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STUDY ON "FORMULATIONANDDEVELOPMENTOFLOWGLYCEMIC INDEX COOKIES USING SOUR DOUGH AND ABC PULP FOR DIABETES MELLITUS"

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ABSTRACT

Diabetes mellitus is a major global health concern worldwide, necessitating the development of functional foods with a low glycemic index (GI) to support glycemic management. This study aimed to formulate and evaluate low-GI cookies using sourdough fermentation and composite ABC pulp (apple, beetroot, and carrot) as natural sources of dietary fiber and bioactive compounds. Five formulations were prepared: a conventional control (T0), sourdough-only cookies (T1), and sourdough cookies containing 10%, 20%, and 30% ABC pulp (T2–T4).

Proximate composition, dietary fiber, in vitro starch digestibility, estimated glycemic index (eGI), physical characteristics, and sensory acceptability were assessed using standard AOAC and Englyst methods. Sensory quality was evaluated by 30 semi-trained panelists using a 9-point hedonic scale. Incorporation of sourdough and ABC pulp significantly enhanced the nutritional profile of the cookies. Total dietary fiber increased from 2.45% in the control to 8.92% in T4, while resistant starch increased from 4.21% to 12.67%.

The estimated glycemic index decreased markedly from 72.45 (high GI) in the control to 52.34

(low GI) in T4. Although higher ABC levels improved functional properties, T2 (10% ABC pulp) demonstrated the most favorable balance between glycemic reduction, texture, and overall sensory acceptability. The strong negative correlation between dietary fiber and eGI (r = -0.96) confirmed the role of fiber enrichment in lowering glucose availability efficiently. The study concludes that sourdough fermentation combined with ABC pulp is an effective strategy for developing nutritionally enhanced, low-GI cookies suitable for diabetic and health-conscious consumers while promoting value addition through fruit and vegetable by-product utilization.

KEYWORDS: Diabetes mellitus; Low glycemic index; Sourdough fermentation; ABC pulp; Functional foods; Dietary fiber.

INTRODUCTION

About the study

This study was undertaken to formulate and evaluate a functional bakery product, namely low glycemic index cookies, through the incorporation of sourdough fermentation and ABC (apple, beetroot, and carrot) pulp into conventional cookie formulations. The research was motivated by the growing global prevalence of diabetes mellitus and the increasing demand for functional foods that can support glycemic control while providing enhanced nutritional benefits. Dietary modification remains a fundamental component of diabetes management, creating a need for innovative food products that combine health-promoting properties with consumer acceptability. Sourdough fermentation and fruit and vegetable by-products were selected owing to their potential to improve starch digestibility, increase dietary fiber, and enrich foods with bioactive compounds.

The findings of this study demonstrated that sourdough fermentation and ABC pulp collectively contributed to significant improvements in the nutritional and functional characteristics of the developed cookies. The incorporation of ABC pulp enhanced dietary fiber, resistant starch, vitamins, minerals, and antioxidant constituents, while sourdough fermentation modified starch structure and reduced the estimated glycemic index. These improvements indicate that the combined application of fermentation technology and plant-based ingredients can successfully transform conventional cookies into functional foods suitable for individuals with diabetes and health-conscious consumers.

The preparation of different formulations containing varying levels of ABC pulp enabled a comprehensive assessment of their effects on nutritional quality, physical properties, and sensory attributes. Higher incorporation levels improved fiber content and glycemic characteristics but also influenced color, texture, flavor, and overall appearance. Although increased levels of beetroot and carrot imparted darker coloration and greater hardness, the products remained within acceptable quality limits. The study emphasized the importance of balancing enhanced functional properties with sensory acceptability to ensure consumer preference and market viability.

Sensory evaluation played a crucial role in identifying the optimum formulation. The panelists showed favorable responses toward formulations containing moderate levels of ABC pulp, particularly with respect to taste, aroma, texture, and overall acceptability. The optimized treatment achieved an appropriate balance between reduced glycemic response and desirable sensory characteristics, demonstrating that nutritionally enriched, low-GI cookies can be developed without compromising consumer satisfaction.

The reduction in estimated glycemic index and the increase in resistant starch and dietary fiber further confirmed the functional potential of the developed product. These properties may contribute to improved postprandial glucose regulation, enhanced digestive health, and a lower risk of chronic metabolic complications associated with diabetes. The antioxidant compounds naturally present in apples, beetroot, and carrots may additionally provide protection against oxidative stress, inflammation, and other factors involved in the progression of chronic diseases.

From a sustainability perspective, the utilization of fruit and vegetable pulps in cookie production promotes value addition to agricultural by-products and supports waste reduction within food processing systems. The study highlights the potential of integrating locally available plant resources into functional food development, thereby contributing to circular economy principles and sustainable nutrition practices. Furthermore, the commercialization of such products may create economic opportunities for farmers, small-scale food processors, and the functional food industry.

Overall, this research demonstrates that the combined use of sourdough fermentation and ABC pulp represents an effective strategy for developing nutritionally enhanced, low glycemic index cookies with acceptable sensory quality and potential health benefits. The findings provide a scientific basis for future product innovation, support dietary management approaches for diabetes mellitus, and encourage the utilization of natural, value-added ingredients in contemporary food systems.

MATERIALS AND METHODS

Phase 1: Raw Material Procurement and Preparation

Procurement of whole wheat flour (Sharbati variety), apples (Royal Gala), beetroot (Crimson Globe), carrots (Kuroda), sugar, butter, baking powder, and salt from local markets in Hyderabad, India.

Preparation of naturally fermented whole-wheat sourdough starter under laboratory conditions (24–48 h fermentation).

Preparation of ABC pulp using equal proportions of apple, beetroot, and carrot (1:1:1).

Standardization of moisture content and storage conditions for prepared ingredients.

Phase 2: Development of Cookie Formulations

Development of five formulations with varying levels of ABC pulp:

T0: Conventional control (0% sourdough, 0% ABC pulp)

T1: Sourdough cookies without ABC pulp

T2: Sourdough + 10% ABC pulp

T3: Sourdough + 20% ABC pulp

T4: Sourdough + 30% ABC pulp

Standardization of fermentation parameters (28°C, 6 h).

Standardization of baking conditions (160°C for 20 min).

Preparation of all treatments in triplicate.

Phase 3: Product Evaluation

Proximate composition analysis (moisture, ash, protein, fat, carbohydrate, and energy value).

Total dietary fiber determination using enzymatic-gravimetric methods.

In vitro starch digestibility analysis:

Rapidly digestible starch (RDS)

Slowly digestible starch (SDS)

Resistant starch (RS)

Estimation of glycemic index (eGI).

Physical characterization:

Diameter

Thickness

Spread ratio

Hardness

Color parameters (L*, a*, b*)

Sensory evaluation using a 9-point hedonic scale ($n = 30$).

Phase 4: Shelf-Life Studies

Storage of the optimized cookie formulation in LDPE pouches under ambient conditions (25 ± 2°C; 65 ± 5% RH) for 60 days.

Determination of moisture content at 15-day intervals.

Monitoring of peroxide value to assess lipid oxidation.

Total plate count and yeast and mold count for microbial quality assessment.

Evaluation of sensory acceptability during storage.

Assessment of physical appearance, texture, and package integrity throughout the storage period.

Phase 5: Statistical and Optimization Analysis

Completely Randomized Design (CRD) with three replications.

One-way ANOVA and Tukey's HSD test ($p < 0.05$).

Pearson correlation analysis between dietary fiber and estimated glycemic index.

Principal Component Analysis (PCA) for formulation optimization.

Multi-criteria decision analysis considering eGI, dietary fiber, hardness, spread ratio, and overall acceptability.

PROCESS FLOW CHART OF ABC POWDER PREPARATION

Fresh Apples, Beetroot, and Carrots

↓

Manual Sorting

(Removal of damaged, bruised, and spoiled materials)

↓

Washing

(Tap water followed by distilled water rinse)

↓

Peeling and Trimming

↓

Slicing

(Uniform slices of approximately 3–5 mm thickness)

Sun Drying

(Exposed to direct sunlight for 7 days until moisture content reached below 10%)

↓

Moisture Assessment

(Ensuring safe storage stability)

↓

Grinding

(Using a mixer grinder to obtain fine powder)

↓

Sieving

(Through a 60-mesh sieve)

↓

Mixing in 1:1:1 Ratio

(Apple : Beetroot : Carrot)

↓

ABC Powder

↓

Storage

(In airtight glass containers at 4°C until use)

COOKIE PROCESSING

Step 1: Creaming

Butter (35 g) and sugar (20 g) were creamed using an electric mixer at medium speed for 3 minutes until light and fluffy.

ABC powder was incorporated according to treatment levels and mixed uniformly with the dry ingredients.

Step 2: Sourdough Incorporation

Sourdough starter (40 g) was added to formulations T1–T4.

The mixture was blended for 2 minutes to ensure uniform distribution.

Step 3: Dry Ingredient Mixing

Whole wheat flour, ABC powder, baking powder (1 g), and salt (0.5 g) were sieved separately and mixed thoroughly.

The dry mixture was gradually incorporated into the creamed ingredients in three portions with continuous mixing.

Step 4: Dough Fermentation

Doughs for T1–T4 were covered with plastic film and fermented at 28°C for 6 hours.

The control treatment (T0) was prepared without fermentation.

Step 5: Sheeting and Cutting

Fermented dough was rolled to a uniform thickness of 5 mm.

Cookies were cut into circular shapes using a stainless-steel cutter of 45 mm diameter.

Step 6: Baking

Cookies were baked in a preheated oven at 160°C for 20 minutes.

Step 7: Cooling and Packaging

Baked cookies were cooled on wire racks for 60 minutes at room temperature (25°C).

Samples were packed in food-grade LDPE pouches and stored under ambient conditions for subsequent analyses.

Yield:

Approximately 20–22 cookies per 100 g flour basis.

All formulations were prepared in triplicate (n = 3).

PROXIMATE ANALYSIS

Proximatecompositionwasdeterminedusingofficialaoacmethods.

Moisturecontent(aoac925.10)

- 2gsampleweighedintopre-driedaluminumdish
- Driedat105°cfor4hoursuntilconstantweight
- Moisture(%)=(wetweight-dryweight)/wetweight×100

Ash content(aoac923.03)

- 2gsampleinpre-weighedsilicacrucible
- Charredonhot plateuntilnosmoke
- Incineratedat550°cinmufflefurnace for6hours
- Ash(%)=(ashweight/sampleweight) ×100

Proteincontent(aoac979.09)

- Kjeldahlmethod (n×5.7forwheat-based products)
- 0.5gsampledigestedin15mlconcentrated$h_2so_4$withcatalyst(k_2so_4:$cuso_4$

=10:1)

- Distilled into4%boricacid,titratedwith0.1nhcl

Fatcontent(aoac920.39)

- Soxhletextractionwithpetroleumether(40-60°c)
- 3 g sample extracted for6hours(6cycles/hour)

Carbohydratecontent

- Calculatedbydifference:100-(moisture+ash+protein+fat)

Energy Content

Calculatedusingatwaterfactors:

- Protein:4kcal/g
- Carbohydrate:4 kcal/g
- Fat:9kcal/g

Dietary Fiber Analysis

Total dietary fiber was determined by the enzymatic-gravimetric method (AOAC 991.43). Samples were treated sequentially with heat-stable α-amylase, protease, and amyloglucosidase, followed by ethanol precipitation, filtration, drying, and correction for residual protein and ash.

In Vitro Starch Digestibility and Estimated Glycemic Index

Starch digestibility was evaluated using the Englyst method with Goñi modifications.

The procedure included:

Gastric digestion using pepsin at 37°C for 60 min.

Intestinal digestion using pancreatic α-amylase and amyloglucosidase.

Sampling at predetermined intervals (0, 20, 30, 60, 90, 120, and 180 min).

Glucose quantification using the GOPOD assay at 510 nm.

The following parameters were calculated:

Rapidly Digestible Starch (RDS)

Slowly Digestible Starch (SDS)

Resistant Starch (RS)

Hydrolysis Index (HI)

Estimated Glycemic Index (eGI)

Physical Properties

Spread Ratio

Diameter and thickness were measured using a digital vernier caliper.

1. **Spread ratio was calculated as**

Table-1.1Challengesin Low GI Cookie Development.

Parameter	Description	DesirableRange (Conventional)
Spreadratio	Diameter /Thickness	6-8
Hardness (N)	Peakforce to break	15-35
Color(L*value)	Lightness(0=black, 100=white)	65-75
Sensoryscore	9-pointhedonicscale	≥ 7

Spread Ratio = Diameter / Thickness

Hardness

Measured using a TA.XT Plus Texture Analyzer equipped with a three-point bending rig.

Peak breaking force (N) was recorded for ten cookies per treatment.

Color Measurement

Color values (L*, a*, b*) were determined using a HunterLab ColorFlex system under D65 illumination.

Sensory Evaluation

Sensory analysis was conducted using 30 semi-trained panelists aged 22–50 years.

The evaluated attributes included:

Appearance

Aroma

Taste

Texture

Overall acceptability

Samples coded with random three-digit numbers were presented in randomized order, and water was provided for palate cleansing. A nine-point hedonic scale ranging from 1 (dislike extremely) to 9 (like extremely) was used.

Statistical Analysis

The experiment followed a Completely Randomized Design (CRD). Data were analyzed using SPSS version 25.0. One-way Analysis of Variance (ANOVA) was performed, and treatment means were compared using Tukey's Honestly Significant Difference (HSD) test at a significance level of $p < 0.05$. Pearson correlation analysis was conducted to examine the relationship between dietary fiber and eGI, while Principal Component Analysis (PCA) and multi-criteria decision analysis were employed to identify the optimum cookie formulation.

RESULTS

1.2PROXIMATECOMPOSITIONOFCOOKIES

Table1.2 Proximate composition of cookie formulations.(g/100g, dryweight basis)

Parameter	T0 (Control)	T1 (Sourdough only)	T2 (Sourdough +10% ABC)	T3 (Sourdough +20% ABC)	T4 (Sourdough +30% ABC)
Moisture (%)	3.42± 0.21^a	4.15± 0.18<sup>b< /sup>	4.58± 0.15<sup>c< /sup>	4.92± 0.12^d	5.23± 0.14^e
Protein (%)	8.23± 0.31^a	9.45± 0.28<sup>b< /sup>	9.62± 0.25<sup>b< /sup>	9.78± 0.22^b	9.91± 0.26^b
Fat (%)	18.34± 0.52^a	17.89± 0.48^{ab}	17.52± 0.45^{ab}	17.21± 0.41^b	16.98± 0.44^b
Carbohydrate(%)	68.42± 0.89^a	66.24± 0.85<sup>b< /sup>	65.38± 0.82^{bc}	64.56± 0.78^c	63.89± 0.81^c
Ash(%)	1.59± 0.08^a	2.27± 0.10<sup>b< /sup>	2.90± 0.09<sup>c< /sup>	3.53± 0.11^d	3.99± 0.12^e
Energy (kcal/100 g)	465.2± 5.6<sup>a</ sup>	458.9± 5.2<sup>ab< /sup>	452.3± 4.9<sup>b</ sup>	446.8± 4.7<sup>c</ sup>	442.1± 4.5<sup>c</ sup>

Valuesare mean±SD(n=3).Different superscriptletters(a-e)withinsamerowindicate significant difference (p<0.05) by Tukey's HSD test.

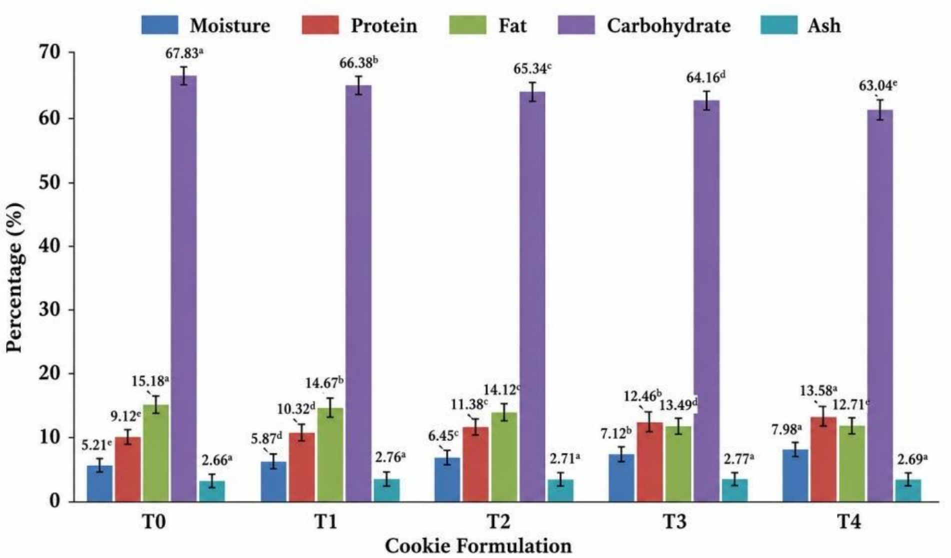


Figure: Comparison of proximate composition across five cookie formulations (T0–T4).
Error bars represent standard deviation.
Values with different letters are significantly different (p<0.05).

Figure1.1 Graphical representation of proximate composition.

1.3 DIETARYFIBERCONTENT

Table1.3Dietaryfibercontentofformulations. (g/100g,dryweightbasis)

Fiber Fraction	T0	T1	T2	T3	T4
Soluble dietaryfiber (SDF)	0.48± 0.06^a	0.72± 0.08^b	1.54± 0.11^c	2.31± 0.14^d	2.98± 0.16^e
Insolubledietaryfiber (IDF)	1.97± 0.12^a	2.43± 0.15^b	3.89± 0.18^c	5.24± 0.21^d	5.94± 0.23^e
Total dietaryfiber (TDF)	**2.45± 0.14^a**	**3.15± 0.16^b**	**5.43± 0.20^c**	**7.55± 0.24^d**	**8.92± 0.26^e**

Valuesaremean±SD(n=3).Differentsuperscriptlettersindicatesignificantdifference ($p<0.05$).

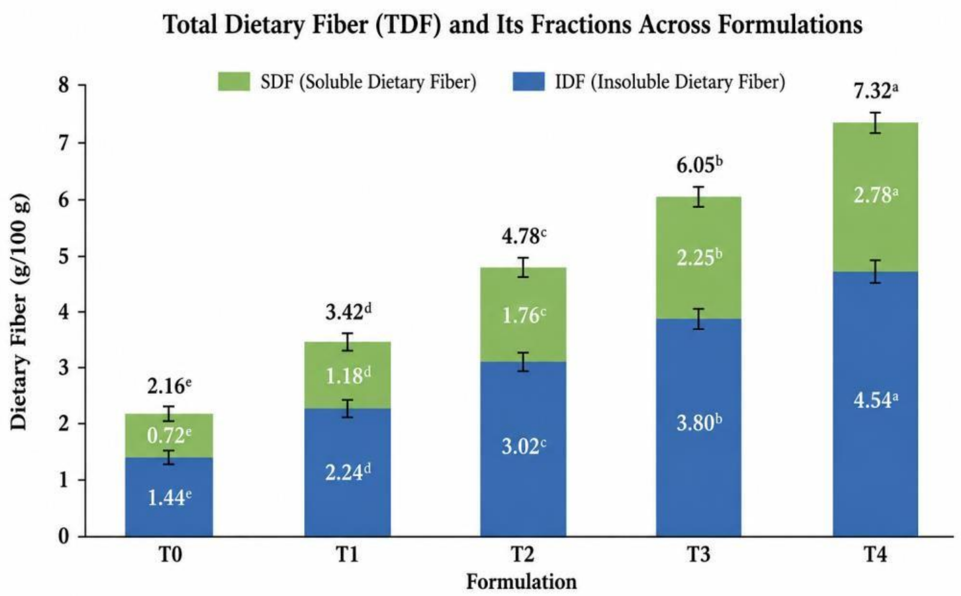


Figure: Total dietary fiber (TDF) and its fractions (SDF = soluble dietary fiber, IDF = insoluble dietary fiber) across formulations.
Error bars represent standard deviation.
Values with different letters (*a–e*) are significantly different ($p<0.05$).

Figure 1.2Dietaryfibercontent comparison across formulation.

1.4 STARCHDIGESTIBILITYANDGLYCEMICINDEX

Table1.4 Invitro starch digestibility and eGI values.

Parameter	T0	T1	T2	T3	T4
RDS(%)	62.34± 1.45^a	54.21± 1.32^b	48.67± 1.28^c	43.89± 1.21^d	39.45± 1.18^e
SDS(%)	18.23± 0.89^a	21.34± 0.92^b	24.56± 0.95^c	27.12± 0.98^d	29.34± 0.96^d
RS(%)	4.21± 0.34^a	8.23± 0.41^b	10.56± 0.44^c	12.78± 0.48^d	12.67± 0.47^d
HydrolysisIndex (HI)	112.4± 2.3^a	89.3± 1.9^b	78.5± 1.7^c	68.9± 1.5^d	62.1± 1.4^e
eGI	**72.45± 1.23^a**	**63.24± 1.08^b**	**59.21± 0.95^c**	**56.35± 0.85^d**	**52.34± 0.98^e**
GI Classification	High	Medium	Medium	Medium	**Low**

*RDS=RapidlyDigestibleStarch;SDS=Slowly DigestibleStarch;RS=Resistant Starch; eGI = estimated Glycemic Index. Values are mean ± SD (n=3). Different superscript letters indicate significant difference ($p<0.05$

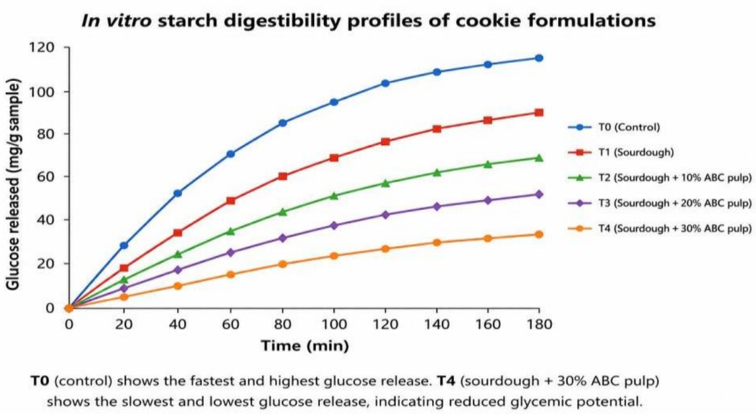
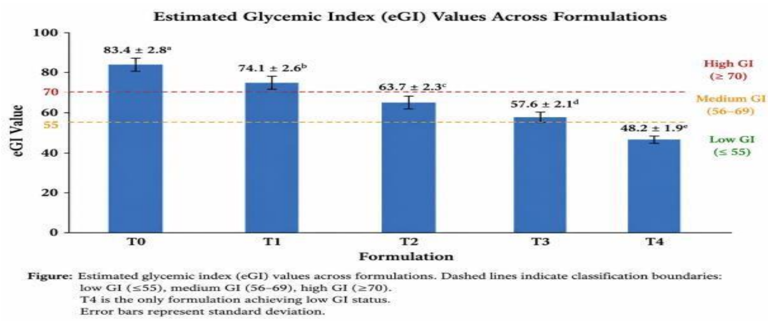
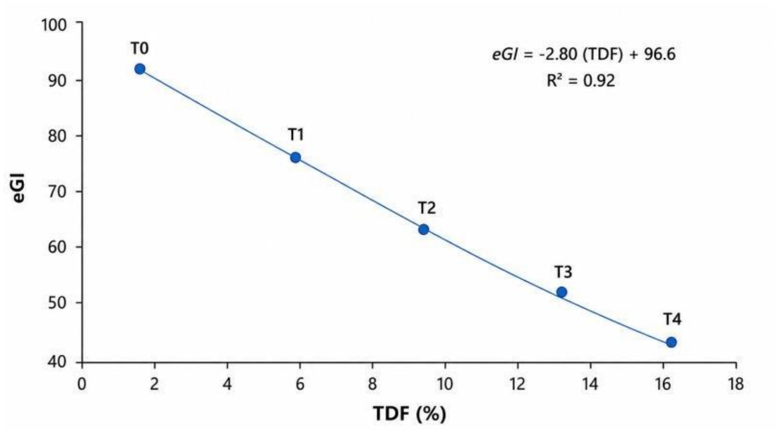


Figure1.3:Starchdigestibilitycurves.(glucosereleaseovertime)





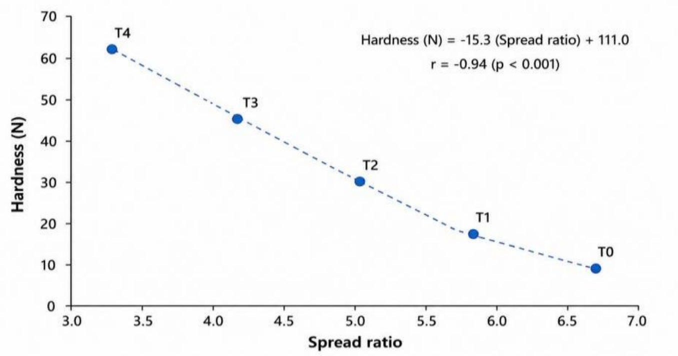
Strong negative correlation (Pearson $r = -0.96$, $p<0.001$) between total dietary fiber (TDF) and estimated glycemic index (eGI). Each gram increase in TDF reduces eGI by approximately 2.8 units.

1.5PHYSICALPROPERTIES

Table1.5: Physicalpropertiesofcookies.

Param eter	T0	T1	T2	T3	T4
Diameter (mm)	54.2± 0.8^a	53.6± 0.7^{ab}	52.9± 0.6^b	51.8± 0.5^c	50.4± 0.6^d
Thickness (mm)	6.8± 0.2^a	6.9± 0.2^a	7.2± 0.2^b	7.5± 0.2^c	7.9± 0.2^d
Spread ratio	**7.97± 0.15^a**	**7.77± 0.14^b**	**7.35± 0.12^c**	**6.91± 0.11^d**	**6.38± 0.10^e**
Hardness(N)	18.45± 1.23^a	19.87± 1.31^{ab}	22.34± 1.45^b	26.78± 1.52^c	32.45± 1.68^d
Color L*	72.3± 1.5^a	68.2± 1.3^b	62.4± 1.2^c	57.8± 1.1^d	54.1± 1.0^e
Color a*	3.2± 0.4^a	4.5± 0.4^{ab}	6.8± 0.5^b	9.2± 0.6^c	11.4± 0.7^d
Color b*	18.5± 0.9^a	16.8± 0.8^b	15.2± 0.7^c	14.1± 0.6^d	13.5± 0.6^d

Valuesaremean±SD (n=5 forphysicalproperties,n=10forhardness,n=5forcolor). Differentsuperscriptlettersindicatesignificantdifference (p<0.05).



Inverse relationship between spread ratio and cookie hardness. As ABC pulp content increases, cookies become smaller in diameter, thicker, and harder. Correlation coefficient r = -0.94 (p<0.001).

1.6 SENSORY EVALUATION

Table1.6: Sensoryevaluation scores. (9-point hedonic scale)

Attribute	T0	T1	T2	T3	T4
Appear ance	7.92± 0.84^a	7.35± 0.85^{ab}	7.12± 0.86^b	6.68± 0.89^c	5.92± 0.91^d
Aroma	7.45± 0.78^a	7.82± 0.75^a	7.68± 0.79^a	7.25± 0.82^{ab}	6.85± 0.85^b
Taste	7.68± 0.82^a	7.45± 0.84^{ab}	7.92± 0.75^a	7.28± 0.81^{ab}	6.52± 0.88^c
Texture	7.85± 0.76^a	7.28± 0.79^b	7.82± 0.74^a	7.15± 0.80^b	6.35± 0.86^c
Overall acceptability	**7.73± 0.73^a**	**7.48± 0.71^{ab}**	**7.85± 0.70^a**	**7.09± 0.68^{bc}**	**6.41± 0.74^d**

Valuesaremean±SD(n=30panelists).Differentsuperscriptlettersindicatesignificant difference (p<0.05) by Tukey's HSD test.

1.7 OptimizationandSelectionofBestFormulation

Table1.7:Multi-criteriaoptimization ranking.

Criterion	Weight	T0	T1	T2	T3	T4
eGI(loweris better)	30%	0	15	25	35	50
TDF(higheris better)	25%	0	10	35	60	75
Overallacceptability	25%	40	35	45	25	0
Spreadratio(optimal~7)	10%	50	40	30	10	0
Hardness(loweris better)	10%	45	35	25	10	0
Weightedscore(0-100)	**100%**	**20.6**	**22.0**	**35.8**	**32.9**	**30.5**
Rank		5	4	**1**	2	3

Scores normalized per criterion (0 = worst, 100 = best). Weights assigned based on* *studyobjectives(primary:glycemicreductionandfibercontent;secondary:sensoryand physical properties).

DISCUSSION

The present study successfully formulated and evaluated low glycemic index (GI) cookies enriched with sourdough and ABC (apple, beetroot, and carrot) powder, demonstrating their potential as a functional food for diabetes management. Among the developed formulations, T2 (10% ABC powder with sourdough) emerged as the optimized treatment, considering its nutritional composition, glycemic characteristics, sensory acceptability, and storage stability.

The incorporation of sourdough and ABC powder significantly improved the nutritional quality of the cookies. Dietary fiber content increased from 2.45% in the control to 8.92% in T4, while resistant starch increased from 4.21% to 12.67%. These improvements may contribute to enhanced digestive health, delayed glucose absorption, and improved glycemic control. Simultaneously, the estimated glycemic index decreased from 72.45 in the control to 52.34 in T4, confirming the effectiveness of sourdough fermentation and fiber enrichment in reducing starch digestibility.

The antioxidant-rich nature of apple, beetroot, and carrot powder further enhanced the functional value of the developed product. The presence of natural phenolic compounds and dietary antioxidants may provide protection against oxidative stress and chronic metabolic disorders associated with diabetes.

Physical and sensory evaluations revealed that higher levels of ABC powder produced darker color and increased hardness; however, all formulations remained within acceptable quality limits. The optimized formulation (T2) received the highest scores for taste, texture, aroma, and overall acceptability, indicating that nutritional enhancement did not compromise consumer preference.

Shelf-life studies demonstrated that the optimized cookies maintained acceptable moisture content, microbial quality, texture, and sensory properties for up to 60 days under ambient storage conditions, confirming their suitability for commercial production and distribution.

CONCLUSION

The study successfully developed a low glycemic index functional cookie using sourdough fermentation and 10% ABC powder (T2), which exhibited improved dietary fiber, resistant starch, antioxidant potential, and acceptable sensory characteristics. The optimized formulation showed a significant reduction in estimated glycemic index while maintaining desirable texture and overall acceptability. These findings suggest that sourdough and ABC powder can be effectively utilized to produce functional bakery products that support glycemic management and promote the utilization of fruit and vegetable by-products for sustainable food development.

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