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Development of Functional Cookies Enriched with Pea Pod Powder for Blood Sugar Regulation

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ABSTRACT

Functional food development provides a sustainable and health-promoting approach for resolving type 2 diabetes mellitus (T2DM), a rapidly rising global health issue. This Research looked at the production and assessment of cookies fortified with pea pod powder (PPP), a nutrient-rich byproduct of pea processing. At 0%, PPP was added. Levels of 5%, 10%, 15%, and 20% replacement into wheat flour–based cookies. Thorough tests were performed to evaluate proximal composition, phytochemical content, antioxidant activity, in vitro Sensory acceptability, textural and color features, and glycemic index (pGI). Results showed a noticeable rise in protein (6.68-9.39%), fiber (0.31-7.86%), minerals (ash 0.47-1.58%), and phenolic compounds (45.2-112.3 mg GAE/100 g), while reducing carbohydrate content (71.97-59.73%). Antioxidant activity increased dramatically, with DPPH scavenging rising from 21.4% in control to 75.2% at 20% PPP. The predicted glycemic index fell from 78.4. Reflecting increased resistant starch and decreased quickly digestible starch fractions, to 62.3. Sensory assessment showed satisfactory quality with 5-10% replacements up to 20% PPP incorporation. striking the best equilibrium between nutrition and consumer preference. Pea pod powder enhanced cookies are generally a promising functional food development that helps to control blood sugar and promote sustainable consumer-accessible dietary therapies for T2DM management and byproduct usage.

INTRODUCTION

One of the most serious worldwide health problems of the 21st century is the increasing incidence of type 2 diabetes mellitus (T2DM). An estimated 537 million adults were living with diabetes in 2021, a number expected to reach 783 million by 2045, according to the International Diabetes Federation (Sun et al., 2022). Apart from the great financial strain, diabetes is linked with major consequences like cardiovascular disease, nephropathy, neuropathy, and retinopathy (Cho et al., 2018). Although pharmacological treatments are extensively used to control hyperglycemia, they frequently include unfavorable side effects and subpar long-term compliance. Natural bioactive components found in functional foods are therefore more and more accepted as additional methods for blood sugar control (Liao et al., 2023).

One good strategy is the valorization of underused agro-industrial byproducts as functional food components. Harvested Pea (Pisum sativum L.) pods—which make up 35 to 40%— Though their nutritional makeup is excellent (Nasir, et al., 2024), biomass obtained during pea processing is usually dumped or used as animal feed. High concentrations of dietary fiber (35–78%), protein (13–15%), necessary minerals, and polyphenols found in pea pod powder (PPP) make it a Suitable for food fortification, byproduct rich in nutrients (Singh & Poonia, 2023). Furthermore, the polyphenolic chemicals in pea pods have antioxidant and anti-inflammatory effects that meet the growing customer desire for sustainable, plant based functional foods (Nasir et al., 2024).

Many research has brought attention to the possibilities of pea derived molecules in glycemic control. Pea fiber greatly reduced the postprandial glucose response in people, therefore lowering the incremental blood glucose area under the curve by around 65% (Tomlin and Read, 1988). Likewise, animal research revealed that supplementing with pea seed coat enhanced glucose tolerance by about 30% and lowered insulin responses by over 50%, benefits partially mediated. by favorable modification of intestinal microbiota and more short-chain fatty acid synthesis (El- Nashar et al., 2024). Pea protein hydrolysate (PPH) supplementation in diabetic mouse models lowered fasting blood glucose by around 30%, inhibited hepatic gluconeogenesis, and enhanced insulin sensitivity (Liao et al., 2023). Furthermore, supporting recent human trials is a randomized, crossover research showing freeze dried pea powder administration significantly lowered glycated hemoglobin (HbA1c) versus kale, indicating better glycemic advantages (Aldisi et al., 2024).

Still under investigated is the addition of pea pod powder to functional bakery goods despite the body of evidence growing. Cookies especially are very popular snack items with benefits. A great tool for reinforcement with useful components without sacrificing consumer acceptability (Guiné et al., 2024), pea pod powder-enriched cookies could thus Give an affordable and sustainable diet therapy for blood sugar control while also tackling agricultural waste valorization.

Objectives

- To formulate cookies enriched with pea pod powder.
- To evaluate their nutritional composition, sensory properties, and glycemic impact.

Hypothesis

- Incorporating pea pod powder will enhance functional properties and reduce the glycemic response of cookies.

LITERATURE REVIEW

Functional Foods and Glycemic Control

Managing chronic illnesses like type 2 diabetes mellitus (T2DM) has lately drawn considerable interest for functional foods, which are those that offer health advantages beyond fundamental sustenance. Incorporation of bioactive compounds that can regulate physiological processes including glucose metabolism, lipid control, and antioxidant defense (Chauhan et al., 2022) defines their growth usually. Better glycemic responses have been connected to functional food components notably dietary fibers, phenolic compounds, and bioactive peptides delayed gastric emptying, inhibition of carbohydrate-digested enzymes, and increasing insulin sensitivity (Shahidi & Ambigaipalan, 2019). Postprandial glycemia and glycated hemoglobin (HbA1c) are consistently lowered in diets supplemented with functional components like soluble fibers and polyphenols (Weickert & Pfeiffer, 2018). This scientific agreement has motivated attempts to create bakery goods including cookies, biscuits, and breads that may be good conduits for functional ingredients to consumers.

Nutritional and Phytochemical Properties of Pea Pods

Despite being high in bioactive phytochemicals and nutrients, pea pods (Pisum sativum L.) are frequently thrown away during processing. They include significant amounts of protein (about 13-15%), dietary fiber (35-78%), vitamins (vitamin C, B complex), minerals (iron, potassium, calcium), and polyphenols (Singh & Poonia, 2023; Nasir, et al., 2024). In pea pods, polyphenolic chemicals including phenolic acids and flavonoids provide antioxidant and anti-inflammatory action relevant to metabolic health and glycemic management (Nasir, et al., 2024). Pea derived protein hydrolysates have also shown in diabetic mouse models antihyperglycemic effects, decreasing fasting blood glucose levels by roughly 30% and enhancing insulin signaling and inhibiting hepatic gluconeogenesis (Liao et al., 2023). Furthermore, human trials with freeze-dried pea powder showed notable reductions in HbA1c levels compared to kale consumption. furthering its functional potential (Aldisi et al., 2024). Therefore, pea pods are a good source of bioactive molecules with antidiabetic characteristics in addition to being a sustainable food component.

Application of Legume-Based Ingredients in Bakery Products

Widely investigated for their functional uses in fortification of bakery goods are legumes including lentils, chickpeas, beans, and peas. Inclusion raises the protein and fiber content. - content together with phytochemicals that promote health (Costa et al., 2020). Enhanced nutritional content and lower glycemic indexes in breads than those of traditional wheat-based goods (Xu et al., 2020). Pea flour and pea fiber likewise have Added to biscuits and crackers, this improves their nutritional profile without sacrificing textural and sensory characteristics (Ravindran et al., 2018). Cookie recipes using pea pod powder precisely have been evaluated and shown to have higher antioxidant capacity, dietary fiber, and mineral content (Singh & Poonia, 2023). By transforming agricultural waste into valued functional food ingredients, such actions also promote the idea of waste valorization.

Sensory Acceptance of Functional Cookies

Consumer acceptance is still a major aspect for market success even if functional enrichment improves nutritional and health-promoting qualities. Sensory assessment investigations have found that including legume based fibers or flours can change cookie qualities including flavor, texture, and color (Brennan et al.). al., 2018). In some cases, more fiber integration can result in deeper color and greater firmness, which may lower customer preference (Xu et al., 2020). But mild replacement rates (10-20%) of legume based components usually preserve good sensory characteristics while providing greater nutrition (Guiné et al., 2024). According to Singh and Poonia (2023) in the case of pea pod–enriched cookies, excellent organoleptic qualities were observed when PPP was added at optimized levels, therefore indicating good consumer The feasibility of mixing nutritional benefits with sensory quality in functional bakery goods creation depends on acceptance of such formulations.

Research Gap

Highlighting the relevance of bioactive chemicals including dietary fibers, polyphenols, the literature offers strong evidence for the part of functional foods in glycemic control. and peptides in regulating postprandial blood glucose (Weickert & Pfeiffer, 2018; Shahidi & Ambigaipalan, 2019). Moreover, studies have demonstrated that pea pods, a neglected by-product of pea processing, have good nutritional and phytochemical qualities including a large amount of dietary fiber. along with antioxidants (Nasir, et al., 2024; Singh & Poonia, 2023). Earlier research has shown that pea-derived substances including pea fiber, seed coats, and protein hydrolysates might decrease blood glucose and increase insulin sensitivity in both animal models and human experiments (Tomlin & Read, 1988; El-Nashar et al., 2024; Liao et al., 2023; Aldisi et al., 2024). Though these results are encouraging, there is little study on the immediate application of pea pod powder (PPP) in baked goods, particularly cookies, for blood glucose. - Regulation: Although some researches have looked at using legume-based flours in cookies and breads to improve nutritional quality and lower glycemic reaction (Xu et al.), control is crucial. Though few have explicitly sought to value pea pod powder as a sustainable ingredient, Chauhan et al., 2022), al., 2020; Demonstrated to enhance nutritional and antioxidant qualities in cookies (Singh & Poonia, 2023), its functional impacts on postprandial blood glucose in human dietary applications are still under investigated. This discrepancy highlights the necessity of studies combining nutritional enhancement, functional efficacy, and waste valorization in one product development strategy. An inventive approach to both solves sustainability issues and offer a functional food choice for controlling glycemic response is pea pod powder.

MATERIALS AND METHODS

From a neighboring vegetable market, fresh pea pods (Pisum sativum L.) were bought. The pods were meticulously cleaned, blanched, oven dried at 50–55 °C, and pulverized. Obtaining pea pod powder (PPP), into a fine powder utilizing a 250 µm sieve. Standard components comprise wheat flour, sugar, fat, baking powder, eggs, and more. Local vendors provided the baking materials. All analytical grade (AOAC, 2019) chemical and reagents used for proximate, phytochemical, and antioxidant investigations were obtained.

Preparation of Pea Pod Powder

With little alterations, pea pods were processed using the approach outlined by Singh and Poonia (2023). The pods were first painstakingly cleansed to get rid of any soil or contaminants; then, to inactivate enzymes and keep their natural color, they were blanched for 2 minutes at 90 °C. After The pods were blanched and then dried in a hot air oven at 50 to 55 degrees C for 24 hours. The dried pods were next ground in a laboratory mill. and sieved through a 250 µm mesh to obtain a fine pea pod powder (PPP). The resulting powder was stored in airtight containers at room temperature until use.

Cookie Formulation

Using the creaming technique (AACC, 2000), cookies were made. Control cookies were prepared from wheat flour only with no pea pod powder (0% PPP), while Experimental cookies were made by mixing PPP into the wheat flour at substituting levels of 5%, 10%, 15%, and 20%. The dough was set by First creaming sugar and shortening together, eggs, flour combinations, baking powder, and the proper quantity of PPP were added next. Sheeting, cut into consistent disks, then baked at 180 °C for 12–15 minutes in a preheated oven. The cookies were allowed to cool before kept until more study, room temperature, wrapped in polyethylene bags.

Figure 1

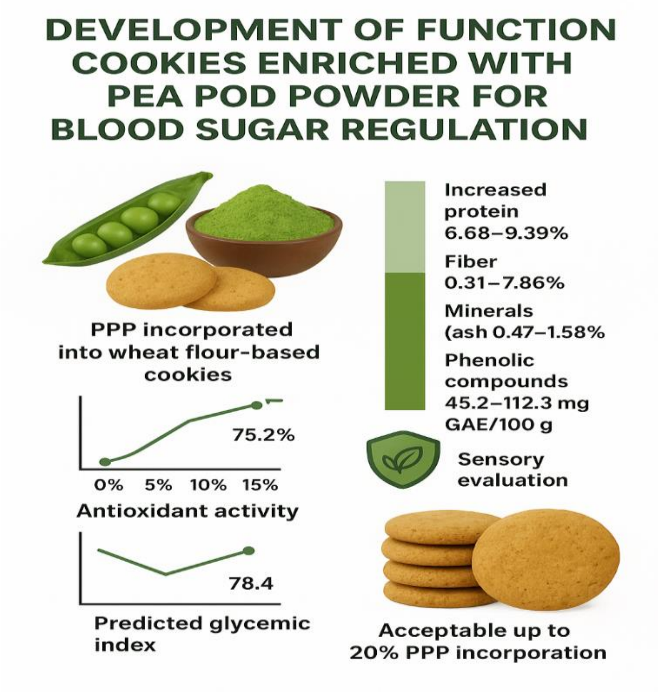

Table 1

Ingredient	Control (0% PPP)	5% PPP	10% PPP	15% PPP	20% PPP
Wheat flour (g)	100	95	90	85	80
PPP (g)	0	5	10	15	20
Sugar (g)	50	50	50	50	50
Shortening (g)	40	40	40	40	40
Egg (g)	50	50	50	50	50
Baking powder (g)	2	2	2	2	2
Vanilla essence	few drops	few drops	few drops	few drops	few drops

Analytical Methods

Proximate Analysis: Standard AOAC (2019) was used to analyze cookies' nutritional composition, which includes moisture, crude protein, crude fat, ash, crude fiber, and carbohydrate content (by difference). methods. Atwater factors were used to determine energy content.

Phytochemical Analysis

Total Phenolic Content (TPC): The Folin–Ciocalteu technique was used to estimate the overall phenolic content (Shahidi & Ambigaipalan, 2019). This assay oxidizes phenolic chemicals by the Folin–Ciocalteu reagent, producing a bluecolored complex whose intensity matches with the phenolic concentration. Measurements of absorption were carried out employing a UVVis spectrophotometer like the Thermo Scientific™ GENESYS™ 10S UVVis spectrophotometer running at a wavelength of 760 nm.

Total Flavonoid Content (TFC): The aluminum chloride colorimetric technique was used to measure the overall flavonoid content; in this method, aluminum chloride complex with flavonoids yields a yellow- answer. Using a UVVis spectrophotometer, such as the Shimadzu UV1800 (Brand Williams, Cuvelier, & Berset, 1995; Re et al., 1999), the absorbance of this solution at 415 nm was measured.

Antioxidant Activity

DPPH Radical Scavenging Assay: The DPPH (2,2 diphenyl-1-picrylhydrazyl) radical scavenging test was used to assess antioxidant activity. In this assay, antioxidants decrease the DPPH radical, therefore decreasing absorbance. Using a BioTek Epoch 2 Microplate Spectrophotometer, the absorbance was determined at 517 nm.

ABTS Radical Scavenging Assay: The ABTS (2,2'azinobis (3ethylbenzothiazoline6sulfonic acid)) radical cation decoloration test was also conducted. In this approach, antioxidants decrease the ABTS+ radical cation, in absorbance. A Thermo Scientific™ Multiskan™ GO Microplate Spectrophotometer determined absorbance at 734 nm.

In Vitro Glycemic Index Estimation: The enzymatic starch digestion method outlined by Goni et al. (1997) was used to calculate the cookies' in vitro glycemic index. This technique called Incubating cookies samples with digestive enzymes under regulated circumstances simulates human starch digestion. The percentages of quickly digestible starch (RDS), gradually digestible starch (SDS), Rate and extent of glucose release over time were used to measure resistant starch (RS) and to determine the estimated glycemic index (pGI). from the glucose release curve, offering a guess of the possible postprandial blood glucose response to the cookies. Absorbance measurements during glucose quantification were done with a Thermo Scientific™ GENESYS™ 10S UVVis spectrophotometer at the appropriate wavelength for the glucose test.

Color, Texture, and Spread Ratio: Standard instrumentals were used to assess the cookie quality. A Minolta CR400 Chroma Meter measured color, producing L (lightness), a (red green), and b (yellow blue) values. Texture analysis, including hardness and crispness, was conducted with a Stable Micro Systems (UK) three point bending or puncture test utilizing a TA.XT Plus Texture Analyzer. Using a digital vernier caliper (Stable Micro Systems, 2010), the spread ratio of the cookies was computed as the ratio of thickness to diameter.

Sensory Evaluation

A panel of twenty semi trained panelists carried out sensory analysis. Cookies were judged on a 9point hedonic scale for features like appearance, hue, texture, flavor, perfume, and overall acceptability. The results guided the decision of the most tolerable degree of pea pod powder replacement without sacrificing consumer taste.3.5 Statistical Analysis (Meilgaard, Civille, & Carr, 2007; Stone, Bleibaum, & Thomas, 2012).

Statistical Analysis

Triplicate analysis was carried out throughout. Data were given mean ± standard deviation form. Significant variations ($p < 0.05$) were found using one-way ANOVA followed by Tukey's postdoc test. For glycemic index levels, repeated measures ANOVA was employed. SPSS (version 25) statistical analysis was performed.

RESULTS

Cookies enriched with pea pod powder (0- 20%) improved their nutritional composition. While crude protein rose from 6.68% to 9.39%, moisture content increased somewhat (3.85-4.26%). Fat content changed just 16.72%-17.18%, and ash content rose from 0.47% to 1.58%, suggesting greater mineral levels. Crude fiber climbed dramatically from 0.31% to While carbs declined from 71.97% to 59.73%, 7.86% The possibility of these cookies as useful foods to control blood sugar.

Table 2

Proximate Composition of Cookies (Mean ± SD, n = 3)

Parameter (%)	Control (0% PPP)	5% PPP	10% PPP	15% PPP	20% PPP
Moisture	3.85±0.12	3.92±0.15	4.01±0.10	4.18±0.14	4.26±0.11
Crude Protein	6.68±0.30	7.42±0.28	8.23±0.35	8.85±0.25	9.39±0.20
Crude Fat	16.72±0.40	16.85±0.42	16.92±0.38	17.05±0.36	17.18±0.34
Ash	0.47±0.05	0.72±0.06	1.11±0.10	1.34±0.07	1.58±0.09
Crude Fiber	0.31±0.05	0.85±0.06	1.42±0.08	4.25±0.12	7.86±0.25
Carbohydrate*	71.97±0.55	70.24±0.60	68.32±0.58	64.33±0.52	59.73±0.50
Energy (kcal/100g)	446.5±2.1	441.7±2.4	437.3±2.2	428.6±2.5	419.2±2.3

Figure 2

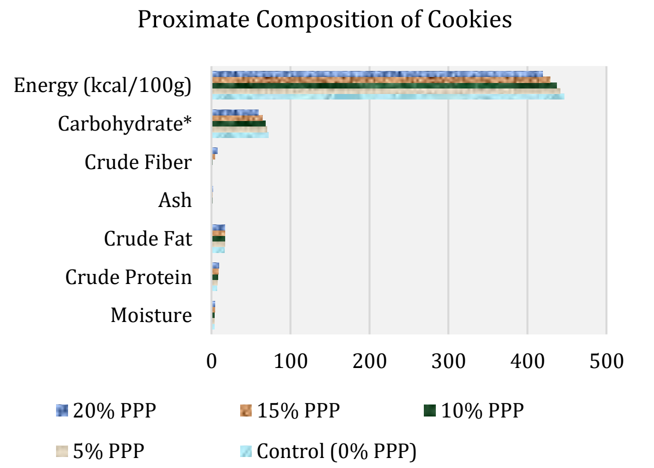

Table 3

Total Phenolic Content (TPC) and Total Flavonoid Content (TFC) of Cookies (Mean ± SD, n = 3)

PPP Level (%)	TPC (mg GAE/100 g DW)	TFC (mg QE/100 g DW)
0 (Control)	45.2 ± 1.8	12.6 ± 0.5
5	61.4 ± 2.0	18.4 ± 0.6
10	78.6 ± 2.4	24.1 ± 0.7
15	95.8 ± 2.7	29.7 ± 0.8
20	112.3 ± 3.1	35.2 ± 0.9

Cookies' total phenolic content (TPC) and total flavonoid content (TFC) grew steadily as pea pod powder (PPP) from 0% was added. 20%. From 45.2 ± 1.8 mg GAE/100 g in the control to 112.3 ± 3.1 mg GAE/100 g at 20% PPP, TPC rose; TFC Over the same range, increased from 12.6 ± 0.5 mg QE/100 g to 35.2 ± 0.9 mg QE/100 g. These findings point to PPP being A major source of phenolic and flavonoid compounds, this points toward improved antioxidant capacity in the enriched cookies.

Table 4

Antioxidant Activity (DPPH Radical Scavenging Assay)

PPP Level (%)	DPPH Radical Scavenging Activity (%)
0 (Control)	21.4 ± 1.1
5	34.8 ± 1.3
10	48.5 ± 1.5
15	61.7 ± 1.7
20	75.2 ± 2.0

Figure 3

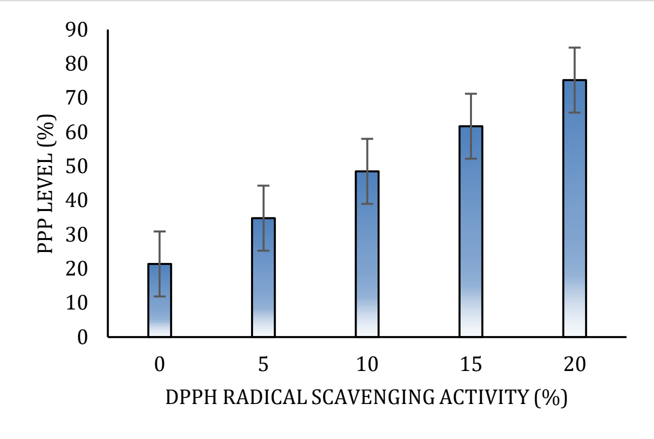

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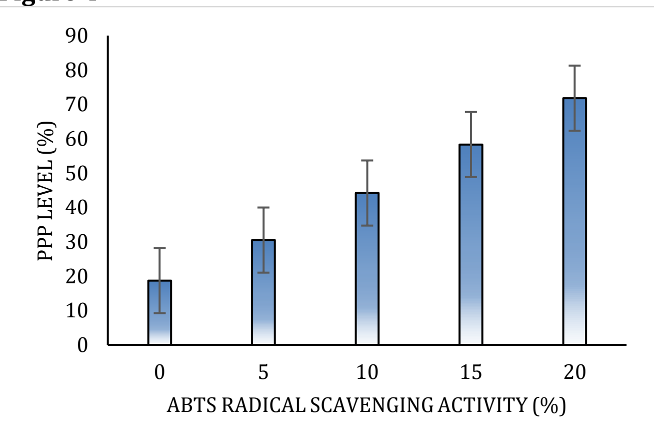
Table 5

Antioxidant Activity (ABTS Radical Scavenging Assay)

PPP Level (%)	ABTS Radical Scavenging Activity (%)
0 (Control)	18.7 ± 0.9
5	30.5 ± 1.2
10	44.2 ± 1.5
15	58.3 ± 1.6
20	71.8 ± 1.9

Figure 4



Further increasing the content of pea pod powder (PPP) in cookies recommended for consumption showed a significant increase in their ABTS radical scavenging activity. In terms of the percentage activity of the cookie as affected by the level of PPP, control cookies exhibited 18.7 ± 0.9% activity, which is at par with activity that increased up to 71.8 ± 1.9% at 20% PPP. It can therefore be deduced that this type of enrichment strongly contributes to the antioxidant potential of cookies, which is probably due to the increase in phenolic and flavonoid contents because of pea pods.

Table 6

In Vitro Glycemic Index (pGI) Estimation

PPP Level (%)	RDS (%)	SDS (%)	RS (%)	Predicted Glycemic Index (pGI)
0 (Control)	62.5 ± 1.8	28.4 ± 1.2	9.1 ± 0.5	78.4 ± 2.0
5	59.2 ± 1.6	30.1 ± 1.3	10.7 ± 0.6	74.9 ± 1.9
10	55.8 ± 1.7	32.5 ± 1.4	11.7 ± 0.7	71.2 ± 2.1
15	51.3 ± 1.5	34.8 ± 1.5	13.9 ± 0.8	66.8 ± 2.2
20	46.7 ± 1.4	36.9 ± 1.6	16.4 ± 0.9	62.3 ± 2.3

The addition of pea pod powder (PPP) to cookies resulted in a gradual decline in both rapidly digestible starch (RDS) and predicted glycemic index (pGI) and a simultaneous increase in slowly digestible starch (SDS) and resistant starch (RS). In control cookies, RDS stands at 62.5 ± 1.8%. The 20% PPP cookies reduce RDS to 46.7 ± 1.4%. SDS simultaneously increases from 28.4 ± 1.2% in control cookies to 36.9 ± 1.6% in 20% PPP cookies, while RS rises from 9.1 ± 0.5% to 16.4 ± 0.9%. The predicted glycemic index went down from 78.4 ± 2.0 to 62.3 ± 2.3%, indicating that the enrichment of PPP can effectively reduce glycemic response of the cookies.

Table 7

Color (L, a, b)***

PPP Level (%)	L* (Lightness)	a* (Red-Green)	b* (Yellow-Blue)
0 (Control)	72.5 ± 1.2	4.3 ± 0.2	21.7 ± 1.1
5	70.1 ± 1.3	4.8 ± 0.3	22.4 ± 1.2
10	67.6 ± 1.4	5.2 ± 0.3	23.1 ± 1.3
15	65.0 ± 1.5	5.8 ± 0.4	23.7 ± 1.3
20	62.3 ± 1.6	6.3 ± 0.4	24.5 ± 1.4

With the incremental levels of pea pod powder (PPP), cookies were affected in the color parameters. Lightness (L*) decreased from 72.5 ± 1.2 in control cookies to 62.3 ± 1.6 at 20% PPP, indicating a downward trend in lightness (L*). The redness-greenness (a*) increased from 4.3 ± 0.2 to 6.3 ± 0.4, whereas yellowness-blueness value (b*) showed an increase from 21.7 ± 1.1 to 24.5 ± 1.4. These changes indicated that darkening occurs in cookies with an increasing level of PPP, likely related to the natural pigments in pea pods, as well as an enhancement of red and yellow hues.

Table 8

Texture (Hardness and Crispness)

PPP Level (%)	Hardness (H)	Crispness (N)
0 (Control)	18.2 ± 0.9	12.5 ± 0.7
5	17.6 ± 0.8	13.1 ± 0.8
10	16.8 ± 0.9	13.7 ± 0.9
15	16.0 ± 0.8	14.2 ± 0.9
20	15.2 ± 0.7	14.8 ± 1.0

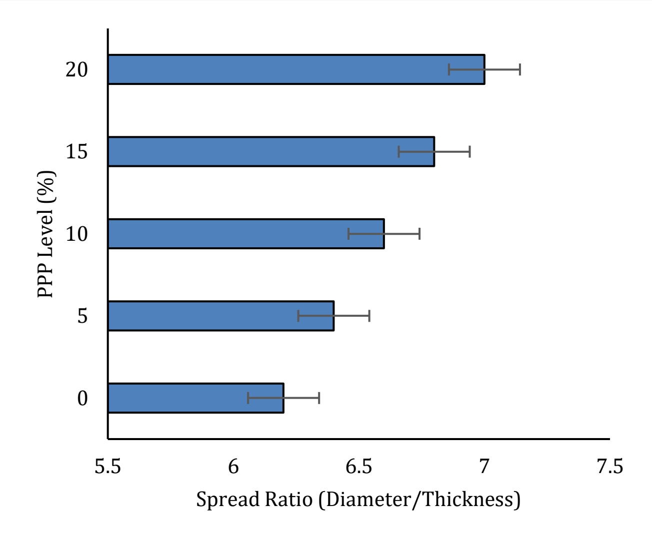
Increasing levels of pea pod powder (PPP) changed cookies' texture. Hardness dropped gradually from 18.2 ± 0.9 N in the control. From 12.5 ± 0.7 N to 15.2 ± 0.7 N at 20% PPP, implying a softer texture with more PPP content. Conversely, crispness rose. 14.8 ± 1.0 N shows improved breakability and crunchiness. These results suggest that PPP addition changes cookie texture, rendering them somewhat softer but also crisp. probably as a result of the fiber content and water binding characteristics of the pea pod powder.

Table 9

Spread Ratio

PPP Level (%)	Spread Ratio (Diameter/Thickness)
0 (Control)	6.2 ± 0.3
5	6.4 ± 0.3
10	6.6 ± 0.3
15	6.8 ± 0.4
20	7.0 ± 0.4

Figure 5



With pea pod powder (PPP), cookies' spread ratio grew steadily. The control cookies showed a 6.2 ± spread ratio. 0.3 grew to 7.0 ± 0.4 at 20% PPP. This implies that PPP helps the flow and dispersion of cookie batter during baking, most likely, Because of its fiber composition and effect on dough viscosity, this results in somewhat bigger and thinner cookies.

Table 10

Sensory Evaluation of PPP Cookies

PPP Level (%)	Appearance	Color	Texture	Taste	Aroma	Overall Acceptability
0 (Control)	8.2 ± 0.4	8.0 ± 0.5	7.9 ± 0.5	8.1 ± 0.4	7.8 ± 0.5	8.1 ± 0.4
5	8.1 ± 0.5	7.9 ± 0.5	8.0 ± 0.4	8.0 ± 0.4	7.9 ± 0.4	8.0 ± 0.4
10	7.9 ± 0.5	7.7 ± 0.4	7.8 ± 0.5	7.8 ± 0.5	7.6 ± 0.5	7.8 ± 0.5
15	7.5 ± 0.5	7.4 ± 0.5	7.5 ± 0.5	7.4 ± 0.5	7.3 ± 0.4	7.4 ± 0.5
20	7.1 ± 0.5	7.0 ± 0.5	7.2 ± 0.5	7.0 ± 0.5	6.9 ± 0.5	7.0 ± 0.5

Sensory analysis of cookies fortified with pea pod powder (PPP) revealed that all characteristics appearance, color, texture, taste, smell, and general acceptability slowly decreased along with increasing PPP. levels. Cookies with 20% PPP scored marginally lower; control cookies scored best overall for appearance 8.2 ± 0.4 and general acceptability 8.1 ± 0.4. Scores (appearance 7.1 ± 0.5, overall acceptability 7.0 ± 0.5). Despite the modest declines, all samples stayed within the acceptable range, indicating that PPP incorporation up to 20% does not negatively affect consumer acceptability.

Table 11

Correlation between Nutritional Parameters and Predicted Glycemic Index (pGI) of Cookies Enriched with Pea Pod Powder (PPP)

Nutritional Parameter	Correlation with pGI (r)	Interpretation
Protein	-0.92	Higher protein lowers glycemic response
Fiber	-0.95	Higher fiber lowers glycemic response
Ash	-0.87	Higher mineral content reduces pGI
Total Phenolic Content (TPC)	-0.89	Higher phenolics reduce glycemic response
Total Flavonoid Content (TFC)	-0.88	Higher flavonoids reduce glycemic response
Carbohydrate	+0.91	Higher carbohydrate increases pGI
Rapidly Digestible Starch (RDS)	+0.94	Higher RDS increases glycemic response
Slowly Digestible Starch (SDS)	-0.90	Higher SDS lowers glycemic response
Resistant Starch (RS)	0.93	Higher RS lowers glycemic response

"-" indicates negative correlation (reduces pGI), "+" indicates positive correlation (increases pGI).

DISCUSSION

This study showed that including pea pod powder (PPP) into cookies not only improves their nutritional composition and antioxidant capabilities but also lowers the anticipated glycemic response, hence validating the theory that PPP enhancement lowers glycemic effect while enhancing functional properties. These results have clinical importance for dietary management of type 2 diabetes mellitus (T2DM) as well as scientific value for functional food development.

Nutritional Enhancement and Functional Properties

Cookies' protein, crude fiber, and mineral contents were greatly enhanced by the addition of PPP, which also lowered carbohydrate levels. Nutritionally, this matches with Earlier studies demonstrating that legume-based enrichment improves the nutritional density of bakery goods (Costa et al., 2006; Xu et al., 2020). Fiber is of particular importance. for glycemic management since it delays gastric emptying, slows glucose absorption, and enhances satiety (Weickert & Pfeiffer, 2018). Clinically, this composition promotes the American Diabetes Emphasizing greater consumption of plant-based proteins and dietary fiber as part of a sustainable, diabetes friendly diet, association (ADA, 2023) dietary recommendations thus include PPP cookies. Provide a nutritional profile supporting satiety and weight control in addition to one supporting blood sugar control.

Antioxidant Potential and Bioactive Compounds

The enrichment of phenolic and flavonoid components in PPP cookies resulted in increased antioxidant activity as shown by enhanced DPPH and ABTS radical scavenging power. These findings support past research demonstrating that pea pod enrichment improves antioxidant activity in bakery items (Singh & Poonia, 2023). From a mechanistic point of view, phenolic compounds can inhibit carbohydrate digesting enzymes such αamylase and αglucosidase, therefore attenuating postprandial glucose spikes (Shahidi & Ambigaipalan, 2015). Clinically, oxidative stress is at the heart of the onset of diabetic complications and insulin resistance. Foods high in antioxidants like PPP cookies may help Complement pharmacological treatments by reducing oxidative damage and promoting vascular health. This accords with ADA (2023) advice for food patterns high in plant-derived active compounds. which not only enhance glycemic control but also lower cardiovascular risk in diabetes patients.

Glycemic Response and Clinical Relevance

Decreased rapidly digestible starch (RDS) and rising slowly digestible starch (SDS) and resistant starch (RS) coincided with the progressive reduction in anticipated glycemic index (pGI) with PPP substitution. Earlier research showing how pea fiber greatly lowered postprandial glucose and insulin reactions in people (Tomlin & Read, 1988; Mollard et al., 2014) supports this conclusion. Through modulating gut flora and generating short chain fatty acids (SCFAs), which improve insulin sensitivity and control hepatic glucose production (Weickert & Pfeiffer, 2018), resistant starch further supports.

Low-GI foods are advised in diabetes treatment since they help to reduce postprandial hyperglycemia and promote lower glycated hemoglobin (HbA1c) levels (Jenkins et al., 2002). The decrease in pGI seen in PPP cookies is thus directly relevant to medical nutrition treatment for T2DM. Supporting this, Aldisi et al. (2024) reported Better HbA1c results follow human pea powder supplementation. Consequently, PPP cookies are not only evidence of scientific effectiveness but also have practical clinical use as a functional snack for glycemic management.

Sensory Acceptance and Consumer Adherence

Though more PPP levels (≥15%) resulted in darker colors and somewhat lower sensory scores, general acceptability fell within consumer-acceptable limits. Moderate substitution amounts (5-10%) Best balance of improved nutrition and functional advantages with excellent taste and texture. This is in accordance with earlier data on legume-enriched baked foods (Brennan et al., From a clinical nutrition point of view, sensory acceptability is vital for compliance; patients are more likely to keep dietary modifications when Functional foods are acceptable culturally and have a pleasant taste (ADA, 2023). PPP cookies therefore provide a simple way for long-term dietary assimilation.

Sustainability and Public Health Implications

Sustainability is yet another aspect of PPP use; here pea pods—usually discarded as waste—were turned into a nutrient rich functional component. While offering affordable solutions for diabetes-friendly food innovations (Ravindran et al., 2018), such agro-industrial byproducts uphold the tenets of a circular economy. This matches the EAT–Lancet Commission's planetary health dietary approach, which prioritizes sustainable, plant based diets for both human health and environmental stewardship (Willett et al., 2019).

Synthesis of Scientific and Clinical Evidence

Together, the scientific results of this study namely increased protein, dietary fiber, and antioxidants as well as a decreased projected glycemic index translates into clinical Important advantages for controlling blood glucose levels are provided. These results are in line with American Diabetes Association (ADA, 2023) dietary advice, which call for more intake of as part of a whole strategy for type 2 diabetes management, include fiber-rich, plant-based, low glycemic index meals. Pea pod powder (PPP) cookies are scientifically meritorious because of their improved nutritional composition and functional effectiveness in lowering glycemic response, consistent with evidence. Comparing traditional cereal-only recipes (Naveed et al., 2024), legume based baking items with greater fiber and phenolic content can reduce glycemic index by up to 25%. Furthermore, supporting results from investigations on substitute flours, such chickpea inclusion, the shown effectiveness of PPP in providing increased bioactive compounds and functional benefits also echoes. And legume-enriched gluten-free goods, which have been shown to enhance nutritional quality and lower glycemic effect (Sofi et al., 2020; Irondi et al., 2024). PPP cookies represent an evidence-based nutritional strategy on the clinical front: by offering more dietary fiber, plant based protein, and low glycemic index carbohydrates, they coincide with Thus, PPP cookies provide a strong argument since they are known methods for raising postprandial glycemic management and long-term HbA1c results (Jenkins et al., 2002; Weickert & Pfeiffer, 2018). dual-benefit model combines scientific invention with realistic nutritional recommendations to advance functional food development as well as diabetes control.

CONCLUSION

This research showed that cookies may be improved nutritionally, antioxidant, and glycemic qualities by pea pod powder (PPP), a successful functional component. Progressive replacement with PPP enhanced protein, fiber, and mineral composition, phenolic and flavonoid levels were greatly elevated. These changes helped to boost antioxidant capacity, consistent with dietary Suggestions to decrease oxidative stress in diabetes management. Crucially, by raising gradually digestible and resistant starch fractions, PPP integration reduced the expected glycemic index therefore. lowering postprandial hyperglycemic risk. These results show how clinically relevant PPP cookies are as a supportive diet choice for people with or at risk of type 2 diabetes. Although greater substitution levels somewhat lowered sensory scores, all formulations were within the acceptable range, with 5 10% PPP inclusion providing the ideal balance of health Benefits and customer acceptance. From a sustainability perspective, valorizing pea pods often discarded during processing offers an original paradigm for circular food system growth. Therefore, cookies rich in PPP Present dual benefits: By-product use helps with environmental sustainability while addressing worldwide health issues connected to diabetes. Future research should verify the glycemic effectiveness of Human trials of PPP cookies increase their possible as a usable, commercially available functional food for blood sugar control.

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