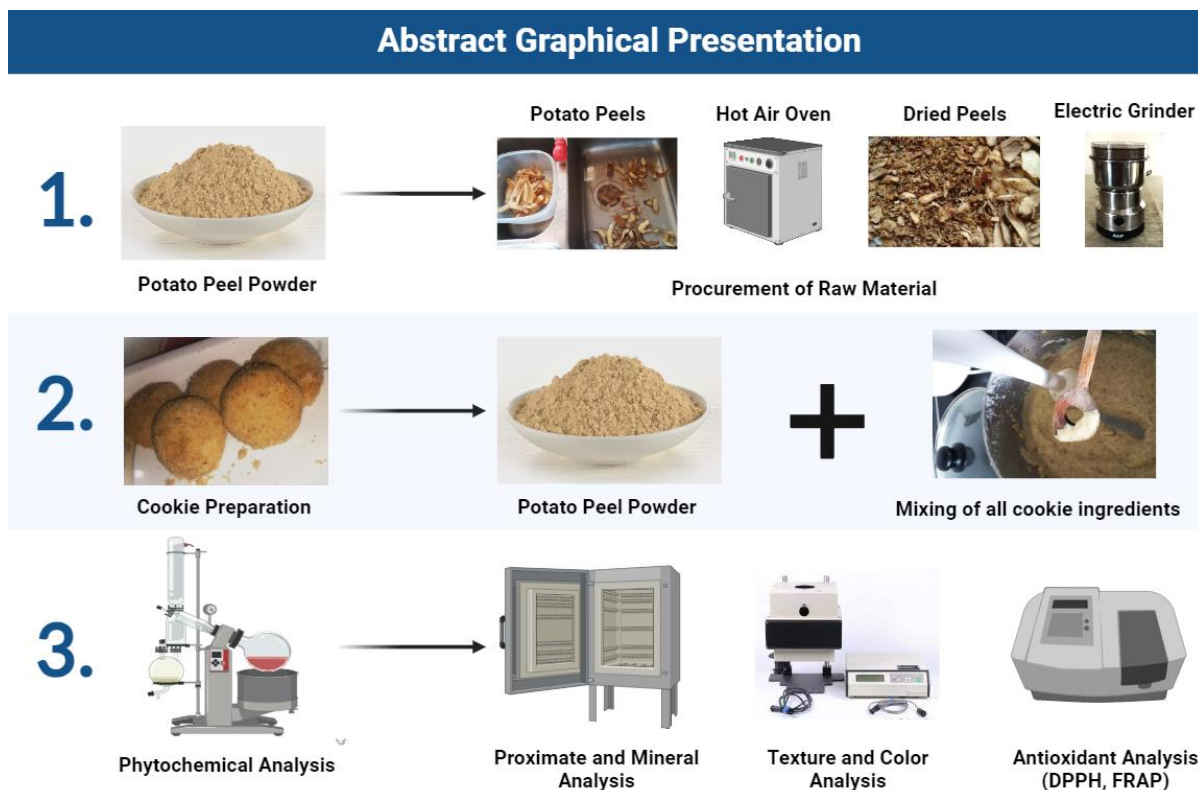


Figure 1. Graphical Abstract (Potato Peel Powder Cookies)

INTRODUCTION

Food waste refers to any food that is discarded, uneaten, or spoiled. According to the United Nations, roughly one-third of all food produced in the world, which amounts to 1.3 billion tonnes, is wasted every year (Nordin et al., 2020). This amount is equivalent to the amount of food needed to feed around 2 billion people annually. Food waste occurs at every stage of the food supply chain, from food production and processing to distribution and consumption (Wunderlich, 2021). Food waste has a significant environmental, economic, and social impact. It contributes to greenhouse gas emissions, leads to the loss of valuable resources, and undermines efforts to address global hunger and poverty. There are a lot of methods to recover food waste but recovery of food waste from peel waste is very beneficial (Giroto et al., 2015).

The recovery of food waste from peel waste involves turning food waste, particularly peel waste from fruits and vegetables, into useful products

through advanced processing and conversion methods such as fermentation, extraction, and enzymatic hydrolysis. Peel waste, which is often discarded, contains valuable nutrients, fibers, and other organic matter that can be utilized to create bio-based products, such as animal feed, bioplastics, or fertilizer (Liu et al., 2023). There are a lot of crops in which peel wastes are used to reduce the loss of food waste like potato peel (Ptak et al., 2021).

Potatoes (*Solanum tuberosum* L.) are a major food crop that has been used for centuries, and has been a major contributor to the economies of many countries. The plant belongs to the Solanaceae family, characterized by chemical compounds with medicinal alkaloids (Sampaio et al., 2020). The classification of potato varieties is based on their morphological and genetic characteristics. The International Potato Center (CIP) has created an elaborate system for categorizing potatoes into different groups based on their utilization, such as table potatoes,

processing potatoes, and potatoes for feed (Elsharif et al., 2020). Potato chemical and nutritional composition suggests a complex carbohydrate along with dietary fiber and various essential vitamins and minerals such as vitamin C, potassium, and vitamin B6. They comprises low calories and have low glycemic index which make them an ideal food for maintaining a healthy diet (McClements, 2020).

Due to its content of macro- and micronutrient, potato peel powder (PPP) is a byproduct of potato processing industry that has been of interest as a functional food ingredient in human food products that can be used to supplement human diet (Pathak et al., 2018; Sampaio et al., 2020). Potato peel powder is also rich in Vitamin C, which is an antioxidant that also scavenges free radicals and protects cells from oxidative stress. Studies have shown that 100g of potato peel powder can provide up to 14.7 mg of vitamin C, which is about 24% of the daily recommended intake. Additionally, potato peel powder contains significant amounts of potassium, which is important in maintaining fluid balance, controlling blood pressure, and supporting nervous system function (Rodríguez-Martínez et al., 2021).

Moreover, PPP is also a rich source of antioxidants, which protect cells from oxidative damage and may prevent chronic diseases. The high content of phenolic compounds and flavonoids makes it a potent antioxidant source. Researchers have found that potato peel powder has a high total phenolic content (TPC), in the range of 0.5 to 9.9 mg/g. Potato peel powder exhibits strong antioxidant activity, as measured by 2,2'-Azinobis (3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) and 2,2-diphenyl-1-picrylhydrazyl (DPPH) assays (Daza et al., 2017). Potato peel powder (PPP) is composed of roughly 9-12% protein and 51-54% carbohydrate (dry weight basis), with the remainder being ash, dietary fiber, and fat. The exact fat content of PPP varies based on the potato breed or variety but generally ranges from less than 1% to around 5% (dry weight basis) (Vilgis, 2015). Due to its availability, low cost, and richness in bioactive compounds, PPP has

emerged as a promising ingredient for various applications in the food industry (Ahmad et al., 2023).

Food fortification is the primary interests of food technologists to meet the increasing consumer's nutritional awareness. As, the target of customers is to approach healthy food options with massive benefits, to improve body functions and reduce the risk of the disease (Arenas-Jal et al., 2020). Cookies are a popular snack due to their high energy levels, but they lack important nutrients like fiber and phytonutrients. Recently, scientists have been exploring the benefits of including dietary fiber in food products to promote human health. One promising approach is to add potato peel powder to cookie recipes, as it is a rich source of fiber and antioxidants. This not only leads to the creation of new and innovative foods but also helps reduce waste by utilizing potato peels more sustainably.

In the current study, the aim of the research was to fortify potato peel powder which is widely used as functional food in food industry. This study was conducted to develop potato peel powder-supplemented cookies in different concentrations. For this purpose, potato peel powder was analyzed for the selected minerals, proximate, TPC, FRAP, and DPPH content. Afterward, cookie samples were analyzed for proximate analysis, and the physical characteristics including diameter, height and spread factor, color, texture, and sensory evaluation.

1. MATERIALS AND METHODS

1.1. Procurement of raw material

The research work was carried out in the Department of Food Science, Government College University, Faisalabad. Potatoes were procured during the harvest season from a nearby market in Faisalabad, Pakistan. Flour, eggs, and baking powder were also obtained from the local market of Faisalabad.

1.2. Proximate Composition of Raw Material

Moisture content, crude fiber, crude protein, ash content, crude fat, and nitrogen-free extract (NFE)

of the raw materials were analyzed by following the American Association of Cereal Chemist-approved methods (AOAC, 2000; AACC, 2010). All these analyses were performed three times for accurate resulting. Potato peel powder was analyzed for moisture content (AACC Method no. 44-15A), crude fat (AACC Method no. 30-10), crude fiber (AOAC Method no. 978-10), crude protein (AOAC Method no. 990-03), total ash (AACC Method no. 08-01) and above all nitrogen-free extract (NFE) by utilizing methods as described by AACC (2010).

1.3. Phytochemical Analysis

Potato peels (PP) were first cleaned and then dried at 50°C in a hot air oven. The dried materials were subsequently broken up in a laboratory-sized mill and ground to a fine powder. The resultant products were separated by screening and 2g of dried peel powder was used for extraction with 20mL of the organic solvent (acetone, ethanol and methanol) in a room temperature shaker for overnight period. The extracts were filtered through Whatman No.1 filter paper and the residue was re-extracted under similar condition. The filtrates were concentrated by evaporation under a rotary evaporator (Buchi Rotavapor Switzerland) with temperatures lower than 45°C. Finally, the percent yield of the natural antioxidant tested was calculated from the extracts after an organic solvent is evaporated (Rowayshed et al., 2015).

1.3.1. Total Phenolic Content (TPC)

Total phenols were measured by the Folin-Ciocalteu reagent, slightly modified from the procedure of Singleton et al. (1999). 0.5 mL of the honey solution was shaken with 2.5 mL of Folin-Ciocalteu reagent (2N) for about 5 minutes at 25°C and then shaken with 2 mL of Na₂CO₃ solution (75 g/L) for 2 hours at the same temperature. The absorbance of the honey solution was measured after the incubation period at 765 nm using a UV-visible spectrophotometer (Perkin-Elmer Lambda 25, Waltham, MA, USA). Gallic acid (0-1000mg/L) was used as the standard chemical for the calibration used in the

preparation of the curve. The results for Total Phenolic Contents were reported as a mean of triplicate assays. It was presented in terms of milligram (mg) of gallic acid equivalent/g of honey.

1.3.2. Free radical scavenging activity (DPPH assay)

Isla et al. (2010) used a method to investigate the free radical scavenging activity (RSA) of the sample. An aliquot (40 µl) of the sample solution was transferred to a black-walled microplate and 2.9 ml of a solution of 0.1 mM DPPH in methanol was added to the microplate, which was then stored in the dark at 25 °C for 30 minutes. The absorbance at 517 nm was then measured, and reduced. As a reference, methanol was used. To calculate the percentage inhibition of DPPH radical, following equation was used: Scavenging activity (%) = $1 - (A_s/A_o) \times 100$ Absorbance of Sample (A) : Absorbance of Sample (A) was determined by adding 40 µl of the sample solution to 2,9 ml of DPPH methanol solution and reading the absorbance value. Absorbance of Control (Aois) : Absorbance of Control (Aois) was determined by adding 40 µl of methanol and 2,9 ml of DPPH methanol solution and reading the absorbance value.

1.3.3. Ferric reducing antioxidant power (FRAP)

Benzie and Strain (1996) used the ferric reducing antioxidant power (FRAP) technique to measure the antioxidant activity. FRAP test is performed on complex materials to oxidize the ferrous ions (Fe²⁺) to ferric ions (Fe³⁺). The increase in absorption at 593 nm is due to the formation of a blue coloured complex between (Fe²⁺/TPTZ). The FRAP reagent consisted of freshly prepared TPTZ (2,4,6-tripyridyl-s-triazine) solution (40 mmol/l in HCL), FeCl₃.6H₂O (2.5 mL) and acetate buffer (0.3 mol/l, pH 3.6) (25 mL) and was warmed at 37°C prior to use. After incubation for 10 minutes at 37°C, the absorbance of the reaction mixture at 593 nm was measured spectrophotometrically. Then 3ml of the FRAP reagent solution and 0.1ml of sample solution

were added together. Ammonium ferrous sulfate was freshly prepared and standardized by using a standard curve (25-1600 μ M Fe+3).

1.4. Mineral Analysis

In line with the recommendations made by the AOAC (2006), wet digestion was employed to evaluate the minerals in the sample of powdered potato peel. The dried material, weighing 0.5g, was placed in a conical flask and heated for 15mL while being digested with a 7:3 solution of HClO₄ and HNO₃, resulting in a solution that was colorless and contained 1-2 mL. This substance was diluted to a concentration of 100 mL for use

in mineral analysis. To test potassium, calcium, magnesium, manganese, zinc, copper, and iron, an atomic absorption spectrophotometer (Varian Inc., Palo Alto, CA, USA) was utilized.

PRODUCT DEVELOPMENT

1.5. Preparation of Potato Peel Powder

Potatoes were first washed properly to eliminate dirt and debris. With a sharp knife, potatoes were peeled. Then, these were dried for a whole day at 60°C in a hot-air oven (NSW-144). After drying, it was ground into flour, put through a sieve with a mesh size of 60, and kept in a refrigerator until needed (Khalifa et al., 2015).

1.6. Formulation of Cookies and Treatment Plan

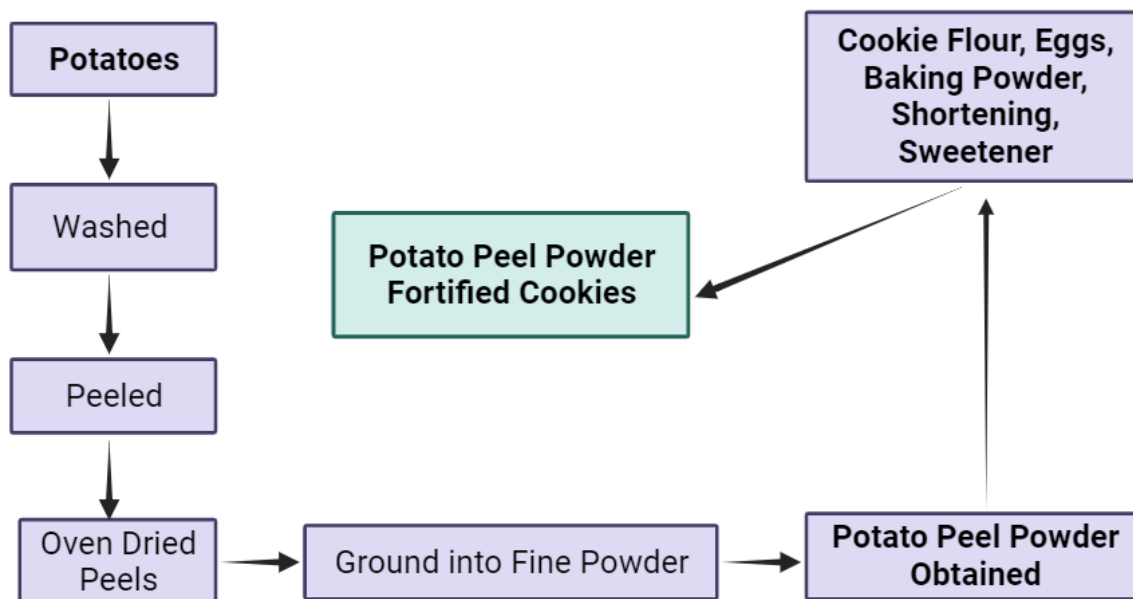


Figure 2. Formulation of Potato Peel Fortified Cookies

Cookies were made by employing the technique described by AACC (2000). The following recipe is 500g of flour, 5g of baking powder, 2 eggs, 250g of shortening, and 250g of sweetener. By adding eggs, shortening and sugar were creamed. A mixer was used to combine flour and baking powder. The dough was then rolled up next to the baking sheet using a rolling pin, to a thickness of 3 mm,

and cut into rounds using a cookie cutter. In the baking oven, cookies were cooked for 10 minutes at 425°F. Cooling was done at room temperature for 30 min before packaging an airtight plastic container and stored for 30 days. Then sensory, physical, and chemical analyses of cookies were performed at 0, 15, and 30 days.

Table 1. The treatment plan for cookie development

Treatment	T ₀	T ₁	T ₂	T ₃
Flour %	100	95	90	85
Potato Peel Powder %	0	5	10	15

1.7. Proximate Analysis of Potato Peel Powder supplemented Cookies

The proximate composition of potato peel powder cookies including moisture content, crude fiber, crude ash, crude fat, crude protein, and NFE % was determined by the AOAC methods as described earlier.

1.8. Physical characteristics of potato peel powder cookies

1.8.1. Diameter, height and spread factor

Following the procedures of AACC (2000), potato peel powder cookies were measured for height, spread factor, and diameter at intervals of day 0, 15 days, and 30 days while being stored at room temperature. By lining up six cookies horizontally next to one another, the diameter of each cookie was measured, and the combined diameter was calculated. Six cookies were stacked on top of each other to measure the height of the cookies in millimeters. Three further tests were conducted. The spread factor was calculated according to the formula;

Spread Factor = Diameter/ Thickness

1.8.2. Color measurement

The color of the cookies was determined using a Hunter's Lab color analyzer (Model: D25 L optical sensor, Hunter Associates Laboratory, Reston, Virginia, USA) by the modified methodology of Ahmad et al., (2016).

1.9. Sensory Evaluation

Cookies were evaluated at the Department of Food Science, Government College University Faisalabad, Pakistan by following the method of Asadi et al. (2021). White fluorescent light was there on independent booths, to display the product (cookies) for semi-trained panelists labeled with various codes. They evaluated coded samples of cookies for their color, texture, taste, mouthfeel, and overall acceptability using a 9-point hedonic scale. Additionally, water was made

available to panelists so they rinse their mouths before the assessment to avoid residual effects.

1.10. Statistical analysis

Data obtained was analyzed by descriptive statistics and interpreted via analysis of variance (ANOVA) using a statistical analysis system (Statistics version 8.1).

2. RESULTS AND DISCUSSION

2.1. Proximate Composition of Raw Material

The proximate composition of Potato Peel Powder (PPP) is shown in Table 2. The present study showed that the potato peel powder has moisture content (65.23 %), ash content (4.79 %), crude protein content (13.03 %), crude fat content (2.79 %) and crude fiber content (12.68 %). So these results have shown that potato peel powder has a high protein and moisture content. The moisture content of potato peels was 80.36 ± 0.17 , which is similar to that of different potato peels obtained from different varieties, ranging from 808-849 g/kg, reported by Nguyen et al. (2022) and Vaitkevičienė, (2019). Current results showed that potato peels contain 4.79 % ash content, which can be associated with the mineral contents in a subjected sample after the complete 45 incineration of the organic fraction. The ash content of different varieties of tubers ranged from 4.46- 16.96 % as reported by Dusuki et al. (2020) but it was found that I. batatas species contain the highest mineral content and scavenging potential. Likewise, Nguyen et al. (2022) found that potato peels have a low amount of ash content ($1.29 \pm 0.01\%$), nearly the same amount as found in the current study. Further, the study by Van Huy et al. (2019) reported that potato peels comprise $3.18 \pm 0.01\%$ protein content, and the study of Vaitkevičienė, (2019) studied 6 different varieties of tubers and reported that their peels contain a diverse range of protein content which lies

between the ranges of 8.9- 16.5% of the subjected samples. Furthermore, the crude fiber content of the present study is in good agreement with the value reported by Nguyen et al. (2022), that potato peels contains $15.00 \pm 0.01\%$ carbohydrate

content but can be related to the crude fiber because of their similar role in the food commodities, namely potato peels as the non-starch polysaccharide intact in the cell wall of potato peels.

Table 2. Proximate composition of Potato Peel Powder

Proximate Content	Moisture	Ash	Crude Fat	Crude protein	Crude Fiber
Concentration (%)	65.23±0.21	4.79±0.31	2.79±0.072	13.03±0.010	12.68±1.17

2.2. Phytochemical Analysis

2.2.1. Total Phenolic Content (TPC)

Phenolic contents in food commodities are greatly dependent on their handling practices, treatment type, and processing technologies in which they are processed. In the current study, the result showed that potato peels contain a total phenolic content of 122.18 ± 1.03 mg GAE/100g as indicated in Table 3. Similar results were reported by Saeed et al., (2022) who secreted the extract from potato peels and reported that this extract could be a great source of phenolic content and reported 3.50 ± 0.13 mg/g and used Gallic acid as the internal standard. Furthermore, in the same study, the authors observed their scavenging potential and reported that potato peels showed $82.16 \pm 0.52\%$ inhibition against the free radicals. Further, another study conducted by Wang et al., (2020) observed the yield of phenolic contents by altering the different technological parameters including temperature, time, acoustic power, solvent-to-solid ratio, and particle size of potato peels. The authors reported that direct ultrasound assisted extraction imparts a better yield as compared to conventional one due to its least destruction and better compatibility with polyphenols.

2.2.2. Free radical scavenging activity (DPPH assay)

Results for the antioxidant activity of grounded potato peels have been listed in Table 3. The peels were assessed for their scavenging potential by using a DPPH assay, which showed $66.18 \pm 0.82\%$ inhibition against free radicals. The result of the

current study is closely corroborated with the findings of Akter et al., (2023), who reported that cabinet and sun-drying potato peel flour showed 54.48 ± 0.90 and $53.89 \pm 0.48\%$ inhibition. Furthermore, Akter et al., (2023) reported that the technological and functional properties of potato peels could be improved through the drying method. The higher antioxidant activity in cabinet drying was observed due to the uniform distribution of heat, which didn't jeopardize the activity of polyphenols.

2.2.3. Ferric reducing antioxidant power (FRAP)

The ferric reducing antioxidant power (FRAP) assay is a general method used to assess the antioxidant potential which is based on the principle of the reduction at low pH of ferric tripyridyltriazine (Fe^{3+} -TPTZ) to an intense blue color ferrous-tripyridyltriazine complex (Fe^{2+} -TPTZ) whose absorbance is analyzed at the wavelength of 593nm. The FRAP assay is closely related to measuring the antioxidant potential of food stuffs which are generally associated with the presence of polyphenols in food products (Naji et al., 2020; Munteanu & Apetrei, 2021).

Results regarding the FRAP assay in Table 3 showed that potato peels have $18.59 \pm 0.23\%$ scavenging potential. Furthermore, Makori et al., (2022) reported that different varieties of potato peels showed a scavenging potential of 2.50–1.06 mg TE/100 g assessed through FRAP assay. However, variations in results could be due to varietal difference or drying method, which directly influences the activity of the polyphenols against free radicals.

Table 3. Antioxidant potential of potato peel powder

Treatments	TFC (mg GAE/100g)	DPPH activity %	FRAP (mmolFeSO ₄ /100g)
Potato Peel Powder	122.18±1.03	66.18±0.82	18.59±0.23

2.3. Mineral Analysis

The results regarding the mineral content in potato peels have been described in Table 4. The mineral analysis of potato peel powder contains 25.54±0.67 mg/100g of sodium, 132.77±2.04 mg/100g of magnesium, 22.78±1.09 mg/100g of calcium, 0.92±0.07 mg/100g of iron, 0.54±0.02 mg/100g of copper, and 1.36±0.05 mg/100g of zinc. These concentrations of mineral content showed that potato peels are deposits of complex micronutrients, which could be a beneficial source of different minerals. Furthermore, Vaitkevicienė,

(2019) conducted a study on purple potatoes and reported that potato peels contain a higher mineral content as compared to a flash of potato. The authors concluded that potato peels could be a better substitute and can be replaced with expensive sources of nutrients like minerals, vitamins, protein, and fibers.

However, current results showed that potato peels mainly comprised sodium, magnesium, and calcium content in major concentration, whereas, iron, copper, and zinc were present in a minor concentration, which could be suitable for the daily adequate limit of a normal body.

Table 4. Mineral analysis of potato peel powder

Minerals	Sodium	Magnesium	Calcium	Iron	Copper	Zinc
Potato peel powder	25.54±0.67	132.77±2.04	22.78±1.09	0.92±0.07	0.54±0.02	1.36±0.05

2.4. Proximate analysis of potato peel powder cookies

The cookies were developed with different concentrations of potato peel powder, ranging from 0% to 15% (T0, T1, T2, and T3). The resulting cookies were then subjected to proximate analysis. Table 5 indicates the results for the proximate composition of fortified cookies.

Moisture content significantly impacts food quality, taste, shelf life, safety, texture, and safety. It's the basic ingredient for food life, controlling microbial load, and preventing food loss (Zambrano et al., 2019). The mean value of moisture content of T0 was found to be the lowest, i.e., 3.08±0.04, whereas it was gradually increased in T1, T2, and T3 (3.30±0.05, 3.62±0.07, and 3.98±0.05, respectively) at 0 days of storage. At 30 days of storage, the mean value of moisture content of cookies ranged from 3.37±0.07 to 4.43±0.06, respectively. The results have shown that with longer storage periods, the moisture content increases.

Protein is a major component of our diet and plays an essential role in the human body. Proteins in any product are the most important in terms of their effects on nutrition and function (Fennema et al., 2017). In this study, the mean protein content of cookies showed that the cookies with 0% PPP obtained the highest mean value of 9.73±0.05 on the first day of storage compared to another treatment. At 30 days of storage, the mean protein content of cookies in all treatments was 9.50±0.04, 9.21±0.03, 8.71±0.06, and 8.21±0.06, respectively. The results indicate that as the storage time increased, the protein content decreased.

Fat is regarded as a macronutrient with several important functions in the human body, including cell proliferation, absorption of fat components, cell wall composition, and many more. Due to the fact that consuming large amounts of fat is linked to several ailments, such as cancer, atherosclerotic disorders, or heart disease, high fiber and low-fat content are significant components of plant medicine. The means values for the fat content of cookies T1

(24.46 ± 0.03), T2 (24.42±0.03), T3 (24.37± 0.03), and T4 (24.35± 0.02). The highest value for fat content was observed in T1, and the lowest was observed in T4 at 0 days of storage. At 30 days of storage, the mean protein content of cookies was 24.41± 0.03 to 24.27±0.04, respectively. The results have shown that with longer storage periods, the fat content decreased.

In food, fibers are non-starch polysaccharides and lignin that human gut enzymes are unable to break down. Depending on the chemical arrangement, there are a wide variety of substances with very different physicochemical properties. Cellulose, pectin, lignin, hemicellulose, and various gum species are among the most important ingredients. In this study, the mean value of fiber content of T0 was found to be the lowest at 1.32±0.020, whereas it was gradually increased in T1, T2, and T3 (1.45±0.020, 1.58±0.010, and 1.70±0.026, respectively) at 0 days of storage, as shown in the table. At 30 days of storage, the mean fiber content of cookies ranged from 1.25±0.026 to 1.61±0.010, respectively. The results have shown that with longer storage periods, the fiber content increases.

The content of ash is derived from the total amount of minerals in food, a residual inorganic substance. residue after the removal of organic waste and water. Although only 4 to 6 % of the human body is made up of them, they are included in the diet. This is necessary for the prevention and treatment of disease. In this study, the mean ash content of cookies showed that the cookies with 0% PPP obtained the lowest mean value of 0.51±0.015 on the first day of storage compared to another treatment. At 30 days of storage, the mean value of ash content of T0 was found to be the lowest, i.e., 0.45±0.020, whereas it was gradually increased in T1, T2, and T3 (0.52±0.064, 0.61±0.017, and 0.71±0.035, respectively). The results show an increase in ash content when stored for longer periods.

In a previous research Dhingra et al., (2012) studied the biochemical composition of potato peel biscuits and the results were similar to our current findings. In another study, Aziz et al. (2019) examined the physicochemical and organoleptic constituents of potato peel-fortified biscuits, which are closely related to our findings.

Table 5. Mean values for Proximate Analysis of potato peel powder cookies of different treatments at 0, 15, and 30-day storage

Treatments	Moisture	Protein	Crude Fiber	Crude Fat	Crude Ash
T0 – 0 day	3.08±0.04	9.73±0.05	1.32±0.020	24.46±0.03	0.51±0.015
T1 – 0 day	3.30±0.05	9.36±0.09	1.45±0.020	24.42±0.03	0.59±0.015
T2 – 0 day	3.62±0.07	8.93±0.06	1.58±0.010	24.37±0.03	0.66±0.032
T3 – 0 day	3.89±0.05	8.42±0.05	1.70±0.026	24.35±0.02	0.79±0.030
T0 – 15 day	3.17±0.03	9.64±0.11	1.29±0.015	24.43±0.02	0.48±0.032
T1 – 15 day	3.42±0.06	9.29±0.05	1.41±0.021	24.36±0.02	0.55±0.031
T2 – 15 day	3.69±0.03	8.88±0.06	1.53±0.026	24.31±0.04	0.63±0.010
T3 – 15 day	4.11±0.02	8.35±0.10	1.64±0.025	24.32±0.02	0.76±0.021
T0 – 30 day	3.37±0.07	9.50±0.04	1.25±0.025	24.41±0.03	0.45±0.021
T1 – 30 day	3.55±0.04	9.21±0.03	1.37±0.050	24.31±0.02	0.52±0.064
T2 – 30 day	3.83±0.07	8.71±0.06	1.49±0.026	24.28±0.03	0.61±0.017
T3 – 30 day	4.43±0.02	8.21±0.06	1.61±0.010	24.27±0.04	0.71±0.035

Note: Values are the means of average ± standard deviation

2.5. Physical characteristics of potato peel powder cookies

Increased supplementation of potato peel powder has resulted in a significant effect on mean square length, thickness, and spread ratio. This analysis

provides important details on the characteristics and quality of cookies.

2.5.1. Spread factor

The spread factor is a key quality element in the case of cookies. The spread ratio of cookies with a higher value is thought to be the most appealing. To determine the quality of these cookies, a spreading ratio is important. The spread factor measures how much cookie dough spreads or expands at the time of baking. It can often be used to determine the possibility that cookie dough will spread when baking cookies (Mancebo et al., 2015).

Table 6 indicates the results of the spread factor of cookies of different treatments at 0, 15, and 30-day storage with potato peel fortification. In this study, the mean values for spread factors of cookies fortified with potato peel powder showed the highest results for T0 (8.68 ± 0.04), whereas they gradually decreased in T1, T2, and T3 (7.77 ± 0.03 , 7.36 ± 0.04 , and 6.93 ± 0.05 , respectively) at 0 days of storage, as shown in the table. Similar results were found at 30 days of storage, the spread ratio decreased with the increased concentration of PPP. In addition, the cookie spread ratio is slightly reduced by replacing wheat flour with PPP, which may result in a decrease in the dough's gluten content. Competition between ingredients in cookies for the absorption of water in batch mixing may be to blame for this sequence of spread ratios (Drisya et al., 2015).

2.5.2. Diameter

The diameter had a great influence on the functional ingredient on the diameter of the cookies. Although it didn't have a very much difference the values decreased at a very small

degree from control to composite treatments. The findings of mean squares for the diameter of cookies are presented in Table 6. According to the findings, the maximum diameter of the cookies was found in T0 (81.79 ± 0.01) whereas the minimum diameter was observed in T3 (73.09 ± 0.03) at 0 days of storage. After 30 days of storage, the mean values regarding the diameter for the treatments were T0 (81.76 ± 0.02), T1 (78.35 ± 0.06), T2 (76.80 ± 0.06), and T3 (73.06 ± 0.02) respectively.

2.5.3. Thickness

Cookie thickness affects the overall shelf life, flavor, cooking time, and color of cookies. The cookies must be a specific thickness to properly cook every cookie at the same time.

In this study, the mean value for the thickness of cookies in Table 6 showed that the cookies with 0% PPP obtained the lowest mean value of 8.85 ± 0.04 on the first day of storage compared to another treatment. At 30 days of storage, the mean value of the thickness of T0 was found to be the lowest, i.e., 8.82 ± 0.04 , whereas it was gradually increased in T1, T2, and T3 (9.06 ± 0.03 , 9.45 ± 0.03 , and 10.17 ± 0.05 , respectively). The results show an increase in thickness when stored for longer periods. An increase in thickness was reported by Jagadiswaran et al. (2021), who studied the effect of value-added ingredients on the development of cookies and reported similar results. Ancuța, P., and Sonia, A. (2020) also reported similar results while studying the cookies' physicochemical properties with different fruits.

Table 6. Mean values for Physical parameters of Cookies at 0, 15, and 30-day storage

Treatments	Spread Factor	Diameter	Thickness
T0 - 0 day	8.68 ± 0.04	81.79 ± 0.01	8.85 ± 0.04
T1 - 0 day	7.77 ± 0.03	78.37 ± 0.07	9.08 ± 0.03
T2 - 0 day	7.36 ± 0.04	76.83 ± 0.06	9.47 ± 0.03
T3 - 0 day	6.93 ± 0.05	73.09 ± 0.03	10.20 ± 0.05
T0 - 15 day	8.66 ± 0.03	81.77 ± 0.03	8.83 ± 0.04
T1 - 15 day	7.76 ± 0.04	78.36 ± 0.07	9.07 ± 0.03
T2 - 15 day	7.35 ± 0.04	76.82 ± 0.06	9.46 ± 0.03
T3 - 15 day	6.92 ± 0.05	73.08 ± 0.01	10.19 ± 0.04
T0 - 30 day	8.65 ± 0.04	81.76 ± 0.02	8.82 ± 0.04
T1 - 30 day	7.75 ± 0.04	78.35 ± 0.06	9.06 ± 0.03

T2 – 30 day	7.34±0.03	76.80±0.06	9.45±0.03
T3 – 30 day	6.91±0.07	73.06±0.02	10.17±0.05

2.5.4. Color analysis of cookies

The color of the product is a major factor that has an impact on consumer preference. In the case of brown pigments, because they become visible as browning and caramelization processes develop, color is part of the criteria used to run the roasting process (Pereira et al., 2013).

In this study, brightness, green/redness, and yellow were affected by the addition of PPP. At 0 days, the L^* values of cookies (T0, T1, T2, and T3) were in the range of 57.28 ± 0.05 , 55.85 ± 0.05 , 53.37 ± 0.21 , and 52.93 ± 0.06 , respectively as shown in Table 7. The highest value for L^* value was observed in T1, and the lowest was observed in T4 at 0 days of storage, as shown in the table. At 30 days of storage, the L^* value decreased with an increase in the concentration of PPP. The result demonstrated that as storage time increased, the brightness values of all cookie samples generally

decreased. At 0 days, the a^* values of the cookie samples showed the highest values for T0 (5.96 ± 0.03) as compared to other treatments T1, T2, and T3. At 30 days of storage, the mean a^* value of cookies ranged from 5.96 ± 0.03 to 4.64 ± 0.03 , respectively. The results have shown that with longer storage periods, the a^* value of cookies decreased. At 0 days, the b^* values of the cookie samples (T0, T1, T2, and T3) were in the range of 15.17 ± 0.07 , 14.92 ± 0.06 , 14.38 ± 0.04 , and 13.08 ± 0.05 , respectively. The mean b^* value of cookies showed that the cookies with 0% PPP obtained the highest mean value of 15.16 ± 0.06 on the 30 days of storage compared to another treatment. In previous research, Tlay et al. (2023) studied biscuits enriched with potato peel powder through different treatments.

Table 7. Color analysis of cookies at 0, 15, and 30-day storage

Treatments	L^*	a^*	b^*
T0 – 0 day	57.28 ± 0.05	5.96 ± 0.03	15.17 ± 0.07
T1 – 0 day	55.85 ± 0.05	5.45 ± 0.03	14.92 ± 0.06
T2 – 0 day	53.37 ± 0.21	4.92 ± 0.05	14.38 ± 0.04
T3 – 0 day	52.93 ± 0.06	14.38 ± 0.04	13.08 ± 0.05
T0 – 15 day	57.27 ± 0.06	5.95 ± 0.02	15.16 ± 0.07
T1 – 15 day	55.83 ± 0.06	5.44 ± 0.02	14.91 ± 0.05
T2 – 15 day	53.36 ± 0.19	4.91 ± 0.05	14.37 ± 0.04
T3 – 15 day	52.93 ± 0.07	4.63 ± 0.03	13.07 ± 0.03
T0 – 30 day	57.26 ± 0.05	5.93 ± 0.02	15.16 ± 0.06
T1 – 30 day	55.82 ± 0.08	5.43 ± 0.02	14.90 ± 0.06
T2 – 30 day	53.35 ± 0.18	4.90 ± 0.04	14.37 ± 0.05
T3 – 30 day	52.92 ± 0.06	4.62 ± 0.03	13.06 ± 0.04

2.6. Sensory Evaluation of Cookies

The sensory evaluation is an experimental method for producing, measuring, evaluating and interpreting sensory responses that are most often perceived by the senses of smell, taste, touch, sight and hearing in response to a food product. The sensory evaluation results of the control cookies and the cookies made with the use of PPP were given in Table 8. The sensory evaluation of cookies

consists of taste, flavor, color, texture, and acceptance. In the present study, a trained panel consisting of MS and PhD students was used for sensory evaluation of cookies performed according to 9-point hedonic scale for different sensory parameters. The average of the colors in the present study varied from 8.11 ± 0.17 to 7.21 ± 0.07 at 0-day storage. The means values of sensory evaluation of cookies were T0 (7.88 ± 0.06), T1

(6.89 ± 0.06), T2 (7.50 ± 0.04), and T3 (6.42 ± 0.09). The highest value for sensory evaluation of cookies was observed in T0 and the lowest was observed in T3. Texture is one of the crucial attributes which influences the consumer acceptability. The texture value of cookies varied between 8.13 ± 0.11 to 6.97 ± 0.11 after 0-day storage. The means values for sensory evaluation of cookie texture are T0 (7.57 ± 0.10), T1 (6.79 ± 0.13), T2 (7.07 ± 0.16), and T3 (6.22 ± 0.14). The best sensorial evaluation of cookie texture was achieved at T0 and the worst was achieved at T3 after 30 days storage time. The taste of cookies ranged from 7.83 ± 0.04 to 6.91 ± 0.07 ; T0 at 0 days had a high Taste Acceptance Score. The biggest taste of cookies was recorded for T0 and the least for T3 after 30 days storage. However, the mean values of flavor are shown in Table 8, and the results indicate that the highest concentration of potato peel powder was added to treatment T3 (6.97 ± 0.11), therefore it showed the lowest value for flavor at 0 days. The mean value of overall acceptability ranged from 7.40 ± 0.05 to 6.86 ± 0.05 . The highest values of the overall acceptability were however found in T0. Similar results were found after 30 days of storage: increasing the concentration of PPP decreased the overall acceptability. The outcomes obtained were consistent with the earlier work of Kaur et al. (2022) where potato peel powder was used as dietary fibre and antioxidants for cookies and the results obtained in the present study were similar. Another study was conducted by Taiyeba et al., (2020) on value added products using sweet potato peels. In our current results, there were no such differences.

It is an experimental technique for generating, measuring, evaluating, and interpreting the sensory responses to a food product, typically perceived through smell, taste, touch, sight, and hearing. The results of control and PPP-incorporated cookies are shown in Table 8. The sensory analysis of cookies includes taste, flavor, color, texture, and overall acceptance. In the current study, sensory evaluation of cookies was done by trained panelists of MS and PhD students

using a 9-point hedonic scale for several sensory aspects.

In the current study, the mean values for color ranged from 8.11 ± 0.17 to 7.21 ± 0.07 at 0 days of storage, respectively. After 30 days of storage, the means values for sensory evaluation of cookies T0 (7.88 ± 0.06), T1 (6.89 ± 0.06), T2 (7.50 ± 0.04), and T3 (6.42 ± 0.09) The highest value for sensory evaluation of cookies was observed in T0, and the lowest was observed in T3.

Texture is an important attribute that has a great impact on consumer acceptability. The texture value of cookies ranged from 8.13 ± 0.11 to 6.97 ± 0.11 during the 0-day storage. The means values for sensory evaluation of cookie texture are T0 (7.57 ± 0.10), T1 (6.79 ± 0.13), T2 (7.07 ± 0.16), and T3 (6.22 ± 0.14). The highest value for sensorial evaluation of cookie texture was observed in T0, and the lowest value was observed in T3 at 30 days of storage. The taste of cookies ranges from 7.83 ± 0.04 to 6.91 ± 0.07 , while a high acceptance score for taste was observed in T0 at 0 days. After 30 days of storage, the highest value for taste of cookies was observed in T0, and the lowest was observed in T3.

However, the mean values of flavor are shown in Table 8, and the results indicate that the highest concentration of potato peel powder was added to treatment T3 (6.97 ± 0.11), therefore it showed the lowest value for flavor at 0 days. The mean value of overall acceptability ranged from 7.40 ± 0.05 to 6.86 ± 0.05 . However, the highest values of overall acceptability were observed in T0. Similar results were found after 30 days of storage: increasing the concentration of PPP decreased the overall acceptability. The results were in accordance with the previous findings of Kaur et al. (2022) on the utilization of potato peel powder as a source of dietary fiber and antioxidants in cookies, and the results of this study were similar to our current research findings. In another study, Taiyeba et al. (2020) studied the utilization of sweet potato peels in value-added products. There were no such differences observed in our current results.

Table 8. Sensory evaluation of cookies at 0, 15, and 30-day storage

Treatments	Color	Flavor	Texture	Taste	Overall Acceptability
T0 – 0 day	8.11±0.17	7.71±0.03	8.13±0.11	7.83±0.04	7.40±0.05
T1 – 0 day	7.74±0.06	7.40±0.06	7.54±0.05	7.3±0.05	7.2±0.03
T2 – 0 day	8.04±0.03	7.58±0.04	7.73±0.08	7.6±0.07	7.26±0.06
T3 – 0 day	7.21±0.07	7.35±0.08	6.97±0.11	6.91±0.07	6.86±0.05
T0 – 15 day	7.88±0.06	7.56±0.05	7.94±0.19	7.44±0.13	7.12±0.08
T1 – 15 day	7.16±0.05	7.16±0.05	7.14±0.14	6.90±0.07	6.90±0.13
T2 – 15 day	7.69±0.05	7.23±0.08	7.36±0.06	7.22±0.16	6.96±0.09
T3 – 15 day	7.02±0.06	7.15±0.05	6.59±0.13	6.50±0.09	6.54±0.06
T0 – 30 day	7.88±0.06	7.31±0.06	7.57±0.10	7.13±0.15	6.78±0.26
T1 – 30 day	6.89±0.06	6.77±0.05	6.79±0.13	6.66±0.09	6.53±0.09
T2 – 30 day	7.50±0.04	6.97±0.10	7.07±0.16	6.83±0.12	6.67±0.10
T3 – 30 day	6.42±0.09	6.71±0.05	6.22±0.14	6.28±0.14	6.23±0.07

Future Perspectives

Future studies should further investigate the potential of potato peel powder as a value-added functional ingredient by optimizing its incorporation level to achieve a balance between nutritional enhancement, antioxidant potential, sensory acceptability, and technological quality. The development of plant-based and functional foods from underutilized resources represents an important direction for improving nutritional value while supporting sustainable food production (Riaz et al., 2026). Future research could also investigate advanced approaches for converting food-processing by-products into functional ingredients and nutraceutical products, particularly through the recovery and stabilization of bioactive compounds, as demonstrated for other plant-based peels (Butt et al., 2026a; Butt et al., 2026b). In addition, emerging technologies such as AI-assisted nutritional optimization could be explored to identify optimal formulations based on nutrient composition, functional properties, and consumer requirements (Butt et al., 2026c). Future investigations should also examine the potential effects of PPP-enriched products on gut health and metabolic outcomes, alongside longer-term storage stability, bioavailability, safety, and consumer acceptance, thereby supporting the development of sustainable and nutritionally enhanced bakery products.

Conclusion

Utilizing potato peel powder in cookies can be a creative and innovative way to reduce food waste. By using potato peels that would typically be discarded, we can help minimize environmental impact and make use of all parts of the potato. Potato peel powder cookies can add a unique flavor and texture to the traditional cookie recipe. The addition of the potato peel powder gives the cookies a slightly earthy and nutty taste. This can be appealing to people looking for a different twist on their baked goods. Incorporating potato peel powder into cookies can provide additional nutritional benefits. Potato peels contain a good amount of fiber, vitamins, and minerals. By using potato peel powder in cookies, we can enhance the nutrient content of the baked goods. The use of potato peel powder in cookies might not appeal to everyone's taste preferences. Some individuals might find the flavor and texture provided by the potato peel powder to be less enjoyable compared to regular cookies. It is important to consider personal preferences and tastes when trying out this unique ingredient. The addition of potato peel flour is said to improve the nutritional properties of the formulated foods. This could include increasing the fiber and protein content of the final products, making them more nutritious.

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