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"Comparative Insights into Glycemic Control: The Synergistic Role of Functional Foods and Ayurveda"

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Abstract:

Background: This study aimed to formulate a functional food product by integrating Ayurvedic wisdom with modern nutritional science, with a focus on diabetes management.
Materials and Methods: The product was developed using wheat, chickpea, fenugreek seeds, hibiscus, and green gram (microgreens). Pre-processing techniques, such as soaking, germination, drying, and milling, were employed to enhance the nutritional quality. Comprehensive nutritional profiling was conducted, including proximate analysis, mineral estimation (calcium and iron), enzyme assay (amylase activity), determination of glycemic load, and phytochemical screening.
Results: The sprouted product (SP) showed improved nutritional characteristics compared to the control product (CP). SP contained lower energy (371.54 kcal/100 g) than CP (399.86 kcal/100 g), with reduced carbohydrates (70.91 g vs. 78.89 g) and fat (5.5 g vs. 5.9 g). Conversely, SP demonstrated higher protein content (9.6 g vs. 7.8 g), significantly greater dietary fiber (10.8 g vs. 4.4 g), and increased iron levels (1.5 mg vs. 1.0 mg). Calcium levels were nearly identical in both variants. Phytochemical analysis revealed that SP had double the phenolic content (80.0 mg) compared to CP (40.0 mg) and higher flavonoids (90.0 µg vs. 70.0 µg). The enzyme assay indicated lower amylase activity in SP (14.13 U/L) compared to CP (29.43 U/L), suggesting slower starch breakdown and a reduced risk of postprandial glucose spikes.
Conclusion: The study demonstrates that integrating Ayurvedic principles with modern nutritional strategies can yield a therapeutic, health-promoting functional food. The developed formulation not only supports diabetes management through improved nutrient composition and reduced glycemic response but also serves as a sustainable dietary option for promoting overall well-being.

Keywords: Functional food, Ayurveda, Diabetes management, Germination, Phytochemicals.

Introduction

In Ayurveda, Ayu or life is explained as a harmonious blend of the body (Sharira), senses (Indriya), mind (Satwa), and soul (Atma). These four elements are inseparable and together sustain existence. Ancient scholars used various terms to describe different dimensions of life: Nityaga conveys the idea of an ongoing stream of awareness, Dhari points to the vital strength that supports and protects the body,

Jeevitam reflects the essence of being alive, and Anubandha highlights the continuity of the soul through successive lifetimes. (*Choudhary et al., 2015*) . Health, or swastha, is not simply freedom from illness but a condition where balance is maintained in all aspects of the body and mind. This balance involves the proper functioning of the doshas (biological energies), agni (digestive and metabolic processes), dhatus (tissues), and malas (waste products), along with mental clarity and emotional stability. True wellness is thus seen as harmony across the physical, psychological, and spiritual spheres. Ayurveda places strong emphasis on prevention and healing at the root level, rather than treating only the outward signs of disease. This holistic perspective has made Ayurveda increasingly relevant in the modern world, especially for managing chronic illnesses, autoimmune disorders, and metabolic imbalances. (*Choudhary et al., 2015*). From this perspective, diabetes mellitus is described in Ayurveda under the names Madhumeha and Kshaudrameha. The condition is marked by frequent urination with a sweet quality, often compared to honey. Madhumeha is considered one of the twenty different types of Prameha disorders, and its development is mainly linked to imbalances in Vata dosha. The very term combines madhu (sweet) and meha (urination), directly pointing to the passage of sweet urine. Other names like Ojomeha and Kshaudrameha are also used in classical writings. (*Karam et al., 2013*)

Traditionally, Madhumeha is classified among the four types of Vatika Prameha, placing it within the broader category of Prameha roga a group of conditions characterized by distinctive physical and chemical changes in the urine. In Madhava Nidana, Acharya Madhava describes Prameha as involving persistent, excessive, and cloudy urination. Similarly, the Charaka Samhita (Indriyasthana) lists Madhumeha among the eight most severe diseases (Ashtamaharoga), underscoring the significance attributed to this condition in early Ayurvedic thought. (*Karam et al., 2013*)

Therefore, the present study was designed to develop a product enriched with Ayurvedic principles and nutritional benefits, to explore its potential in supporting diabetes management and improving overall health outcomes.

Materials and methods

Materials

The ingredients used in this study wheat, chickpeas, fenugreek seeds, and green gram were procured from a local supermarket in Bangalore. Hibiscus flowers, recognized for their Ayurvedic significance, were collected from a home garden in Channapatna, situated in the Ramanagara district.

Methods

The selection of ingredients for this study was primarily guided by their documented Ayurvedic properties and nutritional relevance for the management of diabetes. Preference was given to food sources with a low glycemic index (GI) and glycemic load (GL), including fenugreek seeds (*Trigonella foenum-graecum*), wheat (*Triticum aestivum*), and chickpea (*Cicer arietinum L.*). These ingredients were subjected to standard pre-processing treatments such as soaking, germination, drying, and milling into flour. Hibiscus (*Hibiscus rosa-sinensis*), freshly harvested from the source, was dried and powdered, while green gram (*Vigna radiata L.*) was cultivated as microgreens through soaking and germination, followed by growth for 1–2 weeks before use, as illustrated in Flow Chart 1 (*Gunathunga et al., 2021*).

Standardization

The formulation was developed by combining selected legumes with Ayurvedic ingredients to enhance both flavor and therapeutic potential. Multiple proportion adjustments and trial preparations were conducted before finalizing the optimized product, as presented in Table 1 (*Pakhare et al., 2016*).

Sensory evaluation

The product was formulated in different compositions to optimize flavor and consumer acceptability, followed by sensory evaluation conducted with 25 semi-trained panelists at Padmashree Institute of Management and Sciences. Sensory characteristics were assessed using a 9-point hedonic scale, focusing on parameters such as appearance (color and smoothness), texture (mouthfeel), flavor (intensity), taste (preference and aftertaste), and overall acceptability (*Shruthi et al., 2023*).

Nutritional composition

The developed samples were analysed to determine the nutritional composition, such as energy content (Food energy methods of analysis and conversion factors: 2003), protein content (AOAC 978.04), fat content (AOAC 930.09), carbohydrate content (*Wijaya and Romulo, 2021*), total dietary fiber (AOAC 930.10), moisture content (FSSAI manual methods: cereal & cereal products 03.006:2023), ash (AOAC 930.09), iron content (*Goswami and Kalita, 1988*), and calcium content (*Bird et al., 1961*).

Phytochemicals

The total phenol content was estimated using the Folin-Ciocalteu method, with gallic acid serving as the reference standard. In this procedure, the extract of the developed product was first mixed with distilled water, followed by the addition of a 7% sodium carbonate solution. The mixture was incubated for 20 minutes, after which the Folin-Ciocalteu reagent was added and the solution was further incubated for 10 minutes. The absorbance was then measured at 660 nm to compare with a standard curve prepared from gallic acid solutions (20-100 µg/mL) (*Tambe and Bhambar, 2014*). The total flavonoid content was measured using the aluminium chloride method, with quercetin employed as the standard reference compound, 5% sodium nitrite, 10% aluminium chloride, and 1 M sodium hydroxide, incubate it for periods of 5 to 6 minutes The absorbance was then measured at a different wavelength, 510 nm, to quantify the flavonoid content against a standard curve prepared from quercetin solutions of the same concentration range. (*Ozyurt et al., 2017*).

Enzyme assay

The sample's aqueous extract was pre-incubated with α-amylase (1 U/mL) for 30 minutes. After incubation, 1 mL of a 1% (w/v) starch was further incubated at 37°C for 10 min. The reaction was terminated by adding 1 mL of DNS reagent, prepared using 12.0 g of sodium potassium tartrate tetrahydrate dissolved in 8 mL of 2 M NaOH and 96 mM 3,5-dinitrosalicylic acid solution. The mixture was heated in a boiling water bath for 5 minutes. For comparison, blanks were prepared without the sample extract and amylase enzyme, where the enzyme was substituted with an equal volume of 20 mM sodium phosphate buffer containing 6.7 mM sodium chloride (pH 6.9 at 20°C). The absorbance was measured at 540 nm (*Bhutkar and Bhise, 2012*).

Estimation of minerals

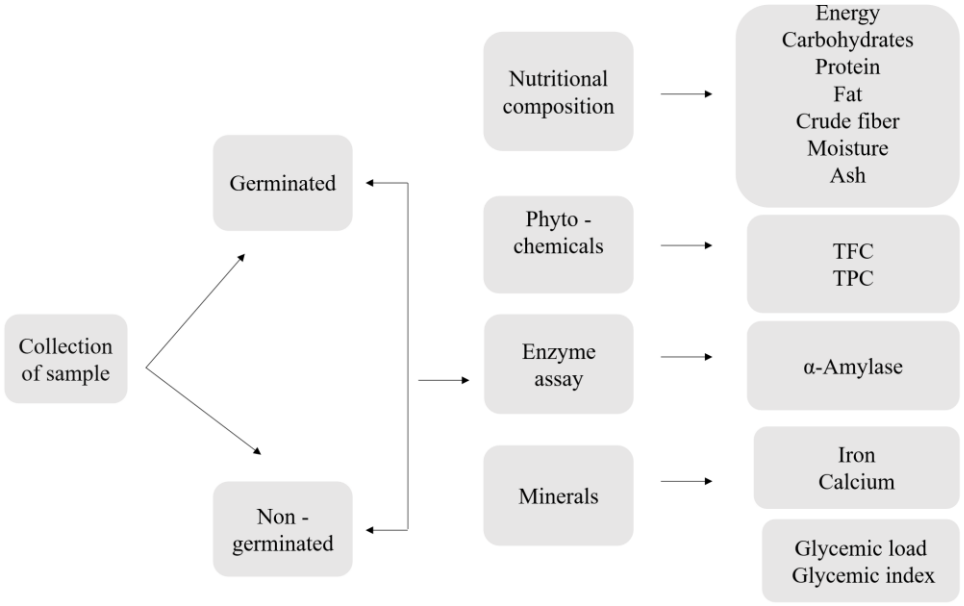
The iron concentration in the formulated sample was determined using the ammonium thiocyanate colorimetric method (*Goswami and Kalita 1988*), while calcium content was quantified through the EDTA titration technique, in which the endpoint was identified by a colour change from pink to blue (*Bird et al., 1961*).

Glycemic index and glycemic load

The glycemic index (GI) represents the rate at which carbohydrates from a food are digested and absorbed, subsequently raising blood glucose levels. In contrast, the glycemic load (GL) provides a more comprehensive measure by accounting for both the GI and the quantity of available carbohydrates in a standard serving, thereby offering a practical indication of the food's overall impact on blood sugar (*Augustin et al., 2015*).

Statistical analysis

The data are presented as mean values along with their corresponding standard deviations (SD). Statistical analyses were carried out using Microsoft Excel for data tabulation and graphical representation. A Student's t-test was performed to determine the level of significance, with a threshold of $P \geq 0.05$. The results were presented in tables and accompanied by discussion.



Flow chart 1: Nutritional analysis of developed product.

FLOW CHART

CLEANING

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SOAKING

↓

SPROUTING

↓

DRYING

↓

MILLING

↓

MIXING (INGREDIENTS)

↓

DOUGH PREPARATION

↓

MOULDING

↓

COOKING (STEAMING)

↓

COOLING AND DRYING

↓

STORAGE AND PACKAGING

Flow chart 2: Steps involved in the preparation of the developed product.

Table 1: Formulations of developed Product

Ingredients (g)	**C***	**T_1***	**T_2***	**T_3***
Wheat	50	50	50	50
Chickpea	40	30	20	25
Fenugreek seeds	10	5	5	5
Hibiscus	-	5	10	15
Microgreens	-	10	15	5
Total	100	100	100	100

*C-Control; *T_1- Trial 1; *T_2- Trial 2; *T_3- Trial 3

Result and discussion

Pre-processing technique

The raw, germinated, and dried weights of the selected ingredients after soaking and germination. Wheat (50 g) showed a moderate increase in weight after 12 hours of soaking and germination, reaching 56 g, before reducing to 47 g upon drying. Chickpea followed a similar trend, increasing from 50 g raw weight to 66 g after germination, and finally yielding 54 g upon drying. Fenugreek seeds exhibited the lowest weight changes, increasing slightly from 30 g to 32 g after germination, with a final dried weight of 27g as shown in Table 2. Microgreens demonstrated the highest weight values across all stages. Starting from 100 g of raw seeds, germination for 24 hours increased the weight to 112 g, followed by a dried yield of 75 g after harvesting increase in weight after germination is mainly due to water absorption during soaking and biochemical activation of metabolic processes and water uptake triggers enzymatic activity, mobilizing stored nutrients such as starch and proteins, which in turn leads to the synthesis of new metabolites. However, these observed differences in weight changes were statistically non-significant ($P \geq 0.05$), suggesting uniformity in germination and drying behavior across the selected ingredients.

Sensory evaluation

The developed product was assessed across three variations (T_1, T_2, T_3) and a control sample. Among these, T_2 achieved the highest scores for overall acceptability (7.2 ± 1.5), flavor intensity (7.27 ± 1.3), color (7.34 ± 1.5), texture (7.04 ± 1.2), appearance (7.0 ± 1.8), and taste (7.16 ± 1.2), indicating its superior sensory profile (Figure 3). The formulation incorporated hibiscus and green gram (microgreens), and the blends developed using germinated ingredients exhibited a darker color, consistent with the findings by Narwal and Yadav (2022).

The phenolic compounds present in hibiscus and microgreens were closely associated with attributes such as astringency, sourness, and bitterness (*Xiao et al., 2015*), which influenced the sensory characteristics of the product.

Table 2: Raw, Germinated, and Dried Weights of selected Ingredients.

Ingredients	**RW*** **(g)**	**Soaking (in hours)**	**GW*** **(g)**	**DW*** **(g)**
Wheat	50	12	56	47
Chickpea	50	12	66	54
Fenugreek seeds	30	12	32	27
Microgreens	100	24	112	75

*RW-Raw weight; *GW-Germinated weight; *DW-Dry weight; *(P≥0.05) NS (non-significance)

Table 3: Sensory Evaluation of the developed Product.

Sensory	**Appearance**	**Colour**	**Taste**	**Texture**	**Flavour**	**Overall Acceptability**
C	7 ± 1.5	6.92 ± 1.4	6.6 ± 1.8	6.44 ± 2.0	6.92 ± 2.0	6.78 ± 1.4
T_1	6.6 ± 1.4	6.8 ± 1.4	6.44 ± 1.8	6.46 ± 1.6	6.46 ± 1.6	6.66 ± 1.0
T_2	7 ± 1.8	7.34 ± 1.5	7.16 ± 1.2	7.04 ± 1.2	7.27 ± 1.3	7.2 ± 1.5
T_3	6.66 ± 1.3	6.8 ± 1.7	6.48 ± 1.6	6.88 ± 1.2	6.44 ± 1.7	6.62 ± 1.5

*C- Control; *T_1- Trial 1; *T_2- Trial 2; *T_3- Trial 3; Values are means ± standard deviations

Raw material (Fenugreek seeds, Wheat, Chickpea, Green gram, Hibiscus)

↓

Soaking

↓

Sprouting

↓

Drying

↓

Milling

↓

Standardization of the processing raw material

↓

Various shapes of the product - Control

Various shapes of the product - Sample

Flow chart 3: Preparation of noodles.

Figure 1: Hibiscus Drying Process

Figure 2: Green Gram Microgreens Growth and Processing

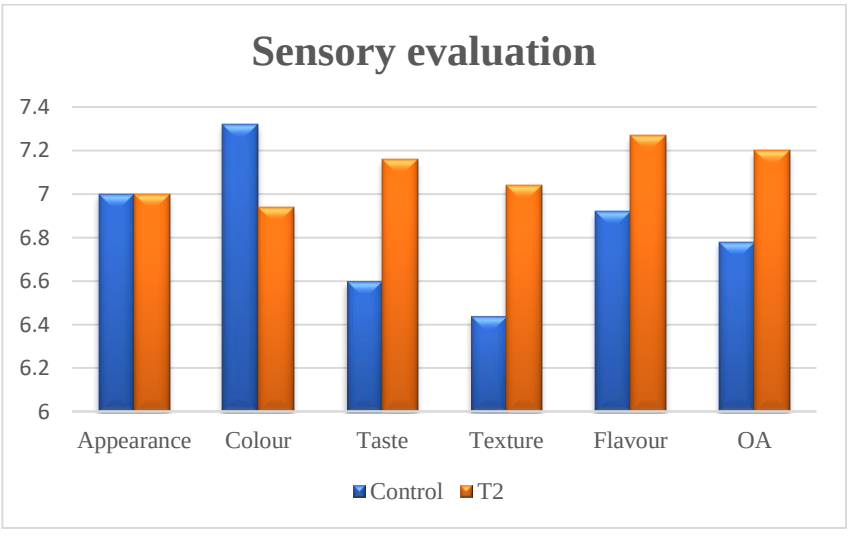

Figure 3: Sensory Evaluation of Developed Product.

Nutritional Composition

Germination resulted in notable improvements in the nutritional composition of the selected ingredients compared to the control, as presented in Table 4, although the differences were statistically non-significant ($P \geq 0.05$). Protein content was markedly higher in GFS (52.5 g) compared to its CFS (37.62 g). Similarly, Rahman *et al.* (2023) reported that germination can improve the protein content in wheat, millet, and legumes, and dietary fiber exhibited a substantial rise, with GCP recording the highest value (10.7 g) compared to CCP (7.5 g). Conversely, the carbohydrate content decreased in germinated samples, particularly in GFS (34.34 g) compared to its CFS (46.79 g), indicating a favorable trend for diabetes management (Madhumeha). In addition to these, HB contributed higher dietary fiber (3.0 g) and ash (8.25%), as observed in similar studies (Dahiya & Kaur, 2019). Meanwhile, microgreens provided superior protein (35.87 g) and energy (359.31 kcal), highlighting their complementary nutritional roles. Overall, germination enhanced protein and fiber while reducing carbohydrate levels, thereby optimizing the ingredients for both nutritional and Ayurvedic benefits. As shown in Table 5, the developed sample product (SP) demonstrated a superior nutritional profile compared to the control product (CP), particularly in terms of diabetes (Madhumeha) management. However, the differences were statistically non-significant $P \geq 0.05$. The SP exhibited lower energy (371.54 kcal) and carbohydrate content (70.91 g) relative to CP (399.86 kcal and 78.89 g, respectively), which is advantageous for controlling postprandial glucose levels. In contrast, the protein content (9.6 g) and crude fiber (10.8 g) were notably higher in SP compared to CP (7.8 g protein and 4.4 g fiber*). Fernandez et al. (2018) reported that an increase in protein and fiber is beneficial for enhancing satiety and slowing glucose absorption, thereby* improving glycemic control in individuals with diabetes (Madhumeha). Additionally, SP showed marginally higher ash (2.06%), iron (1.5 mg), and calcium (0.019 mg) values, contributing to improved mineral availability.

Table 4: Nutritional Composition of Selected Ingredients.

Sl.no	Nutrients	CW*	GW*	CCP*	GCP*	CFS*	GFS*	HB*	MG*
1.	Energy (kcal)	359.52	370.35	338.37	343.5	338.37	345.79	351.65	359.31
2.	Carbohydrates (g)	53.99	91.02	46.79	54.41	46.79	34.34	60.68	53.8
3.	Fat (g)	0.04	0.31	0.09	0.34	0.09	0.23	0.05	0.07
4.	Protein (g)	35.87	35.87	37.62	33.25	37.62	52.5	27.12	35.87
5.	Dietary fiber (g)	1.1	2.36	7.5	10.7	7.5	9.4	3.0	2.14
6.	Moisture (%)	1.01	1.18	0.82	1.10	0.82	0.84	0.90	0.87
7.	Ash (%)	6.8	5.45	4.0	3.45	4.0	5.0	8.25	7.25
P-value		0.23*		0.31*		0.08*		-	-

(n=2) *CW-Control wheat; *GW-Germinated wheat; *CCP-Control chickpea; *GCP-Germinated chickpea; *CFS-Control fenugreek seeds; *GFS-Germinated fenugreek seeds; *HB-Hibiscus; *MG-Microgreens; *(P≥0.05) NS (non-significance)

Table 5: Nutritional Composition of Developed Product.

Sl.no	Nutrient	CP* (g/100g)	SP* (g/100g)
1.	Energy (kcal)	399.86	371.54
2.	Carbohydrates (g)	78.89	70.91
3.	Fat (g)	5.9	5.5
4.	Protein (g)	7.8	9.6
5.	Crude fiber (g)	4.4	10.8
6.	Moisture (%)	1.01	1.13
7.	Ash (%)	2.0	2.06
8.	Iron (mg)	1.0	1.5
9.	Calcium (mg)	0.018	0.019
P-value		0.95*	

*CP- Control product; *SP- Sample product; *(P≥0.05) NS (non-significance)

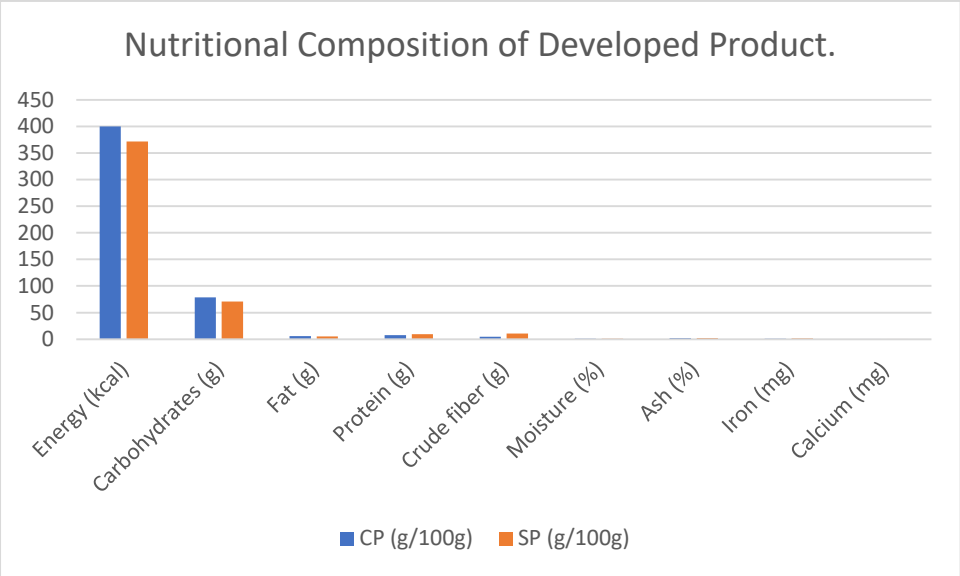

Figure 4: Nutritional Composition of Developed Product.

Phytochemicals

Phenolic compounds were present, evidenced by the development of a greenish-blue color, confirming their presence in both samples. The SP recorded higher flavonoids (90.0 µg) and phenols (80.0 mg) compared to the CP, 70.0 µg and 40.0 mg. Although these differences were statistically non-significant $P \geq 0.05$, the increase in TFC and TPC highlights the nutraceutical potential of the developed product. A similar study *(Bahadoran et al., 2013)* investigated that the total phenolic and flavonoid contents in plant-based food can also prevent the development of long-term diabetes (Madhumeha) complications, thereby improving its suitability for individuals with diabetes by offering enhanced antioxidant and glucose-regulating benefits.

Table 6: Quantitative Analysis of Phytochemicals in the Developed Product.

Sample	Flavonoids (ug)	Total Phenols (mg)
CP*	70.0	40.0
SP*	90.0	80.0
P-value	0.295	

*CP- Control product; *SP- Sample product; *(P≥0.05) NS (non-significance)

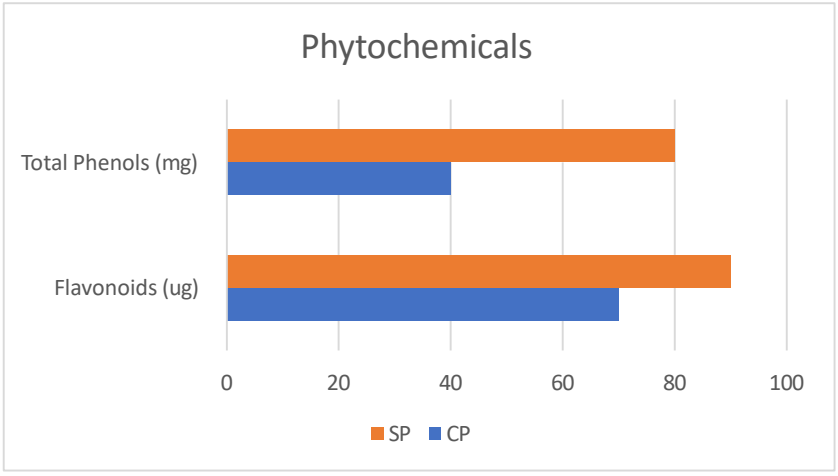

Figure 5: Quantitative Analysis of Phytochemicals in the Developed Product.

Enzyme assay

The amylase content varied between the two samples, with the CP containing 29.43 U/L and the SP containing 14.13 U/L. Amylase is an enzyme responsible for breaking down complex carbohydrates into simpler sugars for absorption. A lower amylase activity, as observed in SP, indicates slower starch breakdown, resulting in a more gradual release of glucose into the bloodstream. *(Tundis et al., 2010)* reported that Amylase enzymes involved in the digestion of carbohydrates, can significantly reduce the post-prandial increase of blood glucose and therefore can be an important strategy in the management of blood glucose level in type 2 diabetes. This controlled digestion helps prevent rapid spikes in blood sugar, supporting better glycemic management.

Table 7: Amylase Activity in the Developed Product.

Sample	Amylase (U/L)
CP*	29.43
SP*	14.13

*CP- Control product; *SP- Sample product

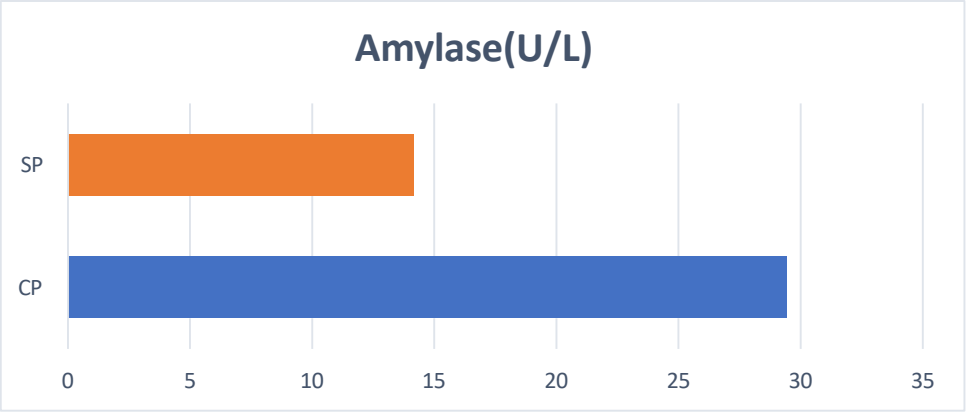

Figure 6: Amylase Activity in the Developed Product

Glycemic load

The glycemic load (GL) of the selected ingredients was calculated using glycemic index (GI) values reported by *Atkinson et al., (2008*). As shown in Table 9, the total GL of the non-germinated ingredients was 51.45, which decreased to 33.9 after germination. Wheat contributed the highest GL, reducing substantially from 40.95 in the non-germinated state to
24.29 in the germinated form. Chickpea also showed a moderate decrease from 5.4 to 4.6, while fenugreek seeds exhibited a negligible change, with values of 5.1 and 5.01. These results highlight that germination significantly reduces the overall glycemic load of the product, mainly due to changes in the carbohydrate profile of wheat. A similar study (Dirim et al., 2018) reported that the glycemic index subsequently decreased after sprouting in wheat. Since a lower GL is associated with improved blood glucose regulation, the germinated formulation demonstrates greater potential for supporting dietary management of type 2 diabetes (Madhumeha) compared to the non-germinated version.

Table 8: Glycemic Load of selected Ingredients.

Sl.no	Ingredients	Non-germinated	Germinated
1.	Wheat	40.95	24.29
2.	Chickpea	5.4	4.6
3.	Fenugreek seeds	5.1	5.01
Total		51.45	33.9

International tables of glycemic index and glycemic load values: 2008 Diabetes Care, 31(12), 2281–22

Shelf life

The shelf-life study of the developed product showed a gradual increase in moisture content, rising from 0.39% to 0.44% in the CP and from 0.31% to 0.39% in the sample product SP between the initial month and one month of storage. This indicates good stability under storage conditions, as lower moisture levels are known to inhibit microbial growth and enzymatic activity (*Zhang et al., 2017*). Consequently, the reduced moisture content contributed to maintaining freshness, extending shelf life, and preserving the health-promoting properties of the product.

Table 9: Shelf-life Study of Moisture Content (%) of the Developed Product.

Product	Initial month	1st month
CP*	0.39	0.44
SP*	0.31	0.39

*CP- Control product; *SP- Sample product

Figure 7: Storage of Developed Product for Shelf-Life (LDPE: Low-Density Polyethylene bags)

Conclusion

The developed product, prepared using germinated ingredients such as wheat, chickpeas, and fenugreek, along with functional components like hibiscus and microgreens, demonstrates potential in lowering blood glucose levels. This can be attributed to its low glycemic load, reduced amylase activity, and the presence of bioactive compounds, including phenols and flavonoids. These functional ingredients help in minimizing postprandial sugar spikes, while the phytochemicals play a role in reducing oxidative stress and supporting overall health. Thus, the product offers a healthier alternative for diabetic patients. Future research should focus on clinical validation, shelf-life enhancement, and large-scale studies. Integrating Ayurvedic principles with modern nutrition may further support the development of functional foods with therapeutic benefits.

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