Development and Characterization of Papaya Enriched Snack Bars for Diabetes Management

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ABSTRACT

The incidence of diabetes has been increased significantly in recent years attributed to sedentary lifestyle and associated behavioral factors. However, this condition can be effectively managed through targeted modifications in lifestyle and dietary patterns. In response to increased consumer demand for healthier snack foods, this study focused on development and characterization of papaya enriched snack bars providing both energy and functional bioactives simultaneously. Papaya pulp powder and papaya leaf powder were added in different concentrations to formulate papaya-based energy bars (T0–T3). Roasted chickpea powder, apricot paste, and date paste were used as base ingredients. The papaya pulp, papaya leaf and the developed papaya-based bars were evaluated for proximate composition, antioxidant potential, sensory qualities. The bars were also tested for in vitro inhibitory activity of α-glucosidase, α-amylase for the evaluation of antidiabetic potential. The findings indicated a significant difference in the proximate composition, antioxidant and antidiabetic potential of the bars. The bars with added papaya pulp and papaya leaf (T1–T3) had higher levels of ash and crude fiber and better antioxidant activity as compared to the control (T0). Amongst bars, T3 showed the highest antioxidant potential determined by DPPH and FRAP assay. The enzymes inhibition activity of bars revealed that T3 was more effective in inhibiting both α-glucosidase and α-amylase indicating the strongest antidiabetic potential. Conclusively, the addition of papaya pulp and leaf powder improved the functional and nutritional properties of chickpea-based bars, without affecting the sensory attributes, indicating their suitability in development of functional snacks.

Keywords: Papaya pulp powder; Papaya leaf powder; Hypoglycemic activity; Antioxidant potential; Functional snacks

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Introduction

Over the recent years, scientific research uncovering the underlying cause of diabetes mellitus has thrived considerably, led by the ultimate development of treatment strategies and effective prevention. Diabetes Mellitus (DM), a group of metabolic disorders is characterized by hyperglycemia, resulting either from decreased or impaired insulin production or action. Diabetes mellitus with chronic hyperglycemia damages vital organs, including the retina of the eye, heart and nervous system, the kidney, and the blood vessels (Alam et al., 2022). Multiple environmental factors are implicated in the onset of DM, including obesity, inflammation, physical inactivity, and genetic predisposition. Globally, DM shows an increasing health crisis, with a high prevalence rate in Asian, African, and Eastern Mediterranean regions (Saeedi et al., 2019). The International Diabetes Federation (IDF) reports that in 2024, about 11.1% of adults aged 20–79 years were living with diabetes worldwide, which is roughly 589 million people. This number is expected to increase further, reaching around 12.9% or 853 million individuals by 2050. The rising prevalence is mainly linked to factors such as urbanization, aging populations, physical inactivity, and increasing obesity rates, with the greatest burden observed in low- and middle-income countries (Genitsaridi et al., 2026).

Diabetes Mellitus has been strongly associated with oxidative stress, characterized by excessive production of reactive oxygen species resultant to chronic hyperglycemia. This ultimately affects glucose metabolism, triggering chronic inflammation leading to impairment of pancreatic β-cells. Pharmacological intervention and lifestyle changes along with antioxidant rich diet has shown the potential to lower oxidative damage and prevent vascular and heart problems in type 2 diabetes mellitus (T2DM). In this context, plant foods with antioxidant and antihyperglycemic properties are being considered as complementary therapies (Ansari et al., 2023).

Low- and very-low-carbohydrate diets have been widely evaluated for glycemic control and the management of T2DM, and have been associated with significant reduction in HbA1c levels, particularly emphasizing minimally processed foods (Goldenberg et al., 2021). Dietary strategies focusing on intake of phytonutrient dense foods with low-glycemic index offer metabolic advantages and may play significant role in the management of T2DM (Qiang et al., 2025). Low glycemic index diets manage postprandial glucose drive and lower insulin demand and have been indicated to improve fasting glucose and HbA1c (Peres et al., 2023). Moreover, plant components high in polyphenols have antioxidant activity and facilitate regulation of glucose signaling pathways, lower oxidative stress, which is a major risk factor in diabetes and associated complications (Martiniakova et al., 2025).

Among such plants, papaya has gained scientific attention for its potential to lower blood glucose levels due to its high content of fiber, vitamin C, saponins, and flavonoids and offer practical benefits because of its affordability, nutrient density, and availability (Zuhria Ismawanti et al., 2019). Papaya leaf extracts are promising functional components in glycemic management. Owing to their rich phytochemical profile, including polyphenols, flavonoids, and alkaloids papaya leaves can inhibit key carbohydrate-digesting enzymes α-amylase and α-glucosidase, increase insulin signaling, and decrease oxidative stress (Nyakundi et al., 2024).

Papaya leaves are rich in phenolics, flavonoids, alkaloids, and carotenoids, bioactive compounds showing potent antioxidant and anti-inflammatory effects have been associated with multiple antidiabetic mechanisms. A significant number of studies have illustrated modulation of glucose metabolism, enzyme inhibition, and lipid profile improvement across in-vitro and animal study

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models (Sharma et al., 2022; Nyakundi et al., 2024). Papaya leaf phytochemistry analysis revealed the presence of ferulic acid, saponins and quercetin compounds. These compounds have shown strong antioxidant and anti-inflammatory activity in α-amylase and α-glucosidase inhibition assays in-vitro (Chaijan et al., 2024).

Research studies demonstrated the potential of papaya leaf extracts in suppressing carbohydrate metabolizing enzymes, thereby, reducing postprandial blood glucose. The papaya leaf extracted in methanol showed elevated α-glucosidase inhibition activity. This leaf fraction focused on a direct mechanistic pathway for glycemic control. An in vivo study for the evaluation of antidiabetic effect of papaya leaf extract highlighted that methanolic papaya leaf extract inhibited the α-glucosidase activity in rats (Abubakar et al., 2019). These findings highlighted the beneficial role of papaya leaf in making different snack bars or functional products, which will help manage T2DM. Despite of bitter taste of papaya leaf, it has exceptional therapeutic use positively impacting plasma insulin, low density lipoproteins and triglycerides (Sobia et al., 2016). *Carica papaya* contains various chemical compounds, such as caffeic acid, myricetin, rutin, quercetin, α-tocopherol, papain, and kaempferol, exhibit significant antioxidant properties (Kong et al., 2021). These compounds are found in different parts of the papaya plant, including the pulp, leaves, and seeds, possess notable antioxidant properties, along with antihypertensive, hypoglycemic, and hypolipidemic effects (Santana et al., 2019).

The increasing global prevalence of T2DM, the role of dietary management in glucose regulation and growing consumer demand for functional products emphasized the urgent need for the development of functional snack bars. Papaya pulp and papaya leaves, with their rich phytochemical profile, combined with other low-glycemic, antioxidant-rich ingredients such as chickpea powder, dried apricot paste, and dates, can be a promising strategy for functional snack formulations. In this context this study aimed to formulate papaya enriched snack bars by incorporating papaya pulp and papaya leaf into chickpea, apricot and date-based bars. Additionally, the study aimed to assess the nutritional composition, antioxidant properties and antidiabetic potential of the formulated bars. This research intends to provide an affordable and functional food-based strategy for glucose regulation in diabetes mellitus management.

Materials & Methods

Procurement of Materials

Papaya pulp, papaya leaves roasted chickpeas, dates, and dried apricots were procured from local organic source. Analytical grade chemicals were used to evaluate the proximate composition, antioxidant and antidiabetic potential.

Development of Papaya-Enriched Bars

Four formulations of snack bars were developed to study the effect of incorporation of papaya pulp and papaya leaf powder on the nutritional, antioxidant and antidiabetic potential of the bars (Table 1). Chickpeas were grinded to powder using an electric grinder, and combined with apricots paste and date paste.

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Table 1: Formulations of papaya pulp and leaf-based bars

Ingredients	**T0**	**T1**	**T2**	**T3**
Chickpea Powder (g)	3.5	3.2	2.95	2.7
Papaya Pulp Powder (g)	0	0.25	0.5	0.75
Papaya Leaf Powder (g)	0	0.05	0.05	0.05
Apricot Paste (g)	3	3	3	3
Date Paste (g)	3.5	3.5	3.5	3.5
Total weight (g)	10	10	10	10

Nutritional Evaluation

The proximate composition of papaya pulp powder, papaya leaf powder and the papaya-based snack bars including the ash content, moisture content, crude fat, crude protein, and crude fiber were evaluated according to AACC (2000). The nitrogen-free extract (NFE) was calculated by method of difference.

Extract Preparation

Ethanolic extracts were prepared by weighing 10 g of powdered sample into a centrifuge tube and adding 100 mL of Ethanol. The mixture was sonicated for 20 minutes in an ultrasonic bath to improve the extraction of bioactive compounds, progressing into centrifugation at 3000 rpm for 10 minutes. The supernatant was carefully collected and used as the working extract for phytochemical and antioxidant assays. All extractions and analyses were performed in triplicates.

Analysis of Antioxidants

The antioxidant capacity of papaya-based bars was evaluated using the DPPH radicle scavenging assay and Ferric Reducing Antioxidant Power (FRAP) assay. DPPH activity was determined following the method described by Brand-Williams et al. (Brand-Williams et al., 1995). Briefly, 2 mL of sample was mixed with 2 mL of 0.1 mM DPPH solution in ethanol and incubated in the dark at room temperature for 30 mins. The absorbance was measured at 517 nm using a spectrophotometer. The FRAP assay was performed according to Benzie and Strain (Benzie and Strain, 1996). A 40 μL aliquot of sample extract was mixed with 1.8 mL of FRAP reagent, consisting of 10 mM TPTZ in 40 mM HCl, 20 mM $FeCl_3$ and 0.3 M acetate buffer (pH 3.6). The mixture was incubated and absorbance was recorded at 595 nm using Trolox as standard.

Phytochemical Analysis

The phytochemical analyses of all the bars were performed in triplicates (Usman et al., 2009). The phenol content of bars was analyzed by using Folin Ciocalteu method. 0.5 mL of extract and 2.5 mL of Folin reagent were mixed in a test tube. After 5 minutes, 2.5 mL of sodium carbonate was added. Then, test tubes were incubated in dark for 45 minutes. After incubation, absorbance was measured by using spectrophotometer at 765 nm. Gallic acid was used as a standard. The total flavonoid content was measured by using aluminum chloride colorimetric method. A 500 μL sample extract was added to 2 mL of water and 150 μL of 5% $NaNO_2$ and the solution was

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kept at room temperature for 6 mins. Afterward, 150 μL of 10% of $AlCl_3$ was added then again incubated for 6 mins. This was followed by the addition of 2 mL of 4% NaOH. Immediately absorbance was measured at 450 nm. Quercetin was used as a standard.

Analysis of Enzyme Inhibition Assays

The anti-diabetic potential of papaya pulp powder and papaya leaf powder snacks bars were assessed using enzyme assays including α-amylase inhibition assay and α-glucosidase inhibition assay. For α-amylase inhibition assay, 100 μL of sample was added in the solution of 0.1 M phosphate buffer (pH 6.8 was maintained) and α-amylase enzyme and incubated for 10 minutes at room temperature. After incubation DNSA reagent was added and the mixture was boiled for 5 minutes to stop the reaction and the absorbance was measured at 540 nm. For α-glucosidase inhibition assay, 100 μL of sample was added in the solution of 0.1 M phosphate buffer maintained at pH 6.9 followed by addition of 50 μL α-glucosidase enzyme. The mixture was incubated for 20 mins at room temperature. Afterwards, 10 mM of PNPG substrate was added and again incubated at 37 °C for 30 mins. Afterwards, 1 M sodium carbonate was added to stop the reaction and absorbance was measured at 405 nm.

Physical Analysis

The physical properties of bars including color and texture were analyzed by using the standard method of AACC (2000). Texture analysis included the measurement of hardness, springiness and cohesiveness of bars by using a textural analyzer. A digital colorimeter was used for the for measurement of L^* value indicating lightness, a^* value indicating positive red and negative green, b^* value indicating positive yellow and negative blue.

Sensory Evaluation

The sensory evaluation of all formulations was carried out using a 9-point hedonic scale by a panel of 20 semi-trained individuals including students from different departments and teachers. The parameters assessed include texture, appearance, mouthfeel, taste, aroma, aftertaste, and overall acceptability.

Statistical Analysis

All the data collected in triplicates was subjected to statistical analysis. Descriptive statistics with mean and standard deviations and one way ANOVA was carried out using IBM SPSS statistics 25 at confidence level of 95%. For post-hoc test, LSD was used to scrutinize the intra group variations.

Results

Proximate Analysis of Papaya Pulp and Leaf Powder

The proximate composition of papaya leaf and pulp powder was analyzed to evaluate the nutritional profile (Figure 1). The outcomes showed that the moisture content of papaya pulp are slightly higher than papaya leaf powder 1.07% and 1.02% respectively. The ash content of papaya pulp powder was higher than papaya leaf powder. The proximate analysis of bars (Table 2) revealed a statistically significant difference in moisture, ash, crude protein, crude fat, crude fiber, and nitrogen-free extract due to enrichment with papaya pulp and papaya powder. The moisture content ranged from 38% in T0 to 39% in T1 with a slight variation across treatments. Crude protein content was highest in the control bar (T0: 5.62%) and decreased slightly but significantly in papaya-enriched formulations (T1: 5.32%, T2: 5.33%, T3: 5.41%), which is due to substituting a portion of chickpea powder the primary protein source in the formulation with papaya pulp powder. Crude fat content increased progressively from T0 (1.40%) to T3 (1.63%). The crude fat content across all formulations remained low, which is advantageous from a diabetes management perspective, as low-fat functional foods are preferred in the dietary management of cardiometabolic risk associated with T2DM. Crude fiber content was significantly higher in T1 and T2 (1.41% each) compared to T0 (1.02%) and T3 (1.38%). Ash content was highest in T0 (3.65%) and declined in papaya-enriched bars, likely reflecting the higher mineral density of roasted chickpea powder relative to papaya pulp powder. The proximate composition of papaya leaf powder exhibited considerably higher ash (16.3%), protein (14.27%), and fiber (16.50%) compared to papaya pulp powder, confirming that leaf powder is nutritionally denser.

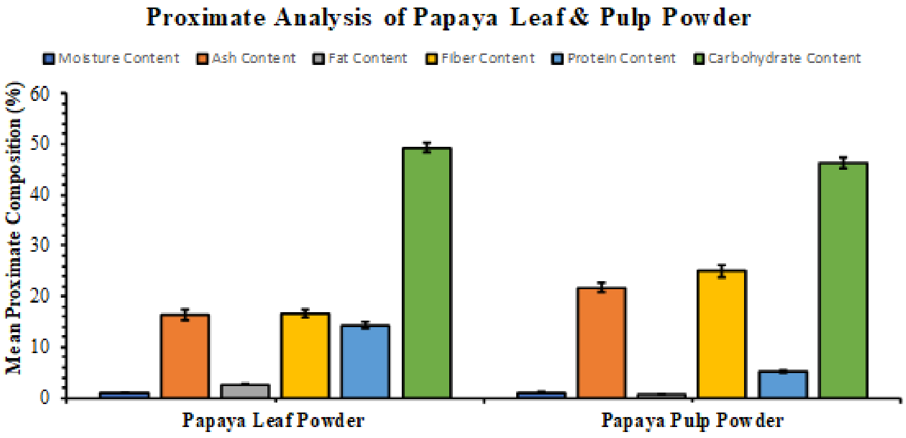

Figure 1: Proximate Analysis of Papaya Leaf and Pulp powder along with the variations

Table 2: Proximate composition of papaya pulp and leaf-based bars

Treatment	Moisture (%)	Ash (%)	Protein (%)	Fat (%)	Fiber (%)	Carbohydrate (%)
T0	38.75±0.07c	3.65±0.02a	5.62±0.03a	1.40±0.01d	1.02±0.03c	48.26±0.04c
T1	39.23±0.09b	2.33±0.01d	5.32±0.02d	1.52±0.10c	1.41±0.01a	50.19±0.15b
T2	39.80±0.17a	2.65±0.01c	5.33±0.02c	1.56±0.09b	1.41±0.02a	48.11±0.11d
T3	38.52±0.15d	2.66±0.01b	5.41±0.03b	1.63±0.02a	1.38±0.02b	50.40±0.18a

Values are represented as mean ± SD (n = 10). Means with different letters varied significantly. T0 = 0% papaya pulp and leaf powder, T1 = 2.5% papaya pulp powder, T2 = 5% papaya pulp powder, T3 = 7.5% papaya pulp powder. All the formulations have same 0.5% papaya leaf powder content.

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Antioxidant Activity

The antioxidant potential and phytochemical composition of papaya pulp & leaf powder (Table 3) and papaya-based snack bars (Table 4) assessed through DPPH radical scavenging activity, ferric reducing antioxidant power (FRAP), total phenolic content (TPC), and total flavonoid content (TFC), demonstrated a clear and progressive enhancement with increasing papaya ingredient incorporation. The DPPH radical scavenging activity increased significantly from 40.80% in T0 to 79.98% in T3, while FRAP values rose from 0.64 to 0.96 μmol TE/g across the same range. TPC and TFC followed parallel dose-dependent trends, with T3 recording the highest values of 1.56 mg GAE/g and 70.21 mg QE/g, respectively, compared to T0 (1.25 mg GAE/g; 35.63 mg QE/g). Antioxidant activity was much higher in treatments that contained papaya powder and papaya leaf powder than in the control group. The polyphenolic and flavonoid chemicals found naturally in papaya leaf and pulp were directly responsible for this enhancement, as they enhanced the bars' capacity to scavenge radicals.

Table 3: Antioxidant properties of papaya pulp and leaf powder

Powders	TPC (mg GAE/g)	TFC (mg QE/g)	DPPH (% inhibition)	FRAP (μmol TE/g)
PLP	1.97±0.01	271.7±0.00	84.70±0.04	3.47±0.01
PPP	1.89±0.01	268.56±0.00	86.44±0.14	3.40±0.02

Values are represented as mean ± SD (n = 10). Means with different letters varied significantly. PLP = papaya leaf powder; PPP = papaya pulp powder

Table 4: Antioxidant properties of papaya pulp and leaf-based bars

Treatments	TPC (mg GAE/g)	TFC (mg QE/g)	DPPH (% inhibition)	FRAP (μmol TE/g)
T0	1.25±0.00d	35.63±0.01d	40.80±0.03d	0.64±0.06d
T1	1.39±0.00c	57.55±0.00c	58.09±0.11c	0.65±0.01c
T2	1.47±0.00b	60.71±0.01b	75.50±0.03b	0.83±0.01b
T3	1.56±0.03a	70.21±0.00a	79.98±0.01a	0.96±0.00a

Values are represented as mean ± SD (n = 10). Means with different letters varied significantly. T0 = 0% papaya pulp and leaf powder, T1 = 2.5% papaya pulp powder, T2 = 5% papaya pulp powder, T3 = 7.5% papaya pulp powder. All the formulations have same 0.5% papaya leaf powder content.

Enzyme Inhibition Assay

α-Amylase Inhibition Assay

Among powders, papaya leaf powder has shown (Table 5) a potent increase in α-Amylase inhibition activity of bars (70.2%) as compared to papaya pulp powder which has shown a mild inhibition in enzyme activity (18.7%). The papaya enriched snack bars (Table 6) have shown mild to moderate increase in inhibition percentage by reducing starch digestion. The mild to moderate trend was due to the less amount of papaya leaf powder in the bars. The findings of α-amylase inhibition activity illustrated the remarkable difference between T0 and other

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treatment groups. T0 with no addition of papaya pulp and papaya leaf has the lowest enzyme inhibition activity among all snack bars.

Table 5: α-Amylase Inhibition Assay of papaya pulp and leaf powders

Powders	**Mean Absorbance**	**% Inhibition**
PLP	0.41 ± 0.01	70.2 ± 1.5
PPP	0.86 ± 0.02	18.7 ± 0.7

Values are represented as mean ± SD (n = 10). Means with different letters varied significantly. PLP = papaya leaf powder; PPP = papaya pulp powder

Table 6: α-Amylase Inhibition Assay of papaya pulp and leaf-based bars

Treatments	**Mean Absorbance**	**% Inhibition**
T0	0.93 ± 0.02	10.2 ± 0.5d
T1	0.81 ± 0.01	22.4 ± 0.8c
T2	0.77 ± 0.02	27.3 ± 0.9b
T3	0.74 ± 0.01	30.1 ± 1.0a

Values are represented as mean ± SD (n = 10). Means with different letters varied significantly. T0 = 0% papaya pulp and leaf powder, T1 = 2.5% papaya pulp powder, T2 = 5% papaya pulp powder, T3 = 7.5% papaya pulp powder. All the formulations have same 0.5% papaya leaf powder content.

α-Glucosidase Inhibition Assay

The findings of α-glucosidase inhibition assay of papaya pulp & leaf powders, and papaya-based bars, have been represented in Table 7 and 8, respectively. The enzyme inhibition results of individual powders revealed that leaf powder has 70.2% α-amylase inhibition and 78.1% α-glucosidase inhibition, substantially greater than pulp powder (18.7% and 24.8%, respectively). The results demonstrated a consistent and significant dose-dependent increase in inhibitory activity across both enzyme assays as the proportion of papaya pulp powder increased from T0 to T3. For α-amylase inhibition, values increased from 10.2% in T0 to 30.1% in T3, while α-glucosidase inhibition progressed from 12.1% in T0 to 37.0% in T3. The impact of papaya pulp powder is more prominent in α-glucosidase assay. All the snack bars showed almost same trend as of alpha amylase. T0 bar showed lowest α-glucosidase inhibition value. The bars supplemented with papaya leaf powder and papaya pulp powder indicated gradually increased inhibition values. Inhibition values progressively increased from T1 (28.3%) to T3 (37%).

Table 7: α-Glucosidase Inhibition Assay of papaya pulp and leaf powders

Powders	**Mean Absorbance**	**% Inhibition**
PLP	0.39 ± 0.01	78.1 ± 1.4
PPP	0.90 ± 0.02	24.8 ± 0.8

Values are represented as mean ± SD (n = 10). Means with different letters varied significantly. PLP = papaya leaf powder; PPP = papaya pulp powder

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Table 8: α-Glucosidase Inhibition Assay of papaya pulp and leaf-based bars

Treatments	Mean Absorbance	% Inhibition
T0	1.00 ± 0.02	12.1 ± 0.6d
T1	0.88 ± 0.02	28.3 ± 1.0c
T2	0.84 ± 0.01	33.5 ± 1.1b
T3	0.80 ± 0.02	37.0 ± 1.2a

Values are represented as mean ± SD (n = 10). Means with different letters varied significantly. T0 = 0% papaya pulp and leaf powder, T1 = 2.5% papaya pulp powder, T2 = 5% papaya pulp powder, T3 = 7.5% papaya pulp powder. All the formulations have same 0.5% papaya leaf powder content.

Physical Characteristics

The findings of physical parameters including texture and color of papaya-based bars have been shown in Table 9 and 10. All the sample bars showed almost same hardness level. The addition of papaya pulp or leaf powder did not significantly alter the bars hardness. Texture analysis (Table 9) revealed that hardness values were remarkably consistent across all formulations (approximately 3.19–3.20 × 10^5 units), indicating that the progressive substitution of chickpea powder with papaya pulp powder at levels up to 7.5% did not significantly alter the structural integrity of the bars. This is a favorable finding, as hardness is a critical quality attribute for snack bars, affecting consumer perception, ease of consumption, and product shelf stability. The inclusion of 0.5% PLP across all treatment bars may have contributed a minor structural reinforcement effect due to its fiber content, though the concentration was too low to produce statistically discernible differences in hardness.

Cohesiveness and adhesiveness showed more notable variation, with T0 exhibiting the highest cohesiveness (12.7 × 10^2), which declined substantially in T1 and T2 before partially recovering in T3 (6.37 × 10^2). This pattern suggests that the interaction between papaya pulp powder and the date-apricot paste matrix alters the internal binding forces within the bar structure. Adhesiveness was highest in T3 (3.44 × 10^2), potentially reflecting the increased moisture-retaining properties of papaya pulp at higher inclusion levels, which can enhance surface stickiness. These textural differences, while statistically significant, fall within a range that would not substantially compromise the mechanical performance of the bars as consumer products. Color analysis (Table 10) demonstrated a systematic and progressive decrease in lightness (L^*) from T0 (27.97) to T3 (19.63), alongside reductions in both the redness (a^*) and yellowness (b^*) values. The shift in a^* values from positive (reddish, T0: 5.50) to lower positive values in treated bars reflects the masking of the reddish-brown tones of date and apricot paste by the greenish contribution of leaf powder.

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Table 9: Texture analysis of formulations

Treatments	**Hardness** ($\times 10^5$)	**Cohesiveness** ($\times 10^2$)	**Adhesiveness** ($\times 10^2$)
T0	3.19 ± 0.01	12.7 ± 0.4	2.27 ± 0.1
T1	3.19 ± 0.02	3.18 ± 0.2	1.74 ± 0.1
T2	3.19 ± 0.01	3.18 ± 0.1	1.73 ± 0.1
T3	3.20 ± 0.02	6.37 ± 0.3	3.44 ± 0.2

Values are represented as mean ± SD (n = 10). Means with different letters varied significantly. T0 = 0% papaya pulp and leaf powder, T1 = 2.5% papaya pulp powder, T2 = 5% papaya pulp powder, T3 = 7.5% papaya pulp powder. All the formulations have same 0.5% papaya leaf powder content.

Table 10: Color analysis of formulations

Treatments	**L* (lightness)**	**a* (red/green)**	**b* (yellow/blue)**
T0	27.97 ± 2.35	5.50 ± 0.40	14.73 ± 0.99
T1	22.23 ± 3.79	3.83 ± 1.04	11.63 ± 2.33
T2	21.50 ± 3.17	3.80 ± 0.77	11.03 ± 1.99
T3	19.63 ± 1.03	3.63 ± 0.15	9.93 ± 0.66

Values are represented as mean ± SD (n = 10). Means with different letters varied significantly. T0 = 0% papaya pulp and leaf powder, T1 = 2.5% papaya pulp powder, T2 = 5% papaya pulp powder, T3 = 7.5% papaya pulp powder. All the formulations have same 0.5% papaya leaf powder content.

Figure 2: Papaya pulp and leaf–based energy bars

Sensory Evaluation

The sensory evaluation included the parameters like texture, color, taste, aroma, aftertaste and overall acceptability (Figure 3). The sensory evaluation, conducted on a 9-point hedonic scale by a panel of 20 semi-trained assessors, revealed that consumer acceptability was well-maintained

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across all formulations, with T1 and T2 achieving the most favorable scores. The control bar (T0) achieved the highest scores for taste and overall acceptability (score 8), consistent with its familiar flavor profile from date, apricot, and chickpea, without the slightly bitter and astringent notes introduced by papaya leaf powder. T1, with moderate papaya incorporation (2.5% pulp + 0.5% leaf), achieved high overall acceptability (score approximately 7.5), indicating that the functional enhancement achieved at this level can be delivered without meaningful compromise to sensory quality. This represents a particularly important practical finding: T1 demonstrates the feasibility of delivering measurably improved antioxidant activity (+17.29% DPPH over T0) and enzyme inhibition (+12.2% α-glucosidase over T0) while maintaining consumer acceptability comparable to control. T3, which exhibited the strongest functional profile across all biochemical parameters, demonstrated a slightly lower but still acceptable overall acceptability score.

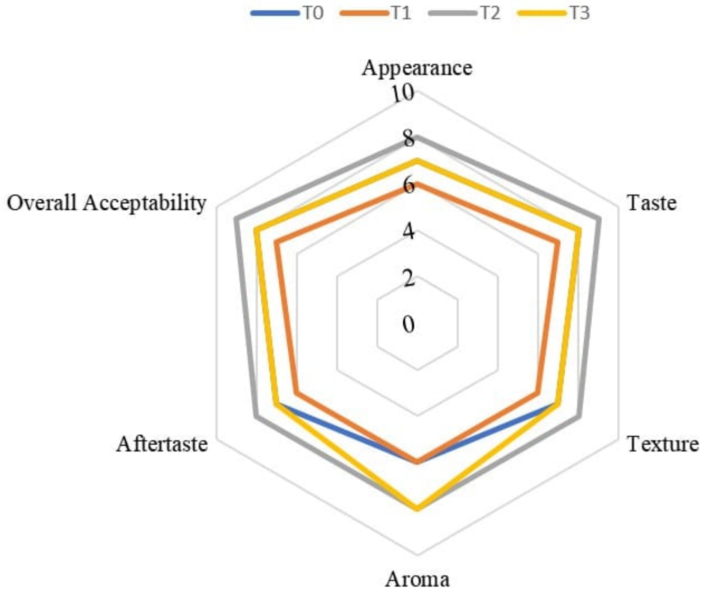

Figure 3: Sensory evaluation of papaya pulp and leaf-based bars

Discussion

Functional snack bars are innovative products with enhanced bioactive and nutritional potential that are perfect to consume for both children and adults. The development of customers interest related to food products has changed since consumer preferred the products made from natural ingredients that offer health benefits. The use of ingredients with bioactive potential and exhibiting anti-inflammatory and anti-oxidative properties influence the cellular and physiological activities in the body and can impart positive influence on health and well-being. Given the increasing burden of T2DM due to excessive caloric intake, sedentary lifestyle and insulin resistance, extensive research is required that how dietary strategies can complement pharmacological interventions. Development of snack foods incorporated with bioactive ingredients are a promising strategy and is consumer acceptable. In current study, functional snack bars were developed containing roasted chickpea powder, date and apricot paste as a base ingredient enriched with papaya pulp powder and papaya leaf powder. The findings revealed that inclusion of papaya leaf and papaya pulp influenced the nutritional, physical and bio-functional potential of the developed bars.

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The papaya-based bars were evaluated for their proximate composition. This study's outcomes revealed that the treatment bars showed the elevated moisture content due to increase in papaya pulp powder. Similar findings were reported that as the proportion of fruit pulp increase in the bars, the moisture content of the bars also increased. This increase was due to the fiber content present in the bar which enhanced the water binding capacity of the bars (Karim et al., 2024). A study based on fruit-based snack bars reported that bars made from papaya and banana showed the moisture content of 7.8%–10.8%. This showed a positive correlation with the fruit pulp used in that bar (Ikuomola et al., 2017). The papaya leaf contributed to the high ash content in the study as compared to the papaya fruit pulp and seeds. This showed that the leaf contributed to the high mineral content due to accumulation of minerals in their vegetative tissues (Moses and Olanrewaju, 2018). For the protein content, the previous research on nutritional assessment of papaya pulp and leaf showed that the papaya leaf has the highest protein content as compared to the pulp (Kanadi et al., 2021). These studies emphasized that the papaya leaf concentration present in our formulations contributed to protein content in the bars. For fat concentration, our finding reports an increase in fat content with increase in papaya pulp concentration in snack bars. The previous research on nutritional assessment of papaya pulp and leaf showed that the papaya leaf has the highest protein content as compared to the pulp (Kanadi et al., 2021). These studies emphasized that the papaya leaf concentration present in our formulations contributed to protein content in the bars. The carbohydrate content decreased as the base ingredient wheat flour and chickpeas decreased in the formulations. The bars containing no any functional ingredient but the base ingredient chickpea powder contributed to the high carbohydrate content (Bautista-Villarreal et al., 2025). The study on snack bar contained chickpea powder showed the highest carbohydrate content of 50% in the bar.

The antioxidant assay revealed that with increase in concentration in bars (T1–T3), a progressive increase in scavenging activity was observed, signifying that phenolics and flavonoids in papaya directly contribute to functional bar's ability to neutralize radicals. Papaya's bioactives were effective in increasing the antioxidant activity of the developed bars. Likewise, Papaya pulp and leaf extracts present in formulations showed significant reducing capacity when assessed by FRAP. Multiple findings reported the strong DPPH radical scavenging activity of papaya pulp and leaf extracts (Asaduzzaman et al., 2020). Previous studies have reported that the addition of papaya pulp in the formulations exhibited the high DPPH scavenging activity (Addai et al., 2016). Another study reported that bars containing dried papaya pulp retained more of its scavenging capacity and an excellent antioxidant source (Jeon et al., 2022). As papaya powders are rich sources of phenols and other bioactive compounds. These compounds enhanced the scavenging activity of free radicals when added in bars. The total phenolic content varied in previous studies according the extraction method, part of papaya used and the type of papaya. The TPC content in those bars ranged from 235–2070 mg GAE/100g. The highest Phenolic content was seen in the bars containing papaya leaf followed by papaya seeds and pulp (Sharma et al., 2022). As far the flavonoid content is concerned, the control group showed the lowest flavonoid content as compared to the papaya enriched functional bars. High levels of quercetin and kaempferol present in papaya contribute to antioxidant potential of functional snack bars (Nugroho et al., 2017). Our findings are consistent with the well-characterized phytochemical richness of *Carica papaya*, which contains phenolic acids including chlorogenic, ferulic, caffeic, and myricetin, alongside flavonoids such as quercetin and kaempferol, and other bioactive compounds including carotenoids and tocopherols. Papaya leaf powder (84.70%) demonstrated markedly superior antioxidant activity compared to papaya pulp powder (86.44%), and its incorporation at even the low concentration of 0.5% contributed meaningfully to the antioxidant enhancement observed across T1 to T3.

The in vitro antidiabetic potential of the bars was assessed via inhibition of α-amylase and α-glucosidase, two key carbohydrate-hydrolyzing enzymes that regulate the rate of glucose absorption in the gastrointestinal tract. Inhibition of these enzymes is a clinically validated mechanism for reducing postprandial hyperglycemia, analogous in principle to the pharmacological action of acarbose, a first-line antidiabetic agent. The enzymatic inhibition assay showed that the papaya enriched bars significantly inhibited the activity of both α-amylase and α-glucosidase. Similar studies demonstrated that papaya leaf and pulp extracted in ethanol showed high α-amylase inhibition capacity (Peres et al., 2023). Although these values reflect moderate inhibition relative to the highly purified extracts commonly reported in isolated phytochemical studies, it is essential to interpret them in the context of a complex food matrix where bioactive compounds are embedded within a macronutrient-dense environment that inherently moderates bioavailability. Notably, T3 consistently exhibited superior inhibition across both enzymes, confirming that higher papaya pulp concentrations deliver greater antidiabetic functional activity. The impact of papaya pulp powder is more prominent in α-glucosidase assay. This indicated that papaya pulp powder remarkably interacts with α-glucosidase enzyme as compared to α-amylase. So, in both α-amylase and α-glucosidase inhibition assay, papaya leaf powder was the primary driver to inhibit the activity of these enzymes (Abubakar et al., 2019). The sensory evaluation revealed that most participants liked the T0 and T1 in terms of taste, aftertaste and overall acceptability. Other characteristics like texture, aroma and appearance did not show any major difference in all the treatment and control groups. The control group showed the highest viscosity. Moving towards treatments the value of viscosity reduced. When we talk about the adhesiveness property of the bars, T3 shows highest values. Other treatment groups also showed low score in contrast to the T0 group. The control bar showed slight red color and treatments bar indicated green one due to papaya leaf powder. The color of control bar is moderately yellow as there are no papaya pulp and leaf in it. Overall, bars containing papaya pulp powder and leaf powder showed highest antioxidative capacity, phenol contents, flavonoid content, strong in-vitro antidiabetic potential and good overall sensory acceptability.

Conclusion

This study successfully developed and characterized four papaya-enriched snack bar formulations incorporating papaya pulp powder and papaya leaf powder alongside roasted chickpea powder, apricot paste, and date paste as a functional food base. The findings demonstrate that progressive incorporation of papaya derivatives significantly and dose-dependently enhances the antioxidant capacity, total phenolic and flavonoid content, and in vitro antidiabetic enzyme inhibitory activity of the bars, with T3 achieving the highest functional performance across all biochemical parameters. Physical characterization confirmed the structural integrity of all formulations, with hardness values maintained consistently despite compositional variation. Sensory evaluation identified T1 as the optimal balance point between functional enrichment and consumer acceptability, achieving meaningfully improved antioxidant and enzyme inhibitory properties while maintaining overall acceptability comparable to control. These findings suggest papaya-enriched snack bars as affordable, accessible, and nutritionally enhanced functional foods with antioxidant and antidiabetic potential relevant to the dietary management of T2DM.

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