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Formulation of Functional Granola Bars Supplemented with Oats and Macadamia Nuts to Improve Lipid Profile

Hina Aslam
Department of Human Nutrition & Dietetics, Riphah International University, Faisalabad Campus, Punjab, Pakistan Email: hinaaslam283@gmail.com

Nida Iqbal
Department of Human Nutrition & Dietetics, Riphah International University, Faisalabad Campus, Punjab, Pakistan Email: dr.nida@riphahfsd.edu.pk

Zohaib Nadeem
Faculty of veterinary sciences (FVS), University of Agriculture, Faisalabad, Punjab, Pakistan Email: drzohaibuaf@gmail.com

Rida Chaudhary
Department of Human Nutrition & Dietetics, Riphah International University, Faisalabad Campus, Punjab, Pakistan Email: ridachaudhary112@gmail.com

Laiba Kamran
Department of Human Nutrition & Dietetics, Riphah International University, Faisalabad Campus, Punjab, Pakistan Email: laibakamran964@gmail.com

Rida Aslam
Department of Psychology, Riphah International University, Faisalabad Campus, Punjab, Pakistan Email: ridaaslam082@gmail.com

Amna Javed
Department of Human Nutrition & Dietetics, Riphah International University, Faisalabad Campus, Punjab, Pakistan Email: jamna7802@gmail.com

Author Details

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Corresponding E-mail & Author*:
Hina Aslam
Email: hinaaslam283@gmail.com
Nida Iqbal
Email: dr.nida@riphahfsd.edu.pk

Abstract

Hyperlipidemia was characterized by elevated total cholesterol concentrations, whereas dyslipidemia was defined by aberrant levels of LDL, Triglycerides, vLDL and HDL within the bloodstream. The study endeavored to formulate functional granola bars fortified with oats and macadamia nuts to improve lipid profile. Dyslipidemia constituted a significant feature of pathological characteristics of lipid profiles, and both oats and macadamia nuts were recognized for their therapeutic attributes, encompassing cholesterol reduction, improved lipid profile, cardioprotective, anti-inflammatory, antioxidant, and metabolic benefits. The research was conducted within the Department of Human Nutrition and Dietetics at Riphah International University, Faisalabad, focusing on cholesterol lowering benefits of oats and macadamia nuts. Granola bars formulated with oats and macadamia nuts. Many formulations were made in which T2 (60 % oats and 40 % macadamia nuts) was more efficient for lowering lipid profile. The ingredients were prepared, subjected to proximate composition analysis, and incorporated into granola bars at varying concentrations. The supplemented granola bars underwent nutritional analysis including TFC and TPC, along with DPPH radical scavenging activity to

assess antioxidant capacity. Sensory evaluation was performed at 0, 15, and 30-day storage intervals utilizing a 9-point Hedonic Scale. Statistical analysis was executed employing a Completely Randomized Design (CRD) model.

INTRODUCTION

Dyslipidemia refers to an abnormal increase in blood lipid concentrations, including cholesterol and triglycerides. Cardiovascular disease (CVD) has emerged as a major global health concern and is among the leading causes of death worldwide. Elevated lipid levels significantly contribute to the development of CVD, alongside other established risk factors such as hypertension, diabetes mellitus, and tobacco use. Statins and fibrates are commonly prescribed to control high cholesterol and triglyceride levels, respectively; however, their long-term use may be associated with adverse effects, particularly involving hepatic and muscular systems. As a result, lifestyle modification remains an essential and effective strategy in the prevention and management of dyslipidemia (Purva et al., 2020).

Lipids are essential for your body's proper functioning, growth, and energy. Cholesterol and Triglycerides are two significant lipids found in the blood. Total Cholesterol includes HDL (High Density Lipoprotein) which helps to remove LDL from the blood, LDL (Low Density Lipoprotein) that can build up in blood vessels and can increase heart disease, stroke, etc. and vLDL (Very Low-Density Lipoprotein) functions to transport triglycerides from the liver to other somatic cells throughout the body. The other type of lipids is Triglycerides which are a form of fat present in the bloodstream, serving as an energy source. Elevated triglyceride levels, particularly in conjunction with low HDL or high LDL, are correlated with increased risks of coronary artery disease (Chen et al., 2024).

Cholesterol is a lipid-soluble compound that is fundamental to human health and normal physiological functioning. It plays a critical role in cellular biology by forming an integral part of cell membranes, where it supports membrane strength and influences permeability and fluidity. Because cholesterol is poorly soluble in aqueous environments, it is transported through the circulation together with triglycerides in specialized lipoprotein particles, including high-density lipoproteins (HDL), low-density lipoproteins (LDL), very-low-density lipoproteins (VLDL), intermediate-density lipoproteins (IDL), and chylomicrons. Clinical evaluation of lipid status is based on the measurement of these lipoprotein fractions in blood. In individuals who are fasting, chylomicrons are typically not detectable in plasma (Huff et al., 2023).

The prevalence of hyperlipidemia, according to the Centers for Disease Control and Prevention indicate that approximately 53% of American adults have abnormal LDL-C levels, yet only 35% achieve recommended lipid targets. Furthermore, approximately 31 million adults have TC levels exceeding 6.24 mmol/L, and individuals with uncontrolled hyperlipidemia face a 200% increased risk of cardiovascular events compared to the general population (Karr, 2017).

In China, the incidence of adult hyperlipidemia has risen to 35.6%, with a notable increase in prevalence among young demographics. The overall prevalence of dyslipidemia was observed to be 24.5%, with a significantly higher incidence among females compared to males (Wang et al., 2023).

The regulation of cholesterol balance in the body is governed by multiple interconnected processes, including absorption from the intestine, endogenous synthesis in the liver via the HMG-CoA reductase pathway, elimination through bile, and receptor-mediated uptake by cells through low-density lipoprotein (LDL) receptors. When LDL particles accumulate in excess, particularly in modified forms such as oxidized LDL, they contribute significantly to vascular injury by promoting endothelial dysfunction, foam cell generation, and the formation of atherosclerotic plaques (Schoeneck & Iggman, 2021).

Dyslipidemia typically presents without noticeable symptoms and is frequently identified incidentally during routine biochemical screening. However, markedly elevated triglyceride levels exceeding 1000 mg/dL may precipitate acute pancreatitis. Although clinical manifestations such as tendon xanthomas, corneal arcus, or eruptive xanthomas can occur in severe or genetically inherited lipid disorders, these features are rarely observed in dyslipidemia primarily driven by dietary factors. Confirmation of dyslipidemia is based on lipid profiling performed in either the fasting or non-fasting state, measuring total cholesterol, low-density lipoprotein cholesterol, high-density lipoprotein cholesterol, and triglycerides. Cardiovascular risk assessment tools are subsequently applied to guide therapeutic decision-making (Mach et al., 2020).

Epidemiological evidence from global and regional investigations indicates a substantial burden of dyslipidemia across populations. Large-scale meta-analyses have demonstrated that elevated triglycerides and reduced HDL-C levels are among the most prevalent lipid abnormalities worldwide, with significant variation observed across geographic regions and between sexes. Given the sustained high prevalence of these lipid disorders, population-wide nutritional interventions remain a critical strategy alongside pharmacological management (Pirillo et al., 2021).

Macadamia Nuts (*Macadamia integrifolia)* refer to the four types of plant species indigenous to the states of New South Wales and Queensland, Australia, including *Macadamia integrifolia*, *Macadamia jansenii, Macadamia ternifolia, and Macadamia tetraphylla.* These species belong to the Proteaceae family with two species (*M. integrifolia, & M. tetraphylla)* being of commercial significance for their nuts. The other two (*M. jansenii and M. ternifolia),* yield nuts containing substantial quantities of cyanogenic glycosides, rendering them toxic and thus unsuitable for human consumption. The edible nuts are highly esteemed for their distinctive flavor and exceptional nutritional value, encompassing essential nutrients such as vitamins (particularly B6), minerals (manganese, iron, magnesium), carbohydrates, and dietary fiber. In contrast to other nutritious edible nuts like almonds, macadamia nuts possess high lipid content (75%), primarily monounsaturated fats, which constitute 59% of their total fat content, and exhibit a comparatively low protein content (8%) (Hu et al., 2019).

Macadamia nuts have recently emerged as a significant export commodity from Hawaii in recent years. Comprising approximately 75% fat by weight, these nuts drive 88% of their energy from lipids. Monounsaturated fatty acids constitute the predominant fat content, with oleic acid being the primary monounsaturate and palmitoleic acid present in substantial quantities, a component notably scarce in olive oil. Macadamia nuts represent a nutritionally complex food source, offering considerable amounts of carbohydrates, fiber, vitamins and minerals (Curb et al., 2000).

Tree nuts are widely consumed as nutritious snacks around the world, either in their raw form or after roasting. They are valued for their high content of essential amino acids and unsaturated fatty acids. Among tree nuts, macadamia nuts (*Macadamia tetraphylla*) are prized for their subtle, buttery flavor and creamy texture. Roasting is the most commonly used method to process macadamia nuts, as it improves shelf life and enhances sensory qualities such as flavor, aroma, color, texture, and overall appearance. The changes during roasting are largely due to Maillard reactions and, to some extent, lipid oxidation. Consumers generally prefer roasted nuts for their crisp texture and distinctive taste. In recent years, macadamia cultivation has expanded rapidly in southern China, particularly in Yunnan and Guangxi provinces, with the total planting area reaching tens of thousands of hectares (Tu et al., 2021).

Macadamia nuts, while not solely prized for their palatability, offer substantial benefits, particularly for cardiovascular well-being. These nuts are replete with monounsaturated fatty acids, commonly referred to as “beneficial fats." The consumption of these wholesome fat has been correlated with a reduction in Low Density Lipoproteins (horrific cholesterol) levels and an elevation in High Density

Lipoprotein (good cholesterol), thereby contributing to enhanced cardiac health. Macadamia nuts have many nutritional benefits as these nuts have excessive Monounsaturated Fatty Acids, which are heart healthy and reduce LDL cholesterol levels, filled with abundant antioxidants like flavonoids and tocotrienols which combat oxidative strain and inflammation, daily intake of these nuts can reduce the chances of heart diseases by increasing HDL cholesterol levels. Other health benefits are strengthened cognitive health, improves skin health, help regulate glucose levels, boosts bone health as well as support in metabolic fitness (Fang & McClements., 2026).

Oats *(Avena sativa L.)* are categorized as a whole grain rich in soluble fibre, β-glucan, lipids, protein and specific micronutrients, and polyphenols (avenanthramides). Whole grains including oats, are vital for healthy lifestyle. Dietary guidelines and nutritional policies in many countries worldwide advocate for whole grain consumption, including USA, Australia, Canada, Mexico, South America nations, European countries, and Asian countries. The predominance of evidence derived from observational and clinical investigations suggests that the consistent consumption of a minimum of three servings of whole grains (16 g/serving), including wheat, oats, rice, rye, barley, millet, quinoa and maize, may lower the risk of developing various chronic ailments (Aune et al., 2016).

Oat, a soluble dietary fiber inherent in the endosperm cell walls of oats, has garnered substantial attention owing to its hypocholesterolemic attributes. In 1997, the United States Food and Drug Administration granted approval for a health claim pertaining to beta-glucan soluble fiber derived from oats for its efficacy in mitigating plasma cholesterol levels and reducing the incidence of heart disease. Concurrently, in 2004, the United Kingdom Joint Health Claims Initiative (JHCI) similarly endorsed a cholesterol lowering health claim for oat beta-glucan (Othman et al., 2011).

Oats serve as a source of soluble fiber, primarily in the form of β-glucan, alongside other minor constituents such as arabinoxylan and xyloglucan. Furthermore, they contain insoluble fiber, protein, lipids, phenolic compounds, vitamins, and minerals. While other components within oats may exert an influence, the demonstrated cholesterol-lowering efficacy of oats is associated with an augmentation in the viscosity of the gastrointestinal contents, which subsequently facilitates the excretion of bile acids and cholesterol via feces. Notably, the isolated consumption of β-glucan has been shown to independently reduce serum cholesterol (Joyce et al., 2019).

Honey is a natural product created by honey bees, recognized for its sweet taste and thick, syrup-like texture. It typically exhibits a golden-yellow color and contains a complex mixture of compounds that contribute to its unique physiochemical and antioxidant properties. Primarily, honey is a concentrated solution of sugars, but it also includes water, proteins, enzymes, organic acids, vitamins, lipids, minerals, phenolic acids, flavonoids, and other bioactive components in smaller amounts. Throughout history, honey has been widely consumed and applied in food, medicine, and beverages. It is valued not only as a natural sweetener but also for its antimicrobial activity, demonstrating antibacterial and antifungal properties. Various ancient civilizations, including those in India, Egypt, and Greece, recognized the therapeutic benefits of honey, and traditional Ayurvedic texts specifically emphasize its medicinal importance. In recent times, honey has attracted renewed interest due to a growing preference for natural remedies and herbal therapies, as people become increasingly cautious about the side effects associated with conventional allopathic medicines (Kumar et al., 2024).

The benefits of consuming granola bars formulated with oats and macadamia nuts are substantial, providing a potent combination of nutrients effective for cholesterol management. Different foods lower cholesterol in various ways such as oats deliver beta-glucan, a soluble fiber, which binds cholesterol and its precursors in digestive system and drags them out of the body before they get into circulation (LeWine, 2024).

MATERIAL and METHODOLOGY

The present study was conducted in the Department of Human Nutrition and Dietetics at Riphah International University, Faisalabad, Pakistan. The research was designed to evaluate the biological effects of granola bars formulated from oats, macadamia nuts, and honey, with the objective of reducing total cholesterol levels and enhancing high-density lipoprotein (HDL) concentrations.

Granola bars are convenient vehicles for incorporating ingredients with functional value. Bars were formulated with oats, macadamia nuts and honey. The macadamia nuts were finely chopped to achieve a particle size comparable to that of oat flakes. The chopped macadamia nuts were then combined with oats and subjected to sautéing for approximately 2–3 minutes over moderate heat, with continuous stirring to ensure uniform toasting. Following this, honey, which is a natural binder, was incorporated into the mixture and stirred thoroughly to facilitate even coating and binding of the ingredients. The resulting mixture was subsequently transferred to a prepared tray, evenly spread, and firmly compressed to form a cohesive layer. Finally, the product was allowed to cool and solidify before being portioned into granola bars (Lopez et al., 2025).

Table 1: *Treatment Plan*

Treatments	Oats	Macadamia Nuts
T_0	100 %	0 %
T_1	70 %	30 %
T_2	60 %	40 %
T_3	50 %	50 %
T_4	40 %	60 %

The product was analyzed for the proximate composition including moisture content, ash content, crude fat, crude fiber, crude protein and NFE by following the method of (AOAC, 2016). The manganese content of the granola bar was analyzed following the procedure outlined by (AOAC, 2016) using Atomic Absorption Spectroscopy (AAS). The total phenolic content of oats and macadamia nuts-based granola bar extracts were calculated according to (Johari and Khong, 2019) and was determined using the method based on the Folin-Ciocalteu assay. The total flavonoid content (TFC) was determined using the aluminum chloride ($AlCl_3$) colorimetric method as described by (Shraim et al., 2021). The antioxidant potential of the sample was determined using the DPPH free radical scavenging assay. The granola bars with various formulations were submitted to sensory assessment using the Hedonic Scale at various storage intervals. The participants assessed selected sensory attributes, namely taste, texture, color, and overall acceptability. Sensory scoring was performed using a nine-point hedonic scale (Sethupathy and Moses, 2019). The collected data were finalized and outcomes from contemporary research were statistically analyzed by applying completely randomized design (CRD) for further analysis according to the protocol defined by Montgomery (2018).

RESULTS and DISCUSSION

Granola bars prepared from oats and macadamia nuts can be considered a promising functional food for managing blood cholesterol levels. Oats are particularly valued for their high content of β-glucan, a type of soluble fiber that forms a viscous gel in the digestive tract. This gel slows down the absorption of cholesterol and bile acids, leading to a reduction in total cholesterol and low-density lipoprotein (LDL) concentrations in the bloodstream. Regular intake of oat-based products has been consistently linked with improved lipid profiles and reduced risk of cardiovascular diseases. Incorporating oats into a convenient snack form such as granola bars increases their acceptability and makes it easier for individuals to include cholesterol-lowering foods in their daily diet.

The integration of oats and macadamia nuts into granola bars presents a practical and nutritious approach to dietary cholesterol management. In this study, granola bars developed from oats and macadamia nuts were analyzed for their bioactive properties using extraction, phytochemical screening, and biological evaluations. The extraction process enabled the recovery of important compounds such as phenolics and flavonoids, while preliminary screening confirmed the presence of key phytochemicals associated with cholesterol-lowering effects. In vitro assays demonstrated notable antioxidant activity, indicating the potential to reduce oxidative stress.

Table 2: *Proximate Analysis of Granola bars supplemented with Oats and Macadamia nuts*

Parameters	T_0	T_1	T_2	T_3	T_4
Moisture	**3.50**±0.25^{a}	**3.40**±0.24^{ab}	**3.35**±0.25^{ab}	**3.30**±0.25^{b}	**3.25**±0.24^{b}
Ash	**2.10**±0.20^{a}	**2.02**±0.19^{ab}	**1.98**±0.19^{ab}	**1.92**±0.18^{b}	**1.85**±0.17^{b}
Fat	**10.20**±0.3^{e}	**11.80**±0.32^{d}	**13.20**±0.30^{c}	**14.60**±0.31^{b}	**16.0**±0.30^{a}
Protein	**8.0**±0.22^{e}	**8.80**±0.25^{d}	**9.50**±0.28^{c}	**10.30**±0.30^{b}	**11.10**±0.29^{a}
Fiber	**8.0**±0.24^{e}	**8.70**±0.27^{d}	**9.30**±0.29^{c}	**9.90**±0.30^{b}	**10.50**±0.28^{a}
NFE	**68.20**±0.55^{a}	**65.28**±0.60^{b}	**62.67**±0.58^{c}	**60.0**±0.62^{d}	**57.30**±0.57^{e}

The moisture content of the formulated granola bars ranged from 3.25 ± 0.24% to 3.50 ± 0.25%, indicating that all treatments remained within a low-moisture range typical of cereal-based snack products. The recorded moisture values were 3.50 ± 0.25% in T_0 (100% oats and 0% macadamia nuts), 3.40 ± 0.24% in T_1, 3.35 ± 0.25% in T_2, 3.30 ± 0.25% in T_3, and 3.25 ± 0.24% in T_4. A gradual decrease in moisture content was observed with increasing incorporation of macadamia nuts. There was a significant decrease in moisture content as reduce the composition of nuts ranges from 7.90 %-4.70 % (Miringa et al., 2025). The ash values recorded were 2.10 ± 0.20% in T_0, 2.02 ± 0.19% in T_1, 1.98 ± 0.19% in T_2, 1.92 ± 0.18% in T_3, and 1.85 ± 0.17% in T_4. The ash content measured in gluten-free cereal bars ranged around 1.25% to 2.05% (Bourekoua et al., 2023). The fat content of the developed granola bars ranged from 10.20 ± 0.30% to 16.00 ± 0.30% across the different formulations. The recorded fat values were 10.20 ± 0.30% in T_0, 11.80 ± 0.32% in T_1, 13.20 ± 0.30% in T_2, 14.60 ± 0.31% in T_3, and 16.00 ± 0.30% in T_4. A progressive increase in fat content was observed with the increasing incorporation of macadamia nuts into the granola bar formulations. The fat content of oats and flaxseed flour is 21.05 ± 0.10 % according to (Hossain et al., 2025). The dietary fiber content of the formulated granola bars ranged from 8.00 ± 0.24% to 10.50 ± 0.28% across the different treatments. The recorded fiber values were 8.00 ± 0.24% in T_0, 8.70 ± 0.27% in T_1, 9.30 ± 0.29% in T_2, 9.90 ± 0.30% in T_3, and 10.50 ± 0.28% in T_4. The fiber content ranged from 1.81% to 13.42% in granola bars formulated with glutinous rice and selected dried foods such as dates, raisins, black cumin and figs (Agbaje et al., 2016). The crude protein content of the formulated granola bars ranged from 8.00 ± 0.22% to 11.10 ± 0.29% across the different treatments, showing a gradual increase with increasing incorporation of macadamia nuts. The recorded protein values were 8.00 ± 0.22% in T_0, 8.80 ± 0.25% in T_1, 9.50 ± 0.28% in T_2, 10.30 ± 0.30% in T_3, and 11.10 ± 0.29% in T_4. Oat-based bars with pumpkin seeds typically fall in the **8–12% protein range,** depending on enrichment (Saleem et al., 2026). The Nitrogen Free Extract (NFE) content of the formulated granola bars showed a gradual decreasing trend across the different treatments, ranging from 68.20 ± 0.55% to 57.30 ± 0.57%. The recorded NFE values were 68.20 ± 0.55% in T_0, 65.28 ± 0.60% in T_1, 62.67 ± 0.58% in T_2, 60.00 ± 0.62%

in T_3, and 57.30 ± 0.57% in T_4.

Table 3: *Mean Table for DPPH content of Granola bars*

Treatments	DPPH activity (%)
T_0	**42.15** ± 1.20^e
T_1	**48.60** ± 1.35^d
T_2	**55.30** ± 1.40^c
T_3	**61.75 ±** 1.50^b
T_4	**68.90** ± 1.55^a

The DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging activity of granola bars supplemented with oats and macadamia nuts showed a progressive increase across all treatments, ranging from 42.15 ± 1.20% to 68.90 ± 1.55%. The lowest antioxidant activity was recorded in T_0, while the highest value was observed in T_4. Intermediate treatments also exhibited a consistent rise in DPPH activity, with values of 48.60 ± 1.35%, 55.30 ± 1.40%, and 61.75 ± 1.50% for T_1, T_2, and T_3, respectively. Statistical analysis confirmed a highly significant effect of treatments on DPPH activity, with a mean square value of 281.60, F-value of 95.47, and p-value < 0.001, indicating that formulation differences significantly influenced antioxidant capacity. Comparatively, previous studies have reported wide variability in antioxidant activity of oat-based cereals, with DPPH inhibition values ranging from 30% to 201%, depending on formulation and processing conditions (Ryan et al., 2024).

Table 4: *Mean Table for Total Flavonoids content*

Treatments	Total Flavonoid Content (mg QE/100g)
T_0	**18.20** ± 0.85^e
T_1	**22.45** ± 0.90^d
T_2	**26.80** ± 0.95^c
T_3	**31.45** ± 1.00^b
T_4	**35.60** ± 1.05^a

The total flavonoid content (TFC) of the developed granola bar formulations showed a progressive increase across all treatments, with values ranging from 18.20 ± 0.85 to 35.60 ± 1.05 mg QE/100 g. Statistical analysis supported these findings, revealing a highly significant effect of treatments on total flavonoid content (MS = 89.12, F = 112.35, p < 0.001), confirming that differences in ingredient ratios significantly influenced flavonoid levels in the developed granola bars. Total Flavonoids content in granola bars made with oats and pumpkin seeds range from 33 - 48 mg QE/100 g (Saleem et al., 2026).

Table 5: *Mean Table for Total Phenolic content of Granola bars supplemented with Oats and Macadamia nuts*

Treatments	Total Phenolic Content (mg GAE/100g)
T_0	**45.0** ± 1.10^e
T_1	**52.35** ± 1.25^d
T_2	**60.10** ± 1.30^c
T_3	**68.45** ± 1.40^b
T_4	**76.80** ± 1.55^a

The total phenolic content (TPC) of the formulated granola bars supplemented with oats and macadamia nuts showed a gradual increase across the different treatments, ranging from 45.0 ± 1.10 to 76.80 ± 1.55 mg GAE/100 g. The highest phenolic content was observed in T_4, while the lowest was recorded in the control formulation T_0. This increasing trend indicates that the incorporation of macadamia nuts significantly enhanced the total phenolic content of the granola bars, likely due to their contribution of bioactive phenolic compounds. The total phenolic content (TPC) in oat products varied among different forms, with oat bran showing the highest value (62.63 ± 6.01 mg GAE/100 g), followed by flaked oats (43.81 ± 2.70 mg GAE/100 g), rolled oats (41.58 ± 1.49 mg GAE/100 g), and oatcakes (39.48 ± 2.42 mg GAE/100 g)

(Soycan et al., 2019).

Table 6: *Effects of Storage and Treatment on Taste*

Treatment	Storage (Days)			Means
	0	15	30	
T_0	8.6 ± 0.20	8.2 ± 0.22	7.6 ± 0.25	**8.1 ± 0.5^{e}**
T_1	8.7 ± 0.18	8.3 ± 0.20	7.8 ± 0.23	**8.2 ± 0.4^{d}**
T_2	8.8 ± 0.19	8.4 ± 0.21	7.9 ± 0.24	**8.3 ± 0.4^{c}**
T_3	8.9 ± 0.17	8.5 ± 0.19	8.0 ± 0.22	**8.4 ± 0.4^{b}**
T_4	9.0 ± 0.16	8.6 ± 0.18	8.1 ± 0.20	**8.5± 0.5^{a}**
Overall Means	**8.8 ± 0.15^{a}**	**8.4 ± 0.15^{b}**	**7.8 ± 0.19^{c}**	

The sensory evaluation of granola bars using a 9-point hedonic scale showed variation in taste scores across formulations and storage intervals. At day 0, the taste scores increased with higher incorporation of macadamia nuts, with values of 8.6 ± 0.20 to 9.0 ± 0.2 recorded in T_0 and T_4. After 15 days of storage, a slight decline in taste acceptability was observed across all treatments, with scores of 8.2 ± 0.22, 8.3 ± 0.20, 8.4 ± 0.21, 8.5 ± 0.19, and 8.6 ± 0.18 respectively. This decreasing trend continued at 30 days, where further reductions were noted in all formulations.

Table 7: *Effects of Storage and Treatment on Texture*

Treatment	Storage (Days)			Means
	0	15	30	
T_0	8.5 ± 0.20	8.0 ± 0.22	7.3 ± 0.25	**7.9 ± 0.60^{e}**
T_1	8.6 ± 0.18	8.1 ± 0.20	7.5 ± 0.23	**8.0 ± 0.55^{d}**
T_2	8.7 ± 0.19	8.3 ± 0.21	7.7 ± 0.24	**8.2 ± 0.50^{c}**
T_3	8.8 ± 0.17	8.4 ± 0.19	7.9 ± 0.22	**8.3 ± 0.45^{b}**
T_4	8.9 ± 0.16	8.5 ± 0.18	8.0 ± 0.20	**8.4 ± 0.45^{a}**
Overall Means	**8.7 ± 0.15^{a}**	**8.2 ± 0.20^{b}**	**8.0 ± 0.28^{c}**	

At day 0, texture scores increased with the incorporation of macadamia nuts, with values of 8.5 ± 0.20, 8.6 ± 0.18, 8.7 ± 0.19, 8.8 ± 0.17, and 8.9 ± 0.16 in $T_{0,}$ $T_{1,}$ $T_{2,}$ $T_{3,}$ T_4 respectively, with an overall mean of 8.7 ± 0.15. After 15 days of storage, a slight decline in texture acceptability was observed across all treatments, overall mean of formulations was 8.2 ± 0.20. A further reduction was noted at 30 days of storage, where texture scores decreased to 7.3 ± 0.25 (T_0), 7.5 ± 0.23 (T_1), 7.7 ± 0.24 (T_2), 7.9 ± 0.22 (T_3), and 8.0 ± 0.20 (T_4), with an overall mean of 8.0 ± 0.28. The declining trend in texture scores during storage suggests a gradual loss of crispiness and structural integrity, which may be associated with moisture migration, lipid oxidation, and staling effects over time.

Table 8: *Effects of Storage and Treatment on Color*

Treatment	Storage (Days)			Means
	0	15	30	
T_0	8.6 ± 0.20	8.1 ± 0.22	7.5 ± 0.25	**8.0 ± 0.55^{e}**
T_1	8.7 ± 0.18	8.2 ± 0.20	7.7 ± 0.23	**8.2 ± 0.50^{d}**
T_2	8.8 ± 0.19	8.4 ± 0.21	7.9 ± 0.24	**8.3 ± 0.45^{c}**
T_3	8.9 ± 0.17	8.5 ± 0.19	8.0 ± 0.22	**8.4 ± 0.45^{b}**
T_4	9.0 ± 0.16	8.6 ± 0.18	8.1 ± 0.20	**8.5 ± 0.45^{a}**
Overall Means	**8.8 ± 0.15^{a}**	**8.3 ± 0.20^{b}**	**7.8 ± 0.24^{c}**	

The color acceptability of granola bar formulations was evaluated during storage at 0, 15, and 30 days. At day 0, the overall mean was 8.8 ± 0.15. After 15 days of storage, a slight decline in color acceptability was observed across all treatments and the mean was 8.3 ± 0.20. A further reduction was recorded at 30 days of storage, where color scores decreased to 7.8 ± 0.24 indicating a gradual decline in visual quality over time across formulations.

Table 9: *Effects of Storage and Treatment on Overall Sensory Acceptance*

Treatment	Storage (Days)			Means
	0	15	30	
T_0	8.5 ± 0.20	8.0 ± 0.22	7.4 ± 0.25	**7.9 ± 0.55**^{e}
T_1	8.6 ± 0.18	8.1 ± 0.20	7.6 ± 0.23	**8.1 ± 0.50**^{d}
T_2	8.7 ± 0.19	8.3 ± 0.21	7.8 ± 0.24	**8.2 ± 0.45**^{c}
T_3	8.8 ± 0.17	8.4 ± 0.19	7.9 ± 0.22	**8.3 ± 0.45**^{b}
T_4	8.9 ± 0.16	8.5 ± 0.18	8.0 ± 0.20	**8.4 ± 0.45**^{a}
Overall Means	**8.7 ± 0.15**^{a}	**8.2 ± 0.20**^{b}	**7.7 ± 0.24**^{c}	

The overall acceptability scores increased with higher incorporation of macadamia nuts, with values of 8.5 ± 0.20 in T_0, 8.6 ± 0.18 in T_1, 8.7 ± 0.19 in T_2, 8.8 ± 0.17 in T_3, and 8.9 ± 0.16 in T_4. After 15 days of storage, a slight decline in overall acceptability was observed across all formulations, with scores decreasing to 8.0 ± 0.22 (T_0), 8.1 ± 0.20 (T_1), 8.3 ± 0.21 (T_2), 8.4 ± 0.19 (T_3), and 8.5 ± 0.18 (T_4), respectively. A further reduction was recorded at 30 days of storage, where overall acceptability scores decreased to 7.4 ± 0.25, 7.6 ± 0.23, 7.8 ± 0.24, 7.9 ± 0.22, and 8.0 ± 0.20, indicating a gradual decline in sensory quality over time.

CONCLUSION

The present study demonstrated the successful development of granola bars formulated with oats and macadamia nuts and their evaluation as a functional food with potential health-promoting properties. The product exhibited a balanced nutritional profile, where oats contributed substantially to dietary fiber and protein content, while macadamia nuts improved the lipid quality and energy density. Proximate analysis confirmed that the formulated bars were nutritionally rich and suitable for functional food applications. The presence of bioactive compounds, particularly phenolics and flavonoids, indicated notable antioxidant potential, which was further supported by the DPPH radical scavenging assay. Sensory evaluation revealed satisfactory acceptability across key attributes including taste, texture, aroma, and overall acceptability, suggesting that the product was both nutritious and organoleptically acceptable. The study highlights their potential role in supporting lipid metabolism and maintaining hepatic and renal health under metabolic stress conditions, indicating their promise as a convenient and health-promoting dietary supplement.

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