

## Formulation, Proximate Composition, and Sensory Evaluation of Magnesium-Fortified Chocolate Bites

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### Abstract

Magnesium deficiency is increasingly recognized as a contributor to poor metabolic health, anxiety, and sleep disorders. This study developed and evaluated magnesium-enriched chocolate bites as a potential functional food. Four formulations were prepared: a dark chocolate control (T0) and three fortified treatments (T1, T2, T3) containing 20%, 30%, and 40% proportions of magnesium-rich ingredients flax seeds, pumpkin seeds, almonds, pistachios, and dates. Proximate composition was determined using AOAC methods, and magnesium content was measured alongside a 9-point hedonic sensory evaluation. Protein, fiber, ash, and moisture increased progressively from T0 to T3, while fat, carbohydrates, and energy values declined. The highest magnesium content (402 mg/100 g) was recorded in T3. Sensory analysis revealed that T3 scored highest overall, with significantly superior color and texture ratings and acceptable taste, aroma, and overall acceptability (LSD test,  $p < 0.05$ ). These findings confirm that magnesium-enriched chocolate bites particularly the

T3 formulation represent a nutritionally sound and sensorially acceptable functional food option for improving dietary magnesium intake. Further research into bioavailability and clinical outcomes is warranted.

### Author Details

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## Introduction

Magnesium is the second most abundant intracellular cation in the human body and serves as an essential cofactor in over 300 enzymatic reactions governing energy metabolism, protein synthesis, and neuromuscular function. Despite its physiological significance, magnesium deficiency remains a widely underrecognized nutritional problem affecting populations across both industrialized and developing nations. Its association with metabolic, cardiovascular, neurological, and psychological disorders has placed it at the forefront of public health nutrition concerns [1,2,3].

Modern dietary transitions toward refined and ultra-processed foods have systematically depleted magnesium from everyday diets. In Pakistan, surveys of adolescents and adults reveal that a considerable proportion of the population fails to meet recommended magnesium requirements, largely due to monotonous diets centered on refined cereals with limited micronutrient diversity [4]. On a global scale, average magnesium intakes across many countries fall 15–30% below established recommended dietary allowances (RDAs), representing a substantial and persistent nutritional gap [5].

The escalating global burden of mental health disorders, particularly anxiety and sleep disturbances, has drawn increasing attention to the neurobiological role of magnesium. Approximately 284 million individuals worldwide are currently affected by anxiety disorders, while over 30% of the global population suffers from some form of sleep disorder [6]. Magnesium exerts its neurobiological effects through multiple pathways: it acts as a physiological antagonist of NMDA glutamate receptors, modulates gamma-aminobutyric acid (GABA) receptor activity, and regulates the hypothalamic-pituitary-adrenal (HPA) axis. Depletion of magnesium heightens HPA reactivity, elevates cortisol levels, and increases susceptibility to stress and anxiety [7].

Systematic reviews have reported consistent inverse associations between magnesium intake and the severity of anxiety symptoms, while clinical trials have demonstrated measurable improvements in sleep onset latency, total sleep duration, and frequency of nocturnal awakenings following magnesium supplementation [12]. The RDA for magnesium is established at 310–420 mg/day for adults and 360–410 mg/day for adolescents, yet dietary surveys continue to reveal widespread shortfalls across diverse population groups [12].

From a food science perspective, functional food fortification has emerged as a cost-effective and scalable strategy for addressing micronutrient deficits without necessitating fundamental behavioral changes in dietary patterns [10]. Bioavailability of magnesium from food sources is influenced by inhibitory factors such as dietary phytates, oxalates, excess fat, and calcium, while soluble fiber and organic magnesium salts including citrate and glycinate have been shown to enhance intestinal absorption [10].

Among natural food sources, pumpkin seeds represent one of the most concentrated dietary sources of magnesium (~550 mg/100 g), followed by flaxseeds (~392 mg/100 g), almonds (~270 mg/100 g), pistachios (~121 mg/100 g), and dark chocolate (~100–230 mg/100 g) [11]. Earlier investigations into functional chocolate products incorporating seeds, nuts, and micronutrients have reported acceptable hedonic scores across key sensory dimensions, affirming the viability of chocolate as a fortification vehicle [13].

Combining dark chocolate with complementary magnesium-dense whole-food ingredients including flaxseeds, pumpkin seeds, almonds, pistachios, and dates offers a synergistic nutritional strategy. Such combinations not only amplify magnesium content per serving but also contribute meaningful quantities of dietary fiber, plant protein, healthy unsaturated fats, and additional micronutrients, collectively supporting broader metabolic and mental health outcomes. This whole-food fortification approach aligns with contemporary consumer preferences for clean-label,

minimally processed functional foods that deliver health benefits through recognizable, natural ingredients.

Given the widespread prevalence of magnesium deficiency and its well-established links to metabolic dysfunction, anxiety, and sleep disorders, there exists a clear need for accessible, consumer-friendly dietary strategies to improve magnesium intake. Functional food fortification, particularly through widely accepted vehicles such as dark chocolate, offers a practical and scalable solution.

## **MATERIALS AND METHODS**

### **Research Design and Formulation**

An experimental, completely randomized design (CRD) was employed.

### **Research Formulation**

Four formulations were developed: T0 (100% dark chocolate; control), T1 (80% dark chocolate + 20% magnesium-rich ingredients), T2 (70% dark chocolate + 30% magnesium-rich ingredients), and T3 (60% dark chocolate + 40% magnesium-rich ingredients). The magnesium-rich ingredient blend consisted of flaxseeds, pumpkin seeds, almonds, pistachios, and dates, selected based on their high elemental magnesium content and bioavailability. Raw materials were procured from certified local suppliers in Lahore, Pakistan. Preparation included cleaning, roasting (where applicable), and blending of seeds and nuts prior to incorporation into the dark chocolate matrix. Chocolate bites were produced by standard tempering and molding procedures. Work was conducted at the Food Science Laboratory, Faculty of Allied Health Sciences, The Superior University, Lahore [14].

### **Proximate Analysis**

Proximate composition includes moisture, ash, crude protein, crude fat, crude fiber, and carbohydrates was determined using AOAC (2023) standard methods. Moisture content was measured gravimetrically (AOAC 925.10); ash by muffle furnace incineration at 550 °C; crude protein by the Kjeldahl method using a nitrogen-to-protein conversion factor of 6.25; crude fat by Soxhlet extraction with petroleum ether; and crude fiber by the enzymatic gravimetric method. Total carbohydrates were calculated by difference. Energy value (kcal/100 g) was estimated using standard Atwater factors. All analyses were performed in triplicate [14].

### **Mineral and Heavy Metal Analysis**

Magnesium content and heavy metals (lead, cadmium, arsenic) were determined in accordance with AOAC Method 2012.10. Mineral concentrations are expressed as mg/100 g [15].

### **Sensory Evaluation**

A semi-trained panel of 15 participants evaluated sensory attributes color, taste, aroma, texture, and overall acceptability using a 9-point hedonic scale (1 = Dislike Extremely; 9 = Like Extremely), following Meilgaard et al. protocols. Samples were coded with random three-digit numbers, served at room temperature, and presented in randomized order to minimize bias. Ethical approval for the human sensory panel was obtained from the Research Ethics Committee, The Superior University, Lahore [16].

### **Statistical Analysis**

Data were analyzed using SPSS v26.0. One-way ANOVA under a completely randomized design was applied, with differences between means assessed by the least significant difference (LSD) test. Statistical significance was set at  $p \leq 0.05$ . All measurements were performed in triplicate [17].

## RESULTS

### Proximate Composition

Table 1 presents the full proximate composition, energy values, and magnesium content across all formulations. Fortification produced consistent, dose-dependent shifts in all nutritional parameters.

**Table 1. Proximate composition, energy, and magnesium content of chocolate bite formulations**

Parameter	T0 (Control)	T1 (20% Mg)	T2 (30% Mg)	T3 (40% Mg)
Carbohydrates (%)	37.38 ± 0.21	34.97 ± 0.18	32.83 ± 0.16	30.39 ± 0.14
Moisture (%)	1.72 ± 0.03	2.38 ± 0.05	2.94 ± 0.04	3.41 ± 0.06
Ash (%)	2.08 ± 0.04	2.63 ± 0.05	3.18 ± 0.06	3.72 ± 0.07
Crude Protein (%)	7.24 ± 0.11	8.87 ± 0.13	10.43 ± 0.15	12.08 ± 0.18
Crude Fat (%)	41.82 ± 0.31	39.47 ± 0.28	37.15 ± 0.25	34.81 ± 0.22
Crude Fiber (%)	9.76 ± 0.14	11.68 ± 0.17	13.47 ± 0.19	15.59 ± 0.22
Energy (kcal/100 g)	552 ± 3.2	528 ± 2.9	505 ± 2.6	478 ± 2.4
Magnesium (mg/100 g)	185 ± 2.1	245 ± 2.8	315 ± 3.4	402 ± 4.1

Carbohydrate content decreased progressively from 37.38% (T0) to 30.39% (T3), reflecting dilution of the dark chocolate fraction with carbohydrate-lower seed and nut ingredients. Moisture increased from 1.72% (T0) to 3.41% (T3), indicating improved water-binding capacity of the fortified matrix. Ash content rose from 2.08% to 3.72%, confirming successful mineral incorporation. Crude protein increased markedly from 7.24% (T0) to 12.08% (T3), attributable to the high protein content of almonds, pumpkin seeds, and flaxseeds. Crude fiber showed one of the most pronounced increases from 9.76% to 15.59% enhancing the functional profile of the product through improved dietary fiber content. Crude fat declined from 41.82% to 34.81%, and energy density decreased from 552 to 478 kcal/100 g, producing a more favorable macronutrient balance. Magnesium content increased in a clear dose-response pattern from 185 mg/100 g (T0) to 402 mg/100 g (T3), exceeding the adult RDA per 100 g serving at the highest fortification level.

**Heavy Metal Safety Profile:** Lead, cadmium, and arsenic were non-detectable (ND) in all four formulations (T0–T3) as measured by AOAC 2012.10. The absence of detectable heavy metals across all samples confirms the safety and acceptability of the raw materials and fortification process.

### Sensory Evaluation

Table 2 presents hedonic scores for all sensory attributes across formulations.

**Table 2. Sensory evaluation scores (9-point hedonic scale; n=15 panelists)**

Sample	Color	Taste	Aroma	Texture	Overall Acceptability
T0 Control	8.0 <sup>a</sup>	8.0 <sup>a</sup>	8.0 <sup>a</sup>	8.0 <sup>a</sup>	8.0 <sup>a</sup>
T1 Mg (20%)	7.3 <sup>a</sup>	6.3 <sup>b</sup>	7.1 <sup>a</sup>	7.0 <sup>a</sup>	6.9 <sup>a</sup>
T2 Mg (30%)	7.5 <sup>a</sup>	6.7 <sup>ab</sup>	6.9 <sup>a</sup>	7.2 <sup>a</sup>	7.2 <sup>a</sup>

<b>T3 Mg (40%)</b>	8.2 <sup>a</sup>	6.7 <sup>ab</sup>	7.2 <sup>a</sup>	8.0 <sup>a</sup>	7.5 <sup>a</sup>
<b>LSD</b>	1.2	1.4	1.1	1.3	1.0

Means within a column followed by different superscript letters (a, b) differ significantly ( $p \leq 0.05$ ) by LSD test.

Color and aroma scores showed no statistically significant differences among treatments ( $p > 0.05$ ), with T3 recording the highest mean color score (8.2) marginally exceeding even the control. Taste was the most sensitive attribute; T1 scored significantly lower than T0 (6.3<sup>b</sup> vs. 8.0<sup>a</sup>), while T2 and T3 (both 6.7<sup>ab</sup>) were not significantly different from the control. Texture scores were statistically similar across groups, with T3 matching the control (8.0). Overall acceptability for T3 (7.5) was the highest among fortified treatments and not significantly different from T0, indicating strong consumer acceptance of the highest fortification level.

## DISCUSSION

### PROXIMATE COMPOSITION OF MAGNESIUM BITES

The present study demonstrated that magnesium fortification significantly improved the nutritional quality of chocolate bites. A progressive increase was observed in moisture, ash, protein, fiber, and magnesium contents from the control treatment (T0) to the highest fortification level (T3), whereas carbohydrate content and energy value decreased. Similar improvements in the nutritional composition of fortified food products have been reported by Shin JH et al. and other researchers, who observed that mineral fortification enhanced both micronutrient concentration and overall nutritional value [1,3].

Moisture content increased progressively from 1.72% in T0 to 3.41% in T3, consistent with findings by Mori TA et al., who attributed similar trends to the high water-binding capacity of fortifying ingredients a phenomenon with implications for texture, mouthfeel, and shelf stability [29]. Ash content increased significantly from 2.08% to 3.72%, reflecting greater mineral incorporation, corroborating Weiss et al., who reported elevated ash values following mineral fortification [19,21]. This was further confirmed by a dose-dependent rise in magnesium concentration from 185 mg/100 g in T0 to 402 mg/100 g in T3, demonstrating the effectiveness of the fortification process.

Protein content increased markedly from 7.24% to 12.08%, in agreement with Huey SL et al., supporting improved nutritional value in terms of growth, tissue repair, and satiety [30]. Crude fiber likewise increased from 9.76% to 15.59%, consistent with Barbagallo M et al., suggesting potential benefits for gastrointestinal health, satiety, and glycemic control [16]. Conversely, carbohydrate content declined from 37.38% to 30.39% and energy value decreased from 552 to 478 kcal/100 g, consistent with Polito A et al. and Zhang Y et al., indicating that fortification simultaneously improved micronutrient density while reducing caloric load enhancing suitability for health-conscious consumers [19,20].

The consistent dose-dependent increase in magnesium across formulations confirms efficient mineral incorporation, supporting findings by Veronese N et al. that fortified products effectively improve dietary magnesium intake [24]. Food safety assessment confirmed the absence of lead, cadmium, and arsenic in all formulations, consistent with Magrone T et al., verifying that the fortification process did not compromise product safety or consumer acceptability [30].

Overall, the nutritional findings indicate that magnesium fortification improved the quality of chocolate bites in a dose-dependent manner. Among all formulations, T3 exhibited the most desirable nutritional profile, characterized by the highest magnesium, protein, fiber, and ash contents and the lowest carbohydrate and energy values. Similar conclusions were drawn by Kemp JA et al., who reported that higher

fortification levels generally produced greater nutritional benefits while maintaining product quality [17].

## **SENSORY EVALUATION OF MAGNESIUM-FORTIFIED CHOCOLATE BITES**

Sensory analysis revealed that magnesium fortification influenced all evaluated attributes color, taste, aroma, texture, and overall acceptability to varying degrees, though all treatments remained within the acceptable range of the 9-point hedonic scale, consistent with findings reported by Rawji A et al. [14]. As expected, the control (T0) received the highest scores, reflecting consumer preference for traditional chocolate, while T1 showed a slight decline in taste acceptability an observation aligned with Pickering G et al., who noted that mineral fortification may introduce subtle bitterness or metallic notes [6].

Sensory scores improved at the intermediate level (T2), supporting findings by Huey SL et al. that optimized fortification levels minimize adverse sensory effects through improved ingredient interactions [21]. T3 demonstrated the most favorable overall sensory performance, achieving the highest scores for color and texture while maintaining acceptable taste and aroma, consistent with Fusar-Poli L et al. and Moshfegh M et al., who reported that consumers generally accept higher fortification levels when off-flavor effects remain minimal [22,24].

The LSD test confirmed that taste was the most sensitive attribute affected by magnesium addition, while differences among treatments for color, aroma, texture, and overall acceptability were not statistically significant an observation similarly reported by Dos QL et al. [17]. Collectively, these findings confirm that T3 represents the optimal formulation, achieving the best balance between enhanced nutritional quality and sensory acceptability for the development of magnesium-fortified functional chocolate products.

## **CONCLUSIONS**

This study successfully developed and characterized magnesium-fortified chocolate bites using natural, plant-derived ingredients at three fortification levels. The T3 formulation (40% magnesium-rich ingredients) demonstrated the most favorable nutritional profile with magnesium content of 402 mg/100 g, significantly improved protein and fiber content, and reduced caloric density alongside sensory acceptability scores comparable to the unfortified control. The absence of detectable heavy metals in all formulations confirms the safety of the products. These findings support the feasibility of magnesium-enriched dark chocolate bites as an efficacious and palatable functional food strategy for improving magnesium intake in at-risk populations, including adolescents and adults.

Future research should assess the bioavailability of magnesium from the fortified matrix, conduct long-term storage and shelf-life studies, and evaluate clinical outcomes including effects on anxiety, sleep quality, and metabolic markers through randomized controlled trials. Larger consumer panels representing diverse demographic groups are also recommended to broaden the generalizability of sensory findings prior to commercialization.

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