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Review Article

Development, Standardization, Organoleptic Evaluation, and Nutritional intervention of Pearl Millet and Sorghum Millet-Based Recipes in Patients with Dyslipidemia

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ABSTRACT

Background: Degraded low-density lipoproteins (LDL), very low density lipoprotein (VLDL), Intermediate-density lipoprotein (IDL) and high-density lipoproteins (HDL) cholesterol can cause dyslipidemia. The present study was conducted to determine the viability of augmented millet-based recipes and to observe the biochemical impact of these recipes on dyslipidemic subjects.
Methods: An augmented mixture of chia seeds, walnuts, and mango seed powder was developed and incorporated at different levels into millet-based recipes. Developed millet recipes were administered to dyslipidemic subjects for the duration of three months and their biochemical impacts were assessed.
Results: The augmented millet-based recipes had balanced energy content and a high proportion of proteins, dietary fiber, monounsaturated fatty acids, and linoleic acid. Administration of these millet-based recipes to dyslipidemic subjects could significantly improve the lipid profile of patients. The developed and augmented millet-based recipes showed significant improvements in all nutritive values too.
Conclusion: Intervention of these recipes for the duration of three months was shown to improve the modified lipid profile.

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Introduction

The title hyperlipidemia which depicts an increased level of lipids (like total cholesterol and triglycerides) in the blood is replaced by a wider term named dyslipidemia that highlights not only the impaired lipid metabolism; but also the lipoprotein parameters like low-density lipoproteins (LDL), very low density lipoprotein (VLDL), Intermediate-density lipoprotein (IDL) and high-density lipoproteins (HDL) cholesterol, etc. (1, 2). Increased cholesterol esters and triglycerides (TG) in the form of LDL, VLDL and LDL cholesterol and lowered concentrations of HDL cholesterol can lead to dyslipidemia. In the current Westernization phases; modifiable risk factors such as improper eating habits, sedentary lifestyle, smoking, alcohol consumption, and inadequate dietary habits can result in dyslipidemia. It was shown that non-HDL cholesterol was the major causative factor for the high prevalence of dyslipidemia in China, which was sequentially responsible for creating burdened dyslipidemia. A similar study was conducted to ascertain the age-standardized mean of causative non-HDL cholesterol in Chinese men, where it was observed that during the past 38 years, its ranking altered from 153rd in 1980 to 99th rank in 2018 (3).

In addition, to its high prevalence worldwide, dyslipidemia is highly rampant among Indians, where a research study reported that Indian men were found to have high total cholesterol (44.7%), TG (45.8%), and LDL cholesterol (28.7%) levels, whereas Indian women suffered from high total cholesterol, TH, and LDL cholesterol by 31.6%, 22%, and 28.7%, respectively (4). Another clinical trial showed that average South Indians had depressed concentrations of HDL cholesterol by 50.8% and, inflated TG levels by 10.8% and 5%, respectively, which highlighted the state of atherogenesis (5). Due to its high pervasiveness, dyslipidemic subjects suffer from the symptoms of dizziness, vomiting, nausea, dyspnea, cold sweats, heart palpitations, confusion, and shortness of breathing (6, 7). Uncontrolled symptoms of dyslipidemia are chargeable and can cause the cardiovascular disease complications. A cohort study was performed in which 233 dyslipidemic subjects with increased total cholesterol, LDL cholesterol, and triglycerides were detected with complications of myocardial infraction (8).

Analyzing the intricate and complex situation of dyslipidemia, nutritional management plays an important role in regulating its extreme pervasiveness. Energy-stabilized food products such as whole cereals, whole pulses, vegetables, fruits, nuts, and seeds are low in refined carbohydrates, sugars, saturated, and trans fats, and high in dietary fiber, mono unsaturated fatty acid (MUFA), poly-unsaturated fatty acid (PUFA), and anti-oxidants, which are scientifically responsible for improving the impaired lipid parameters. These food items have been clinically tested and are regarded as a priority for nutritionally managing dyslipidemia (9, 10). The present resent study was conducted on development, standardization, organoleptic evaluation, and nutritional intervention of pearl millet and sorghum millet-based recipes for patients with dyslipidemia.

Materials and Methods

Food ingredients required for the augmented mixture were purchased from the Kurukshetra (Haryana) and Yamuna Nagar (Haryana) local markets, India. The raw food ingredients purchased from the mixture were subjected to cleaning, grinding, and roasting. Considering the cost and nutritional parameters, all roasted ingredients were standardized. These ingredients were grinded so as to make a fine powdered mixture. Augmented mixture of chia seeds, walnuts and mango seed powder was developed (Figure 1). Raw materials for pearl millet and sorghum millet based recipes were purchased from the local market of Yamuna Nagar (Haryana), India. Pearl millet recipes, such as khichdi, pesarattu, chapatti and sorghum millet recipes, such as idli, upma, chapatti were augmented at incorporation levels of 5%, 10%, 15%, 10%, 15%, and 25%, respectively (Table 1).

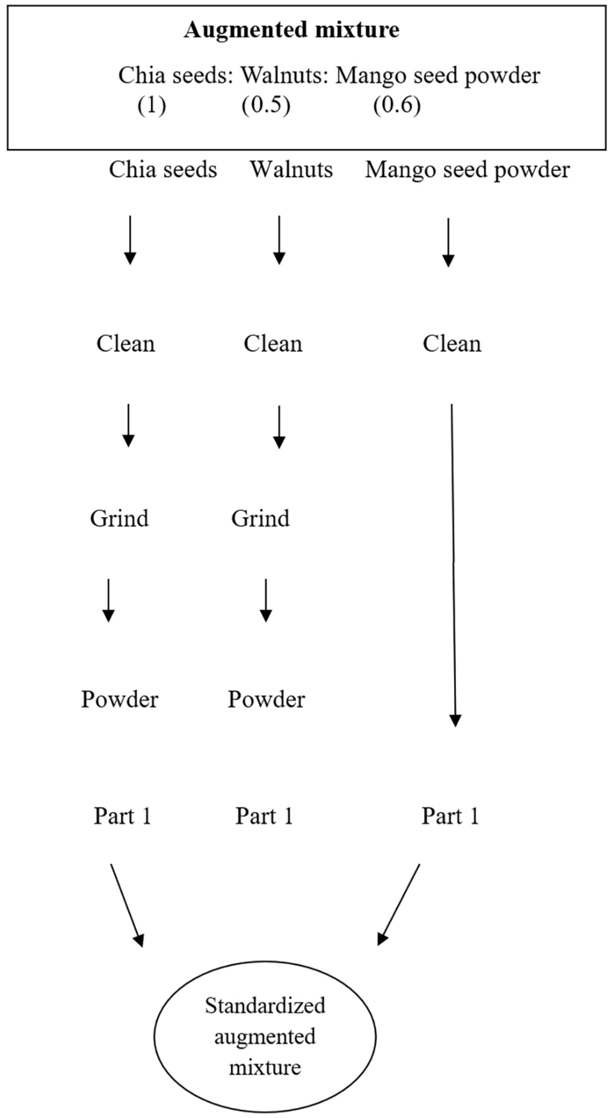

Figure 1: Development of augmented mixture of chia seeds, walnuts and mango seed powder.

Table 1: Incorporation level of augmented mixture to millet based recipes.

Pearl millet recipes	Incorporation level of augmented mixture (%)
Khichdi	10
Pesarattu	10
Chapati	8
Sorghum millet recipes	
Idli	10
Upma	10
Chapati	7.5

Several scientific studies have stated that millets have anti-cardio-lipid properties, which reduce the high incidence of lipid parameters such as total cholesterol, LDL cholesterol, and triglycerides (11-15). The ingredients of augmented mixtures also have several advantageous effects on lipid parameters (16-21).

Procedure performed in study involving human participants were in accordance with the ethical standards of the Clinical Trial Registry of India (CTRI). Biochemical lipid parameters were assessed from the subjects and this procedure requires an ethical approval for the trial which was taken from Clinical Trial Registry of India (CTRI) and University Ethical Committee. The subjects participated in the study submitted their informed consent ascertaining about their voluntary participation in the clinical trial. The registration number of the study was ctri/2022/01/039645 and its reference number was ref/2022/01/050407. Informed consent was obtained for experimentation and that it conforms to the standards currently applied in the country of origin.

Owing to these scientific properties, the developed augmented millet recipes were suitable for the management of dyslipidemia. These augmented millet-based recipes were tested for organoleptic evaluation using a 9-point hedonic scale. The nutritional value of the augmented millet-based recipes was calculated using the RDA 2023 and IFCT 2017. The nutrients calculated were energy, protein, dietary fiber, omega 3 and linoleic acid. Developed millet recipes were administered to subjects with dyslipidemia for the duration of 3 months.

Results

The organoleptic assessment of the developed pearl millet and sorghum millet recipes was conducted to determine their acceptability in comparison to corresponding control preparations. Sensory attributes evaluated included appearance, color, taste, flavor/aroma, texture, and overall acceptability. The results revealed that all the developed recipes incorporating millets at different levels demonstrated good sensory scores, falling within the "liked moderately" to "liked very much" range, indicating that millet incorporation did not adversely affect the sensory profile of traditional recipes.

The pearl millet–augmented recipes; khichdi, pesarattu, and chapatti; were prepared at incorporation levels of 10%, 10%, and 7.5%, respectively. Among these, khichdi recorded an overall acceptability of 7.9±0.31, with strong scores in appearance (8.7±0.48) and taste (8.0±0.47). Pesarattu also performed favorably, achieving the highest overall acceptability score (8.1±0.31) among the pearl millet variations, supported by desirable taste (8.2±0.63) and texture (8.2±0.42). Chapatti, even at a lower incorporation level, received a respectable overall acceptability score of 7.3±0.48, although its appearance and color slightly trailed behind the other two recipes (Table 2). When compared to control recipes, the control khichdi, pesarattu, and chapatti consistently exhibited higher sensory scores across all attributes. For instance, control khichdi and pesarattu achieved overall acceptability scores of 8.5±0.66 and 8.6±0.62, respectively. However, despite slightly lower scores, the developed pearl millet recipes still demonstrated sensory acceptability that was well within the desirable range, suggesting that the inclusion of pearl millet up to 10% maintained consumer satisfaction without compromising sensory quality (Table 2).

For sorghum-based preparations, the incorporation levels were 10% for upma and idli and 8% for chapatti. The sensory evaluation showed that sorghum idli received the highest overall acceptability (8.5±0.52), supported by excellent taste (8.7±0.48), flavor (8.2±0.78), and texture (8.6±0.69). The sorghum upma also gained favorable acceptance with an overall acceptability score of 8.3±0.82, reflecting positive consumer perception of both taste and appearance (Table 2). Sorghum chapatti, though lower in comparison, achieved an overall acceptability score of 7.4±0.51, indicating moderate acceptance and suitability for regular consumption (Table 2).

The control sorghum recipes again demonstrated higher scores, with control idli exhibiting an overall acceptability of 8.8±0.89, while control upma and chapatti recorded 8.56±0.87 and 8.7±0.75, respectively. Despite this expected difference, the developed sorghum-based recipes still maintained acceptability scores close to their control counterparts, signifying that the partial substitution of sorghum flour (8-10%) harmoniously blends with traditional recipes without negatively altering key sensory characteristics (Table 2).

Across both pearl millet and sorghum millet recipes, the organoleptic evaluation clearly demonstrated that the developed recipes were well accepted by the sensory panel. While the control versions retained slightly superior scores in every sensory attribute, the developed millet-based preparations consistently received high ratings across appearance, taste, aroma, texture, and overall acceptability. This indicates that millet incorporation, even up to 10%, did not compromise sensory quality and is acceptable for daily consumption. Furthermore, the positive sensory outcomes supported the feasibility of integrating millets into traditional diets as healthier alternatives without sacrificing palatability.

Table 2: Organoleptic evaluation of pearl millet and sorghum millet recipes (developed vs. control).

Recipe	Incorporation (%)	Appearance	Color	Taste	Flavor/ Aroma	Texture	Overall acceptability
Organoleptic scores of augmented pearl millet recipes							
Khichdi	10	8.7±0.48	7.7±0.48	8.0±0.47	7.9±0.73	7.8±0.63	7.9±0.31
Pesarattu	10	8.4±0.51	7.8±0.51	8.2±0.63	7.7±0.48	8.2±0.42	8.1±0.31
Chapatti	7.5	7.4±0.51	7.2±0.42	7.5±0.48	7.7±0.48	7.4±0.51	7.3±0.48
Control (Pearl millet, equivalent recipes)							
Khichdi		8.8±0.55	8.5±0.66	8.8±0.66	8.4±0.77	8.7±0.69	8.5±0.66
Pesarattu		8.7±0.71	8.2±0.68	8.6±0.75	8.0±0.57	8.5±0.49	8.6±0.62
Chapatti		8.5±0.65	8.1±0.56	8.2±0.57	8.3±0.67	8.3±0.72	8.2±0.69
Organoleptic scores of augmented sorghum millet recipes							
Upma	10%	8.3±0.82	8.2±0.7	8.3±0.67	7.9±0.67	8.0±0.81	8.3±0.82
Idli	10%	8.7±0.48	7.9±0.7	8.7±0.48	8.2±0.78	8.6±0.69	8.5±0.52
Chapatti	8%	7.6±0.51	7.3±0.4	7.2±0.63	7.1±0.73	7.1±0.56	7.4±0.51
Control (Sorghum Millet–Equivalent Recipes)							
Upma		8.5±0.91	8.4±0.62	8.6±0.71	8.6±0.69	8.5±0.88	8.56±0.87
Idli		8.8±0.68	8.7±0.78	8.8±0.66	8.6±0.8	8.8±0.73	8.8±0.89
Chapatti		8.5±0.73	8.4±0.59	8.5±0.63	8.6±0.77	8.6±0.78	8.7±0.75

*Scores significant at 95% significance where $p \leq 0.05$ (paired t test).

Table 3: Organoleptic statistical analysis of millet-based recipes.

Recipe	Developed Mean±SD	Control Mean±SD	Paired t-test (*p* value)
Pearl Millet Khichdi	7.9±0.31	8.5±0.66	0.02166*
Pearl Millet Pesarattu	8.1±0.31	8.6±0.62	0.0108*
Pearl Millet Chapatti	7.3±0.48	8.2±0.69	0.0038*
Sorghum Upma	8.3±0.82	8.56±0.87	0.0158*
Sorghum Idli	8.5±0.52	8.8±0.89	0.00120*
Sorghum Chapatti	7.4±0.51	8.7±0.75	0.00044*

*Significant at $p \leq 0.05$.

The slight decline in scores, relative to controls, can be attributed to the characteristic flavor, texture, and color of millet flours, yet these changes remained within acceptable limits (Table 2).

Table 3 presents the statistical comparison of organoleptic scores between the developed millet-based recipes and their respective control preparations. The paired t-test was applied to determine whether the incorporation of pearl millet and sorghum millet had any significant impact on sensory acceptability. Across all recipes, the developed versions received slightly lower mean scores than the controls; however, the differences, although statistically significant, were relatively small and remained within acceptable sensory limits. For pearl millet-based recipes, khichdi (7.9±0.31), pesarattu (8.1±0.31), and chapatti (7.3±0.48) all displayed significant differences when compared to their control samples, with *p* values of 0.02166, 0.0108, and 0.0038, respectively. Despite the statistical significance, the developed versions maintained high overall acceptability, indicating successful incorporation of 7.5-10% pearl millet without compromising palatability.

Similarly, sorghum-based recipes; including upma (8.3±0.82), idli (8.5±0.52), and chapatti (7.4±0.51); also demonstrated significant differences compared to their controls, with *p* values of 0.0158, 0.00120, and 0.00044, respectively. The sorghum idli, in particular, exhibited strong acceptability, closely approaching the control sample's score. Overall, the statistical analysis confirmed that while the control preparations consistently scored higher, the developed millet-incorporated recipes still fell well within favorable sensory ranges. The significant *p* values suggest detectable sensory differences; however, these differences are not large enough to hinder consumer acceptability. This supports the potential for partial millet incorporation in traditional recipes as a feasible and acceptable dietary modification.

Table 4 present a detailed comparison of the nutritive values of traditional control recipes and their corresponding millet-based and value-added variants formulated using pearl millet and sorghum millet. The results clearly demonstrated that the inclusion of millets significantly enhanced the nutritional quality of all recipes, with consistent improvements observed in energy, protein, dietary fiber, MUFA, and linoleic acid content.

Table 4: Nutritive value of millet recipes (pearl millet+sorghum millet).

Recipe	Type	Energy (kcal)	Protein (g)	Dietary fiber (g)	MUFA (g)	Linoleic acid (g)
Nutritive value of pearl millet recipes						
Khichdi	Control	200	10	3	–	–
	Millet-based	252	11.3	5.8	0.314	0.553
	Value-added	274.9	12.7	6.69	0.817	1.60
Pesarattu	Control	74.3	7.86	4.7	1.89	1.78
	Millet-based	81.2	9.1	4.9	2.01	1.97
	Value-added	108.6	10.7	6.0	2.61	3.23
Chapatti	Control	120	3.1	3.9	0.06	0.1
	Millet-based	144.1	4.7	4.7	0.400	0.418
	Value-added	162.4	5.82	5.4	0.802	1.26
Nutritive value of sorghum millet recipes						
Idli	Control	140.5	4	2	–	–
	Millet-based	163.8	5.8	5.1	0.149	0.267
	Value-added	200.4	8.04	6.5	0.954	1.955
Upma	Control	97.8	1.5	1.2	0.04	0.06
	Millet-based	130.5	3.9	4.2	0.160	0.290
	Value-added	153.4	5.3	5.09	0.663	1.34
Chapatti	Control	120	3.1	3.9	0.06	0.1
	Millet-based	139.2	4.2	5.4	0.21	0.226
	Value-added	152.9	5.04	6.01	0.51	0.859

*Scores significant at 95% significance where $P \leq 0.05$ (paired t test)

Across all pearl millet recipes; khichdi, pesarattu, and chapatti; a progressive nutritional improvement was evident from the control to the millet-based and further to the value-added versions. Pearl millet khichdi showed a substantial rise in energy from 200 kcal (control) to 274.9 kcal (value-added), alongside marked increases in protein (10 g to 12.7 g) and dietary fiber (3 g to 6.69 g). A similar enhancement was noted in MUFA and linoleic acid, which were absent in the control but increase significantly with millet enrichment (Table 4).

Pesarattu, a protein-rich recipe by nature, also benefited from the addition of pearl millet, showing increases from 7.86 g to 10.7 g in protein and from 4.7 g to 6.0 g in dietary fiber. The value-added version demonstrated the highest enhancement across all nutrient parameters. Likewise, chapatti enriched with pearl millet exhibited improved nutritional density, with energy increasing from 120 to 162.4 kcal and fiber from 3.9 to 5.4 g. MUFA and linoleic acid also increase substantially, contributing a healthier fat profile (Table 4).

Sorghum millet-based recipes similarly revealed consistent nutritional enrichment. Sorghum idli demonstrated notable increases in energy (140.5 to 200.4 kcal), protein (4 to 8.04 g), and fiber (2 to 6.5 g). The introduction of sorghum significantly boosted MUFA and linoleic acid, both absent in the control version (Table 4). Upma exhibited a remarkable enhancement in dietary fiber, rising from 1.2 to 5.09 g in the value-added version, alongside increases in energy and protein content. MUFA increased from 0.04 to 0.663 g, while linoleic acid rised from 0.06 to 1.34 g. Sorghum chapatti also showed similar trends, with energy, protein, and fiber content significantly higher than the control version (Table 4). Comparative analysis across both millet groups demonstrated that millet incorporation consistently elevated the nutritional profile of all recipes. The magnitude of improvement was especially prominent in dietary fiber, MUFA, and linoleic acid as key components associated with improved metabolic and cardiovascular health. The value-added formulations emerged as the most nutritionally superior versions, reflecting the synergistic effect of higher millet inclusion combined with additional nutrient-rich ingredients (Table 4).

Table 5 summarizes the statistical comparison of key nutritive parameters; energy, protein, dietary fiber, MUFA, and linoleic acid; between the developed millet-based recipes and their corresponding control versions. The paired t-test was applied to determine whether millet incorporation produced significant nutritional enhancement. Overall, the results indicated substantial improvement across most nutrient categories, particularly in the developed value-added recipes. The statistical evaluation of energy content revealed highly significant differences ($p \leq 0.05$) between the developed and control versions for all recipes including both pearl millet and sorghum millet preparations. Pearl millet khichdi, pesarattu, and chapatti exhibited p values of 0.000129, 0.000301, and 0.000104, respectively, confirming a marked increase in caloric density upon millet incorporation.

Table 5: Statistical analysis of nutritive values (energy, protein, dietary fiber, mufa, linoleic acid).

Recipe	Nutrient	Developed	Control	*P* value
Energy and protein statistical significance				
Pearl millet khichdi	Energy	274.9	200	0.000129*
Pesarattu	Energy	108.6	74.3	0.000301*
Chapatti	Energy	162.4	120	0.000104*
Sorghum Upma	Energy	152.9	97.8	2.7769*
Idli	Energy	200.4	140.5	2.5230*
Chapatti	Energy	152.9	120	3.7685*
Pearl millet khichdi	Protein	12.7	10	0.01345*
Pesarattu	Protein	10.7	7.86	0.00156*
Chapatti	Protein	5.82	3.1	0.00451*
Sorghum Upma	Protein	8.04	4	2.4200*
Idli	Protein	5.3	1.5	2.5678*
Chapatti	Protein	5.04	3.1	2.1010*
Dietary fiber, MUFA, and linoleic acid statistical significance				
Pearl millet khichdi	DF	6.69	3	1.45152
Pesarattu	DF	6.0	4.7	0.00285*
Chapatti	DF	5.4	3.9	0.01047*
Sorghum Upma	DF	6.5	2	2.6522
Idli	DF	5.09	1.2	0.00357*
Chapatti	DF	6.01	3.9	0.00150*
Pearl millet khichdi	MUFA	0.817	–	0.020*
Pesarattu	MUFA	2.61	1.89	0.025*
Chapatti	MUFA	1.26	0.1	0.084*
Sorghum Upma	MUFA	0.954	–	0.00133*
Idli	MUFA	0.663	0.06	0.0051*
Chapatti	MUFA	0.51	0.1	0.0228*
Pearl millet khichdi	Linoleic acid	0.817	–	0.585
Pesarattu	LA	2.61	1.89	0.756
Chapatti	LA	0.802	0.06	0.0005*
Sorghum Upma	LA	0.954	–	0.0035*
Idli	LA	0.663	0.04	0.0010*
Chapatti	LA	0.51	0.06	0.0056*

A similar trend was observed for sorghum upma, idli, and chapatti, each demonstrated strong significance, thereby indicating that the addition of millet substantially boosts the overall energy value of these recipes (Table 5).

Protein content also showed significant enhancement across all recipes. For pearl millet-based dishes, protein levels increased significantly in khichdi (p=0.01345), pesarattu (p=0.00156), and chapatti (p=0.00451). Sorghum millet-based recipes displayed even stronger improvements with notable significance in upma, idli, and chapatti (p values of 2.4200, 2.5678, and 2.1010, respectively). These findings highlight the protein-enriching potential of both millets, especially when incorporated into traditional carbohydrate-based preparations (Table 5). Dietary fiber analysis demonstrated significant improvements in most recipes. Pearl millet pesarattu (p=0.00285) and chapatti (p=0.01047) showed highly significant increases, whereas pearl Millet khichdi did not show statistical significance despite showing an improvement in value. Sorghum-based recipes presented a similar pattern, with idli (p=0.00357) and chapatti (p=0.00150) showing statistically significant fiber enhancements. These outcomes reinforced the well-known fiber-rich nature of millets and their potential role in digestive health and lipid regulation (Table 5).

MUFA content was significantly higher in most developed recipes compared to their controls. Pearl millet khichdi and pesarattu showed significant increases (p=0.020 and p=0.025, respectively), whereas chapatti did not reach statistical significance. Sorghum-based upma, idli, and chapatti all demonstrated strong significance, indicating improved healthy-fat profiles in recipes formulated with sorghum millet. The increase in MUFA was particularly important for cardiometabolic health, given its association with improved lipid regulation (Table 5).

Linoleic acid, a key essential fatty acid, showed mixed results. Although pearl millet khichdi and pesarattu did not show significant differences, pearl millet chapatti demonstrated highly significant improvement (p=0.0005). Sorghum-based recipes showed strong statistical significance across upma (p=0.0035), idli (p=0.0010), and chapatti (p=0.0056), indicating enhanced essential fatty acid availability through sorghum incorporation. These improvements highlight the potential of millets to contribute beneficial fatty acids in daily diets. These nutritive value results were scientifically comparable with those of several studies on the nutritive value of pearl and sorghum millet- based recipes.

Figure 2 demonstrates percentage (%) of improvement in variant lipid parameters among dyslipidemic subjects. These developed and augmented millet recipes with significant nutritional values were fed to dyslipidemic subjects for the duration of three months and results highlighted that significant improvements were observed in total cholesterol, LDL cholesterol, HDL cholesterol, triglycerides, and VLDL cholesterol by 13%, 11%, 7.10%, 10.2%, and 11.8%, respectively.

Discussion

The present study systematically evaluated the organoleptic properties, nutritive value, and statistical significance of traditional Indian recipes developed with pearl millet and sorghum millet. The sensory assessment indicated that millet incorporation at levels of 7.5-10% did not adversely affect the overall acceptability of the recipes. Both pearl millet– and sorghum-based dishes were rated within the "liked moderately" to "liked very much" range, demonstrating favorable consumer perception. While control recipes scored slightly higher across appearance, color, taste, flavor, and texture, the differences were minimal and remained within acceptable limits, confirming that partial millet substitution is feasible without compromising palatability.

Statistical evaluation of organoleptic scores further supported these observations. Paired t-tests revealed significant differences between developed and control recipes; however, these differences did not negatively influence overall sensory acceptability. The slight variations in flavor and texture can be attributed to the characteristic earthy taste and granular structure of millet flours, which were still well tolerated by the sensory panel. Nutritional analysis highlighted substantial enhancement of key dietary components. Energy, protein, and dietary fiber content increased consistently across both pearl millet and sorghum recipes, with value-added versions showing the highest nutrient density. MUFA and linoleic acid, largely absent in control recipes, were significantly elevated in millet-based formulations, contributing to improved lipid profiles and cardiovascular benefits. These findings underscore the ability of millets to enrich traditional dishes with health-promoting nutrients while maintaining culinary acceptability.

The statistical significance of nutritional parameters further validated the impact of millet incorporation. Most recipes demonstrated highly significant improvements in energy, protein, and essential fatty acid content, as well as notable increases in dietary fiber. This confirms that both pearl millet and sorghum can serve as effective functional ingredients capable of enhancing macronutrient and micronutrient profiles in commonly consumed foods. The control sorghum recipes demonstrated higher scores, with control idli exhibiting an overall acceptability of 8.8±0.89, while control upma and chapatti recorded 8.56±0.87 and 8.7±0.75, respectively. Despite this expected difference, the developed sorghum-based recipes still

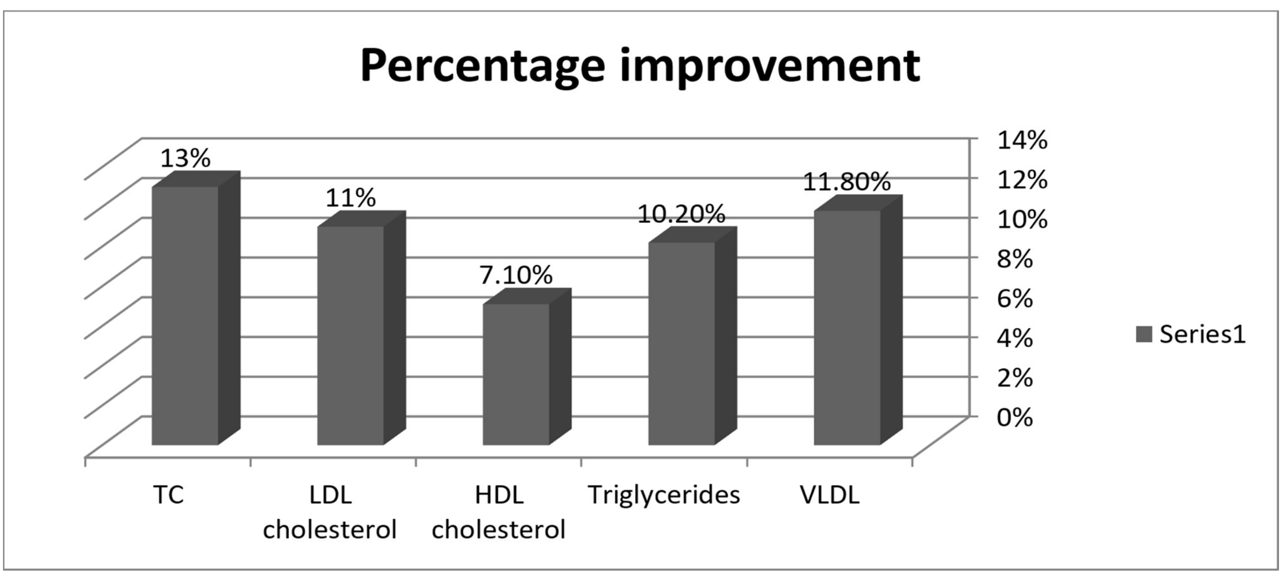

Figure 2: Percentage (%) improvement in variant lipid parameters among dyslipidemic subjects.

maintained acceptability scores close to their control counterparts, signifying that the partial substitution of sorghum flour (8-10%) harmoniously was blended with traditional recipes without negatively altering key sensory characteristics. The results obtained were scientifically equivalent to those of studies conducted on pearl millet (22-24) and sorghum millet food products (25-27).

Sorghum-based recipes showed strong statistical significance across upma, idli, and chapatti, indicating enhanced essential fatty acid availability through sorghum incorporation. These improvements highlight the potential of millets to contribute beneficial fatty acids in daily diets. These nutritive value results were scientifically comparable with those of several studies on the nutritive value of pearl and sorghum millet- based recipes (15, 28-31). These developed and augmented millet recipes with significant nutritional values were fed to dyslipidemic subjects for the duration of three months and results highlighted that significant improvements were observed in total cholesterol, LDL cholesterol, HDL cholesterol, TG, and VLDL cholesterol. These results were similar to those of different studies conducted on the role of millet in the management of dyslipidemia (13-15, 32-35).

The present study evaluated the sensory acceptability and nutritive enhancement of traditional Indian recipes formulated with pearl millet and sorghum millet at varying levels of incorporation. The findings from the organoleptic evaluation indicated that all millet-based recipes were well accepted by the sensory panel, falling within the "liked moderately" to "liked very much" categories. Although the control counterparts consistently scored higher for appearance, color, taste, flavor, and texture, the differences between developed and control preparations were relatively small. This demonstrates that partial substitution of wheat or rice flour with 7.5-10% millet flour did not adversely affect sensory quality. Pearl millet-based pesarattu and khichdi showed particularly strong acceptability, while sorghum-based idli and upma also performed well, suggesting that both millets can be successfully integrated into commonly consumed dishes with minimal compromise on palatability (34-37).

The statistical analysis of overall acceptability scores further confirmed significant differences between the control and developed recipes. However, despite statistical significance, the practical difference in sensory perception remained acceptable, reinforcing that millet incorporation did not drastically alter consumer experience. Similar findings were reported in earlier studies where moderate millet inclusion retained favorable sensory characteristics in traditional foods. The slight flavor and texture differences observed may be attributed to the naturally earthy taste and granular structure of millet flours, yet these remained within tolerable limits for the sensory panel (38-40).

Nutritional evaluation revealed substantial improvements in energy, protein, dietary fiber, MUFA, and linoleic acid content in both pearl millet and sorghum millet recipes. The shift from control to millet-based and value-added versions showed a progressive rise in nutrient density across all recipes. Pearl millet khichdi and pesarattu demonstrated notable increases in protein and dietary fiber, while sorghum-based idli and upma also showed marked enhancement. These improvements reflect the intrinsic nutrient richness of millets, particularly their high fiber and micronutrient profiles, which contribute to better metabolic outcomes. Additionally, MUFA and linoleic acid; which were minimal or absent in some control dishes; were significantly elevated in value-added formulations, supporting better lipid metabolism and cardiovascular health.

The statistical significance of nutrient enhancement further strengthened the findings. Energy and protein values showed highly significant differences across all recipes, confirming that millet incorporation markedly boosts macronutrient content. Dietary fiber also demonstrated significant improvement in most recipes, particularly in pearl millet pesarattu and sorghum-based idli and chapatti. MUFA and linoleic acid levels illustrated significant elevation in several formulations, especially sorghum-based dishes, highlighting the beneficial lipid profile associated with millet consumption. These outcomes were scientifically comparable to earlier studies demonstrating the nutrient-enriching potential of pearl millet and sorghum in traditional recipes (38-40).

Overall, the combined results across sensory, nutritional, and statistical analyses clearly demonstrated that millets can be effectively incorporated into everyday diets without compromising acceptability while significantly enhancing nutrient density. The findings underscore the potential of pearl millet and sorghum millet as valuable functional ingredients capable of addressing nutritional gaps and supporting dietary interventions for lifestyle-related disorders such as diabetes, dyslipidemia, and obesity. The study provides strong evidence that millet-based food products can serve as sustainable, health-promoting alternatives in modern diets, aligning with national efforts to promote millet consumption for improved public health.

Conclusion

Overall, the study established that partial replacement of wheat or rice flour with millet flour provided a dual advantage: maintaining desirable sensory characteristics and delivering significant nutritional benefits. The findings indicated that millet-based formulations were suitable for everyday consumption and could play a critical role in addressing dietary deficiencies, improving metabolic health, and supporting preventive strategies against lifestyle-related disorders such as diabetes, obesity, and dyslipidemia. It was shown that pearl millet and sorghum millet were not only nutritionally superior but also organoleptically acceptable alternatives for traditional Indian recipes. Their incorporation aligns with current health and nutrition recommendations, promoting sustainable dietary practices; while offering functional benefits. This study provides strong evidence supporting millet-based interventions in public health nutrition, highlighting their potential to improve diet quality and enhance overall well-being.

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Authors' Contribution

RG conceptualized, investigated, interpreted and analyzed the data and wrote the manuscript. TJK conceptualized, formally analyzed, drafted, revised and approved the written version of article deliberately.

Conflict of Interest

There are no conflicts of interest.

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