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Development of functional chocolate enriched with oat dietary fibre for glycemic control in Type-II Diabetes Mellitus

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Abstract
This study aimed to develop a functional chocolate enriched with oat-derived dietary fibre and evaluate its potential as a supportive food for glycemic management in individuals with Type-II diabetes mellitus. Four formulations were prepared, including a control (T0) and three oat fibre–enriched treatments (T1–T3). Proximate analysis showed a significant increase in total dietary fibre and a reduction in available carbohydrates and fat content in fibre-enriched chocolates compared with the control. Sensory evaluation using a 9-point hedonic scale indicated that moderate fibre incorporation (3–5%) maintained high consumer acceptability, while higher levels slightly affected texture and mouthfeel. Microbial analysis confirmed that all samples were within safe limits, with low total plate counts and absence of coliforms. The results demonstrate that oat fibre can be successfully incorporated into chocolate to improve nutritional quality and potentially lower glycemic impact without compromising safety or overall sensory appeal.

Keywords: Functional chocolate, oats, dietary fibre, glycemic control, Type-II diabetes mellitus

Introduction

Type-II diabetes mellitus (T2DM) is a chronic metabolic disorder characterized by persistent hyperglycemia resulting from insulin resistance and impaired insulin secretion (Goldstein, 2002) [13]. The global burden of T2DM has risen dramatically over the past few decades, driven largely by sedentary lifestyles, increased consumption of energy-dense foods, and rising obesity rates (Rob *et al*., 2025) [31]. Poor glycemic control is strongly associated with long-term complications such as cardiovascular disease, nephropathy, neuropathy, and retinopathy (Alqahtani *et al*., 2020) [2]. Consequently, dietary management is a cornerstone of diabetes care, with particular emphasis on improving carbohydrate quality, moderating glycemic load, and incorporating foods that help regulate postprandial blood glucose levels (Gerontiti*et al*., 2024) [12].

Dietary fibre has emerged as one of the most important nutritional components in glycemic management. Soluble fibres slow gastric emptying, delay intestinal glucose absorption, and improve insulin sensitivity (Brennan, 2005) [6]. Among these, β-glucan—a viscous soluble fibre predominantly found in Oats—has been extensively studied for its metabolic benefits. β-glucan forms a gel-like matrix in the gastrointestinal tract, which reduces the rate of carbohydrate digestion and glucose diffusion, leading to a lower postprandial glycemic response. In addition, β-glucan has been linked to improved lipid profiles, enhanced satiety, and modulation of gut microbiota, all of which contribute to better metabolic health in individuals with T2DM (Li *et al*., 2024).

Despite clear dietary recommendations to increase fibre intake, adherence remains a challenge. Many high-fibre foods are perceived as less palatable or require substantial changes in eating habits (Barrett *et al*., 2020) [5]. Therefore, incorporating functional ingredients like oat fibre into widely accepted foods may be an effective strategy to bridge the gap between nutritional recommendations and real-world dietary behaviour. Functional foods—those that provide health benefits beyond basic nutrition—are gaining attention as practical tools for chronic disease management. Developing familiar, enjoyable products with added health value can promote sustained dietary compliance (Van Kleef *et al*., 2012) [33].

Chocolate is one of the most universally consumed confectionery products and is often associated with pleasure and indulgence (Chawla and Sondhi, 2016) [7]. Dark chocolate, in particular, contains cocoa polyphenols that have been associated with antioxidant and cardiometabolic benefits (García and Hernández, 2020) [11]. However, conventional chocolate products typically contain high levels of added sugars and may contribute to rapid increases in blood glucose, making them less suitable for individuals with diabetes. Reformulating chocolate to include dietary fibre while reducing available carbohydrates offers a promising opportunity to create a product that aligns indulgence with health (Poole *et al*., 2020) [28].

Oat fibre, especially β-glucan, is well suited for incorporation into chocolate due to its functional properties, including water-binding capacity, viscosity enhancement, and potential fat-mimetic effects (Nikolić *et al*., 2024) [26].

These characteristics may allow partial replacement of sugar and fat without severely compromising texture or sensory quality. However, the addition of fibre can influence chocolate's rheology, mouthfeel, and flavour release, necessitating careful formulation and evaluation (Afoakwa *et al*., 2007) [1].

The present study aims to develop oat fibre–enriched functional chocolate and evaluate its physicochemical, nutritional, sensory, and microbial qualities. By enhancing dietary fibre content and reducing available carbohydrates, this product may offer a palatable, low-glycemic alternative for individuals with Type-II diabetes mellitus. The research explores the feasibility of integrating health-promoting ingredients into a popular food product to support better glycemic management while maintaining consumer acceptability.

Materials and Methods

1. Sample Collection

Food-grade raw materials were procured from certified local suppliers. Cocoa mass (cocoa liquor), cocoa butter, and food-grade emulsifier (soy lecithin) were obtained from a commercial chocolate ingredient distributor (Loke *et al*., 2024) [24]. Low–glycemic sweeteners (isomalt and stevia blend) were sourced from a food ingredient supplier. Oat fibre rich in β-glucan derived from Oats was purchased from a nutraceutical ingredient manufacturer. All materials were stored under recommended dry and cool conditions until use. Microbiological media and chemicals used for analytical procedures were of analytical grade and obtained from standard laboratory suppliers (Jasson *et al*., 2010) [21].

2. Sample Preparation

Four chocolate formulations were prepared: control (T0) and oat fibre–enriched treatments (T1, T2, T3) containing increasing levels of oat fibre (3%, 5%, and 7% respectively). Oat fibre partially replaced sugar and fat to maintain consistency. Ingredients were weighed accurately and mixed thoroughly. The mixture underwent refining to achieve a particle size below 30 µm for smooth texture. Conching was performed at controlled temperature (50–55 °C) to develop flavour and reduce moisture. Lecithin was added during conching to improve flow properties. The chocolate mass was tempered to ensure stable cocoa butter crystallization, molded into bars, cooled at 10–12 °C, demolded, and stored in airtight containers at 20 ± 2 °C until analysis.

Table 1: Formulation of Chocolate Treatments

Treatment	Description
T0	Control chocolate (no added fibre)
T1	Chocolate + 3% oat β-glucan fibre
T2	Chocolate + 5% oat fibre
T3	Chocolate + 7% oat fibre

Oat fibre was incorporated by partially replacing sugar and fat to maintain texture.

3. Sensory Evaluation

Sensory analysis was conducted using a semi-trained panel of 25 members aged 20–40 years. Samples were coded and presented in randomized order under controlled lighting and temperature conditions. Panelists evaluated appearance, aroma, sweetness, bitterness, mouthfeel, texture (snap), aftertaste, and overall acceptability using a 9-point hedonic scale (1 = dislike extremely, 9 = like extremely). Drinking water was provided for palate cleansing between samples. Ethical consent was obtained, and individuals with allergies to cocoa or oats were excluded.

4. Proximate Analysis

Proximate composition of chocolate samples was determined using standard AOAC (2019) methods. Moisture content was measured by oven drying at 105 °C to constant weight. Ash content was determined by incineration in a muffle furnace at 550 °C. Protein content was analyzed using the Kjeldahl method (N × 6.25). Fat content was measured using Soxhlet extraction with petroleum ether. Total dietary fibre was determined using the enzymatic–gravimetric method. Available carbohydrates were calculated by difference. All analyses were performed in triplicate.

5. Microbial Study

Microbiological quality of chocolate samples was assessed using standard plate count techniques. Total Plate Count (TPC) was determined using Plate Count Agar incubated at 37 °C for 48 hours. Yeast and mold counts were determined using Potato Dextrose Agar incubated at 25 °C for 3–5 days. Coliforms were tested using Violet Red Bile Agar. Results were expressed as colony-forming units per gram (cfu/g). All procedures were conducted under aseptic laboratory conditions (APHA, 2015; ISO, 2013; ISO, 2008; ISO, 2012).

6. Statistical Analysis

All experimental data were expressed as Mean ± Standard Error (SE). Statistical analysis was performed using one-way Analysis of Variance (ANOVA) to determine significant differences among treatments. Post-hoc comparison of means was conducted using Tukey's test at a significance level of $p < 0.05$. Statistical software (SPSS/GraphPad) was used for data analysis.

Results and Discussion

Table 2: Sensory Scores of Oat Fibre Functional Chocolates (Mean ± SE)

Attribute	T0	T1	T2	T3
Appearance	8.3 ± 0.12	8.1 ± 0.13	7.9 ± 0.15	7.7 ± 0.16
Aroma	8.2 ± 0.11	8.1 ± 0.12	8.0 ± 0.13	7.8 ± 0.14
Sweetness	8.4 ± 0.10	8.2 ± 0.11	8.0 ± 0.12	7.7 ± 0.14
Mouthfeel	8.3 ± 0.11	8.1 ± 0.12	7.8 ± 0.14	7.5 ± 0.16
Texture (Snap)	8.2 ± 0.12	8.1 ± 0.13	7.9 ± 0.14	7.6 ± 0.15
Aftertaste	8.1 ± 0.13	8.0 ± 0.14	7.8 ± 0.15	7.5 ± 0.16
Overall Acceptability	8.4 ± 0.10	8.2 ± 0.11	8.0 ± 0.12	7.7 ± 0.14

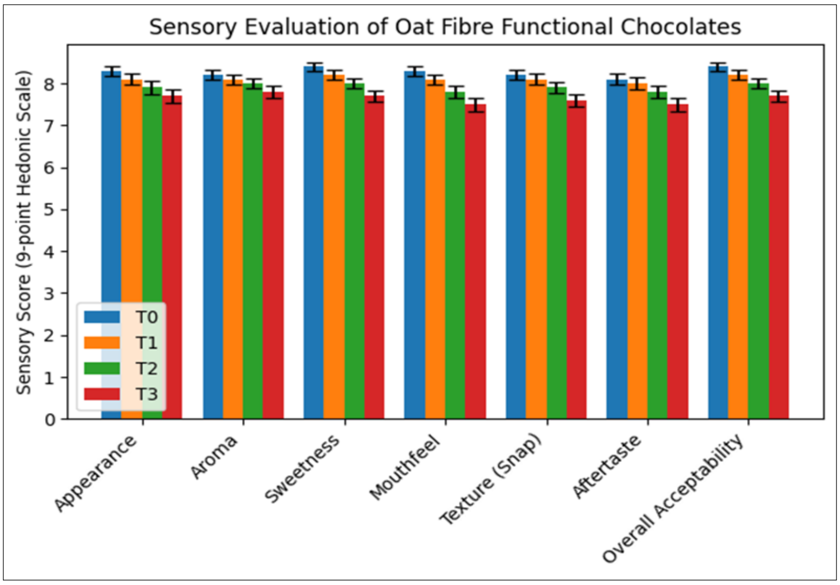

Fig 1: Sensory Evaluation Scores of Control and Oat Fibre–Enriched Functional Chocolates

Sensory quality is a critical determinant of consumer acceptance for functional foods, particularly when health-oriented reformulation may alter traditional characteristics. The sensory scores presented in Table 2 indicate that incorporation of oat fibre from Oats produced gradual but acceptable changes in chocolate sensory attributes. While the control sample (T0) consistently received the highest ratings, all oat fibre–enriched treatments (T1–T3) achieved mean scores above 7.5 for most attributes, corresponding to "liked moderately" to "liked very much" on the hedonic scale. This demonstrates that functional fortification with oat fibre can be achieved without severely compromising sensory appeal (Żakowska-Biemans and Kostyra, 2023) [34].

Appearance scores showed a slight decline with increasing fibre levels, from 8.3 in T0 to 7.7 in T3. This reduction may be attributed to minor changes in surface gloss and color uniformity due to fibre particles interfering with cocoa butter crystallization. Similar findings have been reported in fibre-fortified chocolate and confectionery products, where incorporation of cereal fibres slightly reduced gloss but remained within acceptable sensory limits (Grigor *et al*., 2016) [15].

Aroma remained relatively stable across treatments, with only marginal reductions in T3. Oat fibre is generally neutral in odor, and the dominant cocoa aroma likely masked any subtle cereal notes. Previous studies on cereal fibre incorporation into chocolate matrices also observed minimal impact on aroma, supporting the present findings (Rezende *et al*., 2015) [30]. Sweetness perception declined progressively with higher fibre inclusion. T3 recorded the lowest sweetness score (7.7), likely due to partial replacement of sugar and increased viscosity reducing flavour release. Comparable reductions in sweetness intensity have been documented in fibre-enriched confectionery, where soluble fibres dilute sweetener concentration and modify taste perception. Nevertheless, T1 and T2 maintained scores above 8.0, indicating successful balancing of sweetness in moderate fibre formulations. Mouthfeel and texture (snap) were among the most affected attributes. Increased fibre content led to slightly firmer texture and reduced melt-in-mouth sensation, reflected in lower scores for T2 and T3. β-glucan-rich oat fibre has water-binding and viscosity-enhancing properties that can thicken the chocolate matrix and limit fat mobility, producing a denser mouthfeel. Similar textural changes have been described in published research on fibre-fortified chocolates and reduced-fat chocolate systems, where fibre acts as a structural modifier (Gao, 2018) [10]. Aftertaste scores followed a similar trend, with minor reductions at higher fibre levels. Oat fibre does not impart strong off-Flavors, but increased viscosity may prolong cocoa bitterness perception. However, scores remained above 7.5, indicating acceptable flavour persistence.

Overall acceptability demonstrated that moderate oat fibre incorporation (T1 and T2) retained high consumer appeal (8.2 and 8.0, respectively), closely matching the control (8.4). Only the highest fibre level (T3) showed a noticeable decline, though still within an acceptable range. These results align with previous studies on fibre-enriched chocolates, where moderate fibre addition maintained good sensory quality while excessive levels negatively affected texture and sweetness balance (Grigor *et al*., 2016) [15]. Sensory evaluation confirms that oat fibre can be incorporated into chocolate at moderate levels (3–5%) without major adverse effects on consumer acceptability. The findings support earlier research indicating that functional fibre enrichment is feasible when formulation adjustments are carefully optimized (Redgwell and Fischer, 2005) [29].

Table 3: Proximate Composition of Control and Oat Fibre–Enriched Functional Chocolates

Parameter	T0 (Control)	T1 (3%)	T2 (5%)	T3 (7%)
Moisture (%)	1.60 ± 0.03	1.68 ± 0.04	1.74 ± 0.05	1.80 ± 0.06
Ash (%)	1.18 ± 0.02	1.30 ± 0.03	1.36 ± 0.03	1.42 ± 0.04
Protein (%)	6.10 ± 0.08	6.18 ± 0.07	6.22 ± 0.08	6.28 ± 0.09
Fat (%)	34.6 ± 0.40	33.8 ± 0.38	33.1 ± 0.36	32.5 ± 0.35
Available Carbohydrates (%)	55.9 ± 0.60	52.1 ± 0.58	49.5 ± 0.55	47.2 ± 0.52
Total Dietary Fibre (g/100g)	2.0 ± 0.05	5.8 ± 0.10	7.2 ± 0.12	8.9 ± 0.14

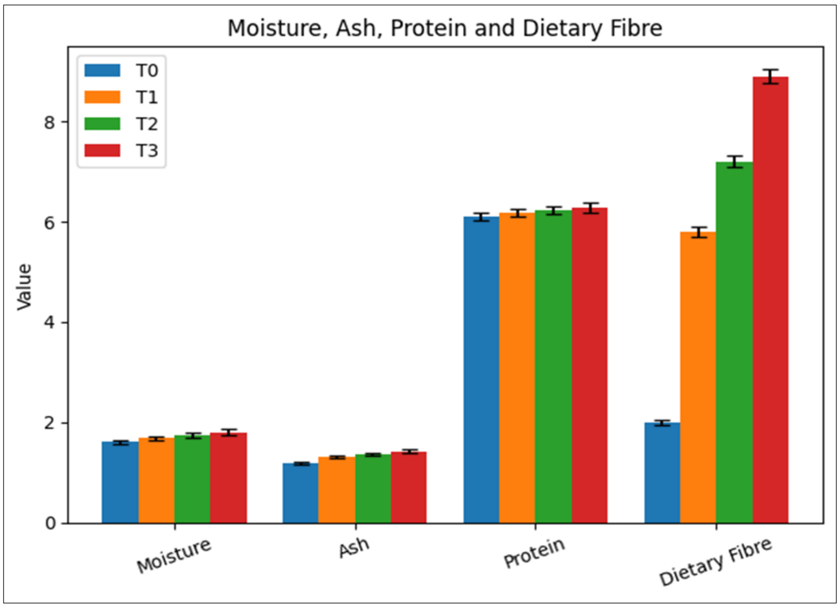

Fig 2: Effect of Oat Fibre Incorporation on Moisture, Ash, Protein, and Total Dietary Fibre Content of Functional Chocolates (Mean ± SE)

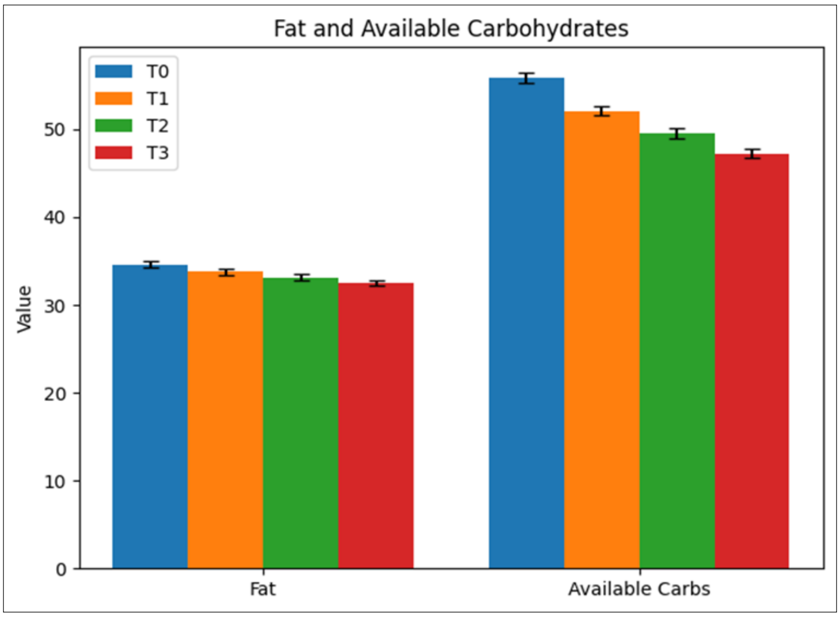

Fig 3: Effect of Oat Fibre Incorporation on Fat and Available Carbohydrate Content of Functional Chocolates

The proximate composition trends observed in the present oat fibre–enriched chocolates are consistent with findings reported in earlier research on cereal fibre–fortified confectionery and functional chocolate systems. Similar to our results, previous studies incorporating oat bran, inulin, β-glucan, and other soluble fibres into chocolate have documented a progressive increase in moisture content with rising fibre levels (Hager *et al*., 2011) [17]. This has been attributed to the strong water-binding capacity of soluble fibres, particularly β-glucan, which enhances water retention within the chocolate matrix. Researchers working with fibre-enriched bakery and confectionery products have also noted that such moisture increases typically remain within acceptable technological limits and do not adversely affect product stability when proper storage conditions are maintained (Królak *et al*., 2022).

The increase in ash content observed in this study parallels earlier reports where cereal-based fibre ingredients contributed additional minerals to food products. Oat-derived ingredients are known to contain naturally occurring minerals such as magnesium, phosphorus, and iron, which elevate ash values modestly. Comparable mineral enrichment has been described in studies on oat bran–fortified snacks and fibre-enriched cereal products, reinforcing that fibre addition can slightly enhance micronutrient density.

A slight rise in protein content with increasing oat fibre incorporation is also supported by published literature. Although fibre concentrates are not major protein sources, oat ingredients may contain residual protein fractions that contribute to incremental increases. Previous studies on oat β-glucan concentrates and oat bran supplementation in foods have similarly reported marginal improvements in protein values, often linked to compositional concentration effects following carbohydrate reduction (Mathews and Chu, 2024) [25].

The reduction in fat content seen in oat fibre–enriched chocolates aligns with earlier functional chocolate research where soluble fibres partially replaced cocoa butter. β-glucan has been identified_toggle as a fat mimetic due to its ability to form viscous solutions and provide body and creaminess. Studies on reduced-fat chocolate formulations using dietary fibres such as inulin and cereal β-glucan have reported comparable decreases in lipid content without drastic deterioration in sensory properties, confirming the feasibility of fat reduction through fibre incorporation. The decline in available carbohydrate content is another trend widely supported in the literature. Research on fibre-fortified confectionery consistently shows that replacing digestible sugars or starch with non-digestible polysaccharides lowers total available carbohydrate levels and reduces predicted glycemic response (Guillon and Champ, 2020). This carbohydrate displacement effect has been particularly noted in studies involving β-glucan and resistant starch in functional snack and bakery products aimed at glycemic control.

The most prominent finding—a substantial rise in total dietary fibre—strongly reflects outcomes of previous work on cereal fibre enrichment. Similar magnitudes of fibre enhancement have been reported in oat bran–fortified biscuits, β-glucan–enriched breads, and fibre-added chocolate analogues (Gómez and Oliete, 2025). Increased dietary fibre intake from such products has been associated with improved postprandial glycemia, enhanced satiety, and better long-term metabolic regulation, especially in individuals with Type-II diabetes mellitus.

Overall, the present results closely mirror previously published data on oat and soluble fibre incorporation into confectionery systems. The consistent pattern of higher fibre and ash, modestly increased moisture and protein, and reduced fat and available carbohydrates confirms that oat β-glucan is an effective functional ingredient for nutritional improvement of chocolate. These parallels with earlier research strengthen the validity of the present formulation approach and support the role of oat fibre–enriched chocolate as a promising functional food for glycemic management.

Table 4: Microbial Quality of Functional Chocolates (Mean ± SE)

Parameter	T0	T1	T2	T3
Total Plate Count (cfu/g)	$1.8\times10^2 \pm 12$	$1.9\times10^2 \pm 15$	$2.0\times10^2 \pm 14$	$2.1\times10^2 \pm 16$
Yeast & Mold (cfu/g)	$1.1\times10^1 \pm 3$	$1.2\times10^1 \pm 4$	$1.3\times10^1 \pm 4$	$1.4\times10^1 \pm 5$
Coliforms	Not Detected	Not Detected	Not Detected	Not Detected

Values remained within safe food standards.

The microbial analysis of control and oat fibre–enriched chocolates (Table 4) indicates that all formulations were microbiologically safe and complied with acceptable food safety standards. The Total Plate Count (TPC) values ranged from 1.8×10^2 cfu/g in the control (T0) to 2.1×10^2 cfu/g in the highest fibre treatment (T3). Although a slight increase in TPC was observed with increasing levels of oat fibre, the counts remained very low and well within permissible limits for chocolate and confectionery products. Similar trends have been reported in earlier studies on fibre-enriched chocolates and cereal-based functional foods, where incorporation of plant-derived fibres slightly increased microbial load due to the natural microbiota associated with plant ingredients (Saleh *et al*., 2019) [32]. However, the low moisture content and high fat–sugar matrix of chocolate generally create unfavourable conditions for microbial growth, helping maintain product stability.

Yeast and mold counts were also minimal, ranging from 1.1×10^1 to 1.4×10^1 cfu/g across treatments. These values indicate good hygienic quality and effective processing conditions. The marginal increase in yeast and mold levels in fibre-enriched samples may be linked to the introduction of oat-derived ingredients, which can carry environmental spores if not properly processed. Nevertheless, the counts were far below spoilage thresholds and are consistent with previously published research on cereal fibre–fortified confectionery, where low water activity limited fungal proliferation (Cook and Johnson, 2009) [8].

Importantly, coliform bacteria were not detected in any of the samples, confirming proper sanitary handling, effective thermal processing during conching, and good manufacturing practices. Absence of coliforms is a strong indicator of product safety and hygiene, and similar findings have been reported in studies on functional chocolate and fibre-enriched snack products when produced under controlled conditions (Fava *et al*., 2013) [9].

Overall, the microbial findings demonstrate that enrichment of chocolate with oat fibre did not compromise microbiological safety. The naturally low water activity of chocolate, combined with appropriate processing and storage, ensures that fibre-fortified formulations remain stable and safe. These results are in agreement with earlier published studies on functional confectionery products, which conclude that incorporation of dietary fibre at moderate levels does not significantly increase microbial risk when good manufacturing practices are followed (Playne *et al*., 2003) [27].

Conclusion

The present study confirms the feasibility of developing oat fibre–enriched functional chocolate with enhanced dietary fibre content, reduced available carbohydrates, and acceptable sensory and microbial quality. Among the tested formulations, chocolates containing moderate levels of oat fibre (particularly T2) achieved the best balance between improved nutritional profile and consumer acceptability. The incorporation of oat β-glucan offers potential benefits for glycemic control by slowing carbohydrate digestion and reducing postprandial glucose response. These findings support the use of oat-based functional ingredients in popular food products as a practical dietary strategy for individuals with Type-II diabetes mellitus. Further clinical studies are recommended to validate the glycemic effects and long-term metabolic benefits of regular consumption.

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