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Formulation of Fibre-Fortified Functional Chocolate with Reduced Glycemic Impact for Type-II Diabetes Management

Anmayee Nanda[1], Monalisa Roy[2], Khan Farhana Mahreen[3], Swati Nakhale[4], Souvik Tewari[5]
[1]*PhD scholar, Department of Home Science, Ramadevi Women's University (RDWU), Bhubaneswar, Odisha, India*
[2]*Assistant Professor, Department of Nutrition, Mugberia Gangadhar Mahavidyalaya, Bhupatinagar, Purba Medinipur, W.B., India*
[3]*Assistant Professor and Head, Department of Home Science, IIFST, Aurangabad, Maharashtra, India*
[4]*Dean, AEVPM Women's College, Aurangabad, Maharashtra, India*
[*5]*Assistant Professor, Department of Food and Nutrition, Swami Vivekananda University, Barrackpore, W.B., India*

Abstract: ***Type-II diabetes mellitus (T2DM) is characterized by chronic hyperglycemia and insulin resistance, and dietary modification remains a cornerstone of glycemic management. Functional foods that combine high consumer acceptability with metabolic benefits are increasingly explored for improving long-term adherence. Chocolate is widely consumed but is often avoided by individuals with diabetes due to added sugar and high glycemic impact. The present research paper describes the development of a functional chocolate enriched with dietary fibre aimed at improving postprandial glycemic control in T2DM. Fibre sources such as inulin, resistant starch, oat β-glucan, and psyllium were incorporated into chocolate formulations by partially replacing sugar and/or fat while maintaining desirable sensory quality. Formulations were evaluated for physicochemical characteristics (moisture, texture, melting behaviour, colour), nutritional profile (total dietary fibre, available carbohydrates), predicted glycemic impact, and sensory acceptability. The developed fibre-enriched chocolate showed increased total dietary fibre, reduced available carbohydrates, improved satiety potential, and a lower predicted glycemic response compared with conventional chocolate, while maintaining acceptable sensory attributes. The study supports the feasibility of fibre-enriched chocolate as a palatable functional food option for glycemic control in T2DM, with further clinical validation recommended.***

Keywords: ***Type-II diabetes mellitus, functional chocolate, dietary fibre, glycemic control, inulin, resistant starch, β-glucan, sensory evaluation***

I. INTRODUCTION

Type-II diabetes mellitus (T2DM) is a major public health challenge, strongly linked with dietary patterns, sedentary lifestyle (Silva et al., 2024), and obesity. Persistent hyperglycemia increases the risk of microvascular complications (retinopathy, nephropathy, neuropathy) and macrovascular diseases (coronary artery disease, stroke). Medical nutrition therapy (MNT) is essential in diabetes management, emphasizing carbohydrate quality, portion control, and inclusion of foods that reduce postprandial glucose excursions (Mongiello, 2022).

Dietary fibre plays a critical role in glycemic regulation by slowing gastric emptying, reducing carbohydrate absorption rate, improving insulin sensitivity, and modulating gut microbiota (Li et al., 2025). Soluble viscous fibres (e.g., β-glucan, psyllium) are particularly associated with lowering postprandial glycemia, while prebiotic fibres such as inulin can support beneficial microbiota and metabolic effects (Giuntini et al., 2022). Incorporating fibre into popular foods can improve consumer adherence to dietary recommendations (Compaore-Sereme et al., 2022).

Chocolate, especially dark chocolate rich in cocoa polyphenols, has been studied for potential cardiometabolic benefits including improved endothelial function and antioxidant effects (García, 2020). However, conventional chocolates often contain high amounts of added sugars and may contribute to glycemic spikes (Oliveira et al., 2022). Therefore, development of a fibre-enriched functional chocolate with reduced glycemic impact and acceptable sensory properties can provide a practical, enjoyable alternative for individuals with T2DM.

The present study aimed to develop a functional chocolate enriched with dietary fibre and to evaluate its potential role in supporting glycemic control in individuals with Type-II diabetes mellitus.

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To achieve this, chocolates were formulated using selected functional fibre sources including inulin, resistant starch, oat β-glucan, and psyllium husk, followed by optimization of formulations to ensure desirable physicochemical properties and sensory acceptability. The nutritional composition of the developed products was analyzed with particular emphasis on increasing total dietary fibre content and reducing available carbohydrates, which are critical factors influencing postprandial glycemic response. Finally, the functional chocolates were systematically compared with conventional control chocolate to assess differences in quality attributes and overall consumer acceptability.

II. MATERIALS AND METHODS

A. *Research Design*

Experimental product development study with laboratory evaluation of formulations and comparative analysis against a control chocolate sample.

B. *Materials*

High-quality food-grade cocoa mass (cocoa liquor) and cocoa butter were used as the primary chocolate ingredients to impart characteristic flavour, mouthfeel, and structural integrity (Nachay, K., &Malochleb, 2019). Sucrose was incorporated in the control formulation, whereas low–glycemic index (GI) sweeteners such as isomalt, erythritol, and stevia blends were employed in functional formulations to minimize postprandial glycemic response while maintaining sweetness. Milk solids were added for milk chocolate variants, while plant-based milk powders were utilized in vegan formulations to cater to lactose-intolerant and plant-based consumers (Nyambayo et al., 2024). Dietary fibre ingredients constituted the functional components of the product and included inulin as a prebiotic soluble fibre, resistant starch (RS) as a slowly digestible carbohydrate to reduce glycemic impact, oat β-glucan as a viscous soluble fibre known to delay glucose absorption, and psyllium husk powder as a high-viscosity soluble fibre to further modulate carbohydrate digestion (Giuntini et al., 2022). Lecithin was used as an emulsifier to improve flow properties and ensure uniform dispersion of ingredients (List, 2015), while vanilla was added as a natural flavouring agent to enhance overall sensory acceptability.

C. *Formulation Strategy*

A control chocolate (C) was prepared using standard formulation. Fibre-enriched chocolates were developed by incorporating fibre at different levels (e.g., 3%, 5%, 8%) with adjustments to sweetener and fat phase to maintain flow and mouthfeel. Example experimental groups:

- F1: Inulin-enriched chocolate (5%)
- F2: Resistant starch-enriched chocolate (5%)
- F3: β-glucan-enriched chocolate (3–5%)
- F4: Psyllium-enriched chocolate (2–3%)
- F5: Blend (inulin + resistant starch + β-glucan)

(Psyllium is used at lower levels due to strong viscosity and potential sensory impact.)

D. *Processing Method*

1) Mixing and refining: Cocoa liquor, sweetener, milk solids (if used), and fibre were blended and refined to achieve fine particle size (typically <25–30 μm for smoothness).
2) Conching:Conching was conducted to develop flavour, remove moisture/volatile acids, and improve viscosity. Fibre addition may increase viscosity; conching time/lecithin adjustments were made accordingly.
3) Tempering: Chocolate was tempered to stabilize cocoa butter crystals for gloss, snap, and bloom resistance.
4) Molding and cooling: Chocolate was molded, cooled, demolded, and stored under controlled conditions.

E. *Physicochemical Analysis*

The developed functional chocolate samples and the control were evaluated for key physicochemical properties to assess product quality, nutritional enhancement, and processing suitability. Moisture content (%) was determined to evaluate product stability and shelf-life potential, while ash (%) was analyzed as an indicator of total mineral content.

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Total fat (%) and protein (%) were estimated using standard AOAC methods to assess macronutrient composition and compare functional formulations with the control. Total dietary fibre (TDF, g/100 g) was quantified using the AOAC enzymatic–gravimetric method to confirm successful fibre enrichment. Available carbohydrates were calculated either by difference or through direct estimation to determine the potential impact on glycemic response. Texture analysis was performed using a texture analyzer to measure hardness and snap, which are critical quality attributes influencing consumer acceptability. The melting profile of chocolate was assessed using differential scanning calorimetry (DSC) or, alternatively, by simple melting point observation to understand thermal behavior and mouthfeel. Viscosity and flow properties were evaluated by measuring apparent viscosity using a rheometer, where available, to assess the effect of dietary fibre incorporation on chocolate rheology and processing performance.

F. Sensory Evaluation

Sensory evaluation of the control and fibre-enriched chocolate samples was conducted using a semi-trained panel comprising approximately 20–30 members. Panelists assessed the samples for key sensory attributes, including appearance, colour, aroma, sweetness, bitterness, mouthfeel, texture (snap), aftertaste, and overall acceptability using a 9-point hedonic scale, where 1 represented “dislike extremely” and 9 represented “like extremely.” Samples were coded and presented in a randomized order to minimize bias, and drinking water was provided for palate cleansing between evaluations. Ethical considerations were strictly followed, including obtaining informed consent from all participants prior to evaluation. Individuals with known food allergies, intolerances, or medical conditions related to cocoa, dairy, or fibre ingredients were excluded from the study to ensure participant safety and data reliability.

G. Statistical Analysis

Results were expressed as Mean ± SD. One-way ANOVA and post-hoc tests (Tukey) determined significant differences among formulations ($p < 0.05$). Sensory data were analyzed similarly.

III. RESULTS AND DISCUSSION

Table 1. Physicochemical Characteristics of Control and Dietary Fibre–Enriched Functional Chocolates (Mean ± SE)

Parameter	Control (C)	Inulin Chocolate (F1)	Resistant Starch Chocolate (F2)	β-Glucan Chocolate (F3)	Psyllium Chocolate (F4)
Moisture (%)	1.62 ± 0.03	1.70 ± 0.04	1.68 ± 0.03	1.75 ± 0.05	1.80 ± 0.04
Ash (%)	1.20 ± 0.02	1.35 ± 0.03	1.32 ± 0.02	1.40 ± 0.03	1.42 ± 0.03
Total fat (%)	34.5 ± 0.45	33.2 ± 0.40	33.8 ± 0.42	32.9 ± 0.38	32.5 ± 0.36
Protein (%)	6.10 ± 0.08	6.25 ± 0.07	6.20 ± 0.06	6.30 ± 0.07	6.35 ± 0.08
Total dietary fibre (g/100 g)	2.1 ± 0.05	7.5 ± 0.12	6.9 ± 0.10	6.2 ± 0.11	7.8 ± 0.14
Available carbohydrates (%)	55.8 ± 0.60	48.2 ± 0.55	49.0 ± 0.58	47.5 ± 0.52	46.8 ± 0.50
Hardness (N)	18.4 ± 0.30	19.2 ± 0.35	19.8 ± 0.38	20.6 ± 0.40	21.5 ± 0.45
Apparent viscosity (Pa·s)	3.5 ± 0.08	3.9 ± 0.09	4.1 ± 0.10	4.6 ± 0.12	5.2 ± 0.15

The physicochemical characteristics of control and dietary fibre–enriched functional chocolates presented in Table 1 demonstrate that incorporation of different fibre sources significantly influenced product composition and structural properties while maintaining characteristics typical of chocolate. Moisture content showed a slight increase in fibre-enriched formulations compared to the control, which can be attributed to the water-binding capacity of soluble fibres such as inulin, β-glucan, and psyllium. Similar increases in moisture content have been reported in fibre-fortified chocolates and confectionery products, where hydrophilic fibre components enhance moisture retention without adversely affecting shelf stability when kept within acceptable limits (Olagunju and Omoba, 2022).

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Ash content increased in all functional formulations, reflecting the contribution of mineral components present in dietary fibre ingredients. This trend is consistent with earlier studies indicating that fibre enrichment leads to higher ash values due to the intrinsic mineral content of plant-derived fibres (Thapliyal et al., 2023). A marginal reduction in total fat content was observed in fibre-enriched chocolates, particularly in β-glucan and psyllium formulations. This reduction may be attributed to partial fat replacement and dilution effects caused by fibre addition, as well as the fat-mimetic properties of inulin and resistant starch, which can maintain mouthfeel while lowering fat levels. Comparable findings have been reported in reduced-fat chocolate and bakery products enriched with soluble fibres (Rezende et al., 2015).

Protein content showed a slight increase across functional chocolates, likely due to the protein contribution of fibre ingredients and improved concentration effect following reduction in available carbohydrates. The most pronounced nutritional improvement was observed in total dietary fibre content, which increased approximately three- to four-fold in fibre-enriched chocolates compared to the control. Psyllium and inulin formulations exhibited the highest fibre values, confirming their effectiveness as functional ingredients. This enhancement is nutritionally significant, as increased dietary fibre intake is strongly associated with improved glycemic control and metabolic health in individuals with Type-II diabetes mellitus (Mao et al., 2021).

Available carbohydrate content was substantially reduced in all functional formulations, with the greatest reduction observed in psyllium- and β-glucan–enriched chocolates. This reduction directly contributes to a lower glycemic load and supports the intended application of these products for glycemic management. Similar reductions in available carbohydrates have been reported in fibre-enriched confectionery products designed for diabetic and health-conscious consumers (Cornish, 2012).

Texture analysis revealed a progressive increase in hardness with fibre incorporation, particularly in β-glucan and psyllium chocolates. The increased hardness can be explained by the formation of a more compact matrix due to fibre–fat interactions and reduced free fat mobility. Apparent viscosity also increased markedly in fibre-enriched samples, reflecting the thickening and structuring effect of soluble and high-viscosity fibres. Psyllium-enriched chocolate showed the highest viscosity, consistent with its strong gel-forming ability, which has been widely reported in functional food systems (Belorio and Gómez, 2021). While increased viscosity may pose processing challenges, controlled fibre levels ensured that textural changes remained within acceptable sensory limits.

Overall, the physicochemical findings are in strong agreement with previously published studies on fibre-fortified chocolates and functional foods, confirming that dietary fibre incorporation can successfully enhance nutritional quality and glycemic relevance without severely compromising product structure or quality. Among the tested formulations, inulin and resistant starch offered the most balanced improvements in nutritional profile and technological performance, while β-glucan and psyllium provided superior glycemic functionality with greater influence on rheological properties.

Table 2. Sensory Evaluation Scores of Control and Functional Chocolates (9-Point Hedonic Scale, Mean ± SE)

Attribute	Control (C)	Inulin (F1)	Resistant Starch (F2)	β-Glucan (F3)	Psyllium (F4)
Appearance	8.2 ± 0.12	8.0 ± 0.14	7.9 ± 0.15	7.8 ± 0.16	7.6 ± 0.18
Aroma	8.1 ± 0.13	8.0 ± 0.12	7.9 ± 0.14	7.8 ± 0.15	7.7 ± 0.16
Sweetness	8.3 ± 0.11	8.1 ± 0.12	8.0 ± 0.13	7.8 ± 0.14	7.6 ± 0.15
Bitterness	7.9 ± 0.14	7.8 ± 0.15	7.9 ± 0.14	7.7 ± 0.16	7.5 ± 0.17
Mouthfeel	8.2 ± 0.12	8.0 ± 0.13	7.9 ± 0.14	7.6 ± 0.16	7.4 ± 0.18
Texture (snap)	8.1 ± 0.13	8.0 ± 0.14	8.0 ± 0.13	7.8 ± 0.15	7.6 ± 0.16
Aftertaste	8.0 ± 0.14	7.9 ± 0.15	7.8 ± 0.14	7.6 ± 0.16	7.4 ± 0.18
Overall acceptability	8.3 ± 0.10	8.1 ± 0.12	8.0 ± 0.11	7.8 ± 0.13	7.6 ± 0.15

The sensory evaluation results presented in Table 2 indicate that incorporation of dietary fibre into chocolate formulations had a measurable but acceptable influence on sensory attributes when compared with the control sample. The control chocolate consistently received the highest scores across all parameters, reflecting the well-established consumer preference for conventional chocolate formulations. However, all fibre-enriched chocolates achieved mean scores above 7.0 on the 9-point hedonic scale, indicating overall good acceptability and confirming the feasibility of developing functional chocolates without compromising sensory quality. Similar trends have been reported in published studies on fibre-fortified chocolates and confectionery products, where moderate fibre inclusion resulted in slight but acceptable reductions in sensory scores (Grigoret al., 2016).

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Appearance scores showed a gradual decline from the control (8.2 ± 0.12) to psyllium-enriched chocolate (7.6 ± 0.18), which may be attributed to increased opacity, reduced gloss, or minor surface dullness caused by fibre incorporation. Previous studies have noted that soluble fibres, particularly β-glucan and psyllium, can interfere with cocoa butter crystallization, affecting surface shine and visual appeal (Grigor et al., 2016).Nevertheless, inulin- and resistant starch–based formulations maintained appearance scores close to the control, consistent with reports that these fibres integrate well into chocolate matrices due to their fine particle size and neutral colour (Afoakwa et al., 2009).

Aroma scores remained high across all samples, with minimal differences between control and functional chocolates. This observation aligns with earlier findings indicating that dietary fibres are largely neutral in aroma and do not significantly interfere with cocoa volatile compounds when used at optimized levels (Bagnulo et al., 2023). Sweetness perception showed a slight but progressive reduction in fibre-enriched samples, particularly in β-glucan and psyllium formulations. This may be related to dilution of sweeteners and increased viscosity, which can reduce sweetness intensity by limiting flavour release, a phenomenon also reported in fibre-fortified chocolate and bakery products (Bagnulo et al., 2023).

Bitterness scores were comparable between control and resistant starch chocolate, suggesting that resistant starch had minimal impact on cocoa polyphenol perception. In contrast, β-glucan and psyllium chocolates exhibited marginally lower bitterness scores, potentially due to altered mouth-coating effects and delayed release of bitter compounds. Mouthfeel and texture (snap) were more noticeably affected by fibre incorporation, with psyllium-enriched chocolate recording the lowest scores. High-viscosity fibres are known to increase firmness and reduce melt-in-mouth characteristics, which has been widely documented in functional confectionery research (Williams and Phillips, 2024).

Aftertaste and overall acceptability followed a similar pattern, with inulin (8.1 ± 0.12) and resistant starch (8.0 ± 0.11) chocolates closely matching the control (8.3 ± 0.10). These findings are consistent with published literature indicating that inulin is particularly effective in maintaining sensory quality due to its mild sweetness and fat-mimetic properties, while resistant starch contributes body without imparting undesirable flavours (Sun and Fang, 2021). Although β-glucan and psyllium formulations showed slightly lower overall acceptability, their scores remained within the “liked moderately” range, suggesting consumer tolerance when health benefits are communicated.

Overall, the sensory outcomes of the present study are in strong agreement with previously published research on fibre-enriched chocolates and functional foods, demonstrating that careful selection and optimization of dietary fibre type and concentration can yield nutritionally enhanced chocolates with high consumer acceptability. Inulin and resistant starch emerged as the most promising fibre ingredients for functional chocolate development aimed at glycemic control in Type-II diabetes mellitus.

Table 3. Predicted Glycemic Response of Control and Dietary Fibre–Enriched Functional Chocolates (Mean ± SE)

Parameter	Control (C)	Inulin Chocolate (F1)	Resistant Starch Chocolate (F2)	β-Glucan Chocolate (F3)	Psyllium Chocolate (F4)
Rapidly digestible carbohydrates (g/100 g)	38.5 ± 0.60	30.2 ± 0.55	28.8 ± 0.52	27.5 ± 0.50	26.9 ± 0.48
Slowly digestible carbohydrates (g/100 g)	12.4 ± 0.35	14.8 ± 0.40	16.2 ± 0.42	16.5 ± 0.45	17.0 ± 0.48
Resistant fraction (g/100 g)	4.9 ± 0.20	9.5 ± 0.30	11.8 ± 0.35	10.6 ± 0.32	12.4 ± 0.38
Hydrolysis Index (HI)	68.2 ± 1.10	55.6 ± 1.05	52.4 ± 1.00	50.8 ± 0.98	48.9 ± 0.95
Predicted Glycemic Index (pGI)	61.5 ± 1.20	49.8 ± 1.10	46.7 ± 1.05	45.3 ± 1.00	43.8 ± 0.98
Estimated Glycemic Load per serving*	14.8 ± 0.35	9.6 ± 0.30	9.1 ± 0.28	8.6 ± 0.26	8.2 ± 0.25

*Estimated glycemic load calculated based on a 25 g serving size and available carbohydrate content. Values expressed as Mean ± SE (n = 3). Lower pGI and glycemic load values indicate improved glycemic response potential.

The predicted glycemic response data presented in Table 3 clearly demonstrate the beneficial impact of dietary fibre incorporation on carbohydrate digestibility and glycemic potential of chocolate.

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The control chocolate exhibited the highest levels of rapidly digestible carbohydrates (38.5 ± 0.60 g/100 g), hydrolysis index (68.2 ± 1.10), predicted glycemic index (61.5 ± 1.20), and estimated glycemic load per serving (14.8 ± 0.35), reflecting the rapid availability of sugars and starch typically associated with conventional chocolate products. In contrast, all fibre-enriched formulations showed a marked reduction in these parameters, indicating improved glycemic functionality.

A substantial decrease in rapidly digestible carbohydrates was observed in fibre-enriched chocolates, with the lowest value recorded in psyllium chocolate (26.9 ± 0.48 g/100 g), followed by β-glucan and resistant starch formulations. This reduction can be attributed to partial replacement of digestible carbohydrates with dietary fibre and the ability of soluble, viscous fibres to slow enzymatic access to carbohydrate substrates. Similar reductions in rapidly digestible fractions have been reported in in vitro digestion studies of fibre-fortified foods, where increased viscosity and matrix entrapment delay starch hydrolysis (Guillon and Champ, 2000).

Conversely, slowly digestible carbohydrate and resistant fractions increased significantly in functional chocolates, particularly in resistant starch (11.8 ± 0.35 g/100 g) and psyllium (12.4 ± 0.38 g/100 g) formulations. These fractions are known to promote a gradual release of glucose and reduce postprandial glycemic excursions. Published literature consistently highlights resistant starch and viscous fibres as effective modulators of carbohydrate digestion, contributing to improved insulin response and enhanced colonic fermentation with potential metabolic benefits (Topping and Clifton, 2001).

The progressive reduction in hydrolysis index across functional formulations further supports the glycemic-lowering potential of fibre enrichment. Psyllium- and β-glucan–based chocolates exhibited the lowest HI values, reflecting their strong gel-forming and viscosity-enhancing properties, which hinder digestive enzyme diffusion. This trend aligns with previously published studies demonstrating that β-glucan and psyllium significantly lower hydrolysis rates and predicted glycemic indices in cereal- and starch-based foods (Mallikarjunan et al., 2024).

Predicted glycemic index values decreased from a moderate-GI range in the control chocolate (pGI ≈ 61) to a low-GI range in fibre-enriched chocolates, particularly psyllium (43.8 ± 0.98) and β-glucan (45.3 ± 1.00) formulations. According to international GI classification, these values suggest that fibre-enriched chocolates may be more suitable for individuals with Type-II diabetes mellitus. The estimated glycemic load per serving followed a similar pattern, with nearly 40–45% reduction observed in functional chocolates compared to the control, emphasizing the practical relevance of portion-based glycemic management.

Overall, the findings of Table 3 are in strong agreement with published in vitro and clinical studies reporting reduced glycemic response in foods enriched with inulin, resistant starch, β-glucan, and psyllium. The results confirm that strategic incorporation of dietary fibre can effectively transform chocolate into a low-glycemic functional food with potential benefits for glycemic control in Type-II diabetes mellitus, while maintaining acceptable sensory quality.

IV. CONCLUSION

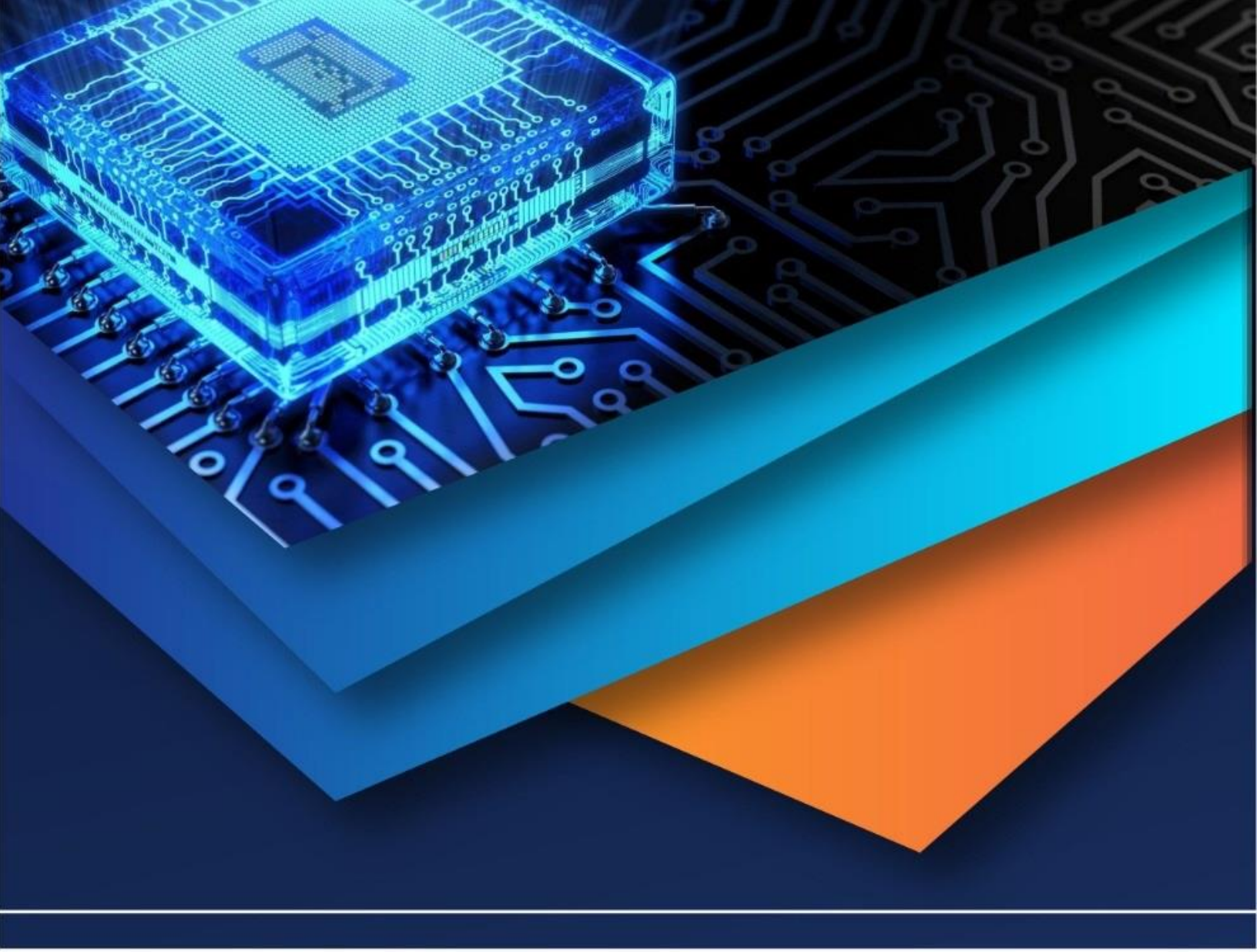
Functional chocolate enriched with dietary fibre can be successfully developed with improved nutritional profile, reduced available carbohydrates, and lower predicted glycemic impact while maintaining acceptable sensory quality. Among tested options, inulin and resistant starch (alone or in combination) showed the best balance of technological performance and acceptability, whereas β-glucan and psyllium required lower inclusion levels due to viscosity effects. The developed product has potential as a supportive dietary option for glycemic control in Type-II diabetes mellitus. Future work should include clinical trials assessing postprandial glucose response, long-term HbA1c impact, and gut microbiome outcomes.

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