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DEVELOPMENT AND COMPREHENSIVE EVALUATION OF CHICKPEA-BASED VEGAN CHEESE ALTERNATIVES: PHYSICOCHEMICAL, NUTRITIONAL AND SENSORY PROFILES

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Abstract

In the light of increasing health, sustainability, and ethical concerns, plant-based diets are rapidly gaining traction. This study developed chickpea-based vegan cheese analogues, evaluating three formulations: a control (C), a variant enriched with turmeric, black pepper, and oregano (VC1), and one with dried tomatoes and basil (VC2). A multi-analytical approach was used to quantify total polyphenol content (TPC), antiradical activity (DPPH), and antioxidant capacity (CUPRAC), alongside proximate composition and sensory profiles. Results showed that enriched formulations (VC1 and VC2) possessed significantly higher phenolic concentrations and enhanced antioxidant potential than the control, with VC1 exhibiting the highest values. Moreover, these variants achieved superior hedonic ratings, suggesting that strategic integration of natural additives effectively optimizes both the functional architecture and consumer acceptability of plant-based dairy alternatives. .

Key words*: antioxidant activity, chickpea, polyphenols, proximate composition, vegan cheese alternatives.*

INTRODUCTION

Food systems exert a massive impact on the planet, accounting for up to 37% of net greenhouse gas emissions (Grasso et al., 2023). As a primary driver of the climate crisis and biodiversity loss, the animal-based sector necessitates a fundamental rethink of global dietary patterns (Benton et al., 2021). Driven by a growing global population and the urgent need to reduce our environmental footprint, the industry is increasingly focused on developing innovative plant-based alternatives to traditional staples like cheese. Consequently, the plant-based dairy sector is undergoing rapid expansion, challenging food producers to create vegan substitutes that balance innovation with nutritional density and affordability. This shift is further propelled by rising market demand from consumers adopting meat- and dairy-free diets for ethical, environmental, or health-related reasons (Mefleh et al., 2022). Currently, the nutritional profile of most commercial alternatives is deficient, as they primarily rely on starch and solid fats (such as coconut oil) as base ingredients. This results in a product with low protein content and high levels of saturated fats, making it significantly inferior to traditional cheese. Furthermore, discrepancies in taste and price prevent these products from meeting consumer demands, even though this category holds the highest untapped demand potential within the plant-based market (Grasso et al., 2023). With a view to developing plant-based dairy alternatives featuring optimized nutritional profiles and a reduced environmental footprint, various research collectives are currently evaluating the feasibility and

technological potential of plant-derived protein ingredients (Grasso et al., 2023; Grossmann & McClements, 2021; Mefleh et al., 2022).

Pulses are fundamental components of traditional diets and serve as a vital source of plant-based proteins. Through flours and isolates, they provide innovative solutions for meeting daily protein requirements (Boye et al., 2010). Among these, the chickpea (*Cicer arietinum* L.) ranks second in global consumption and is cultivated in over 50 countries. Beyond its therapeutic role in managing diabetes, it offers a dense matrix of essential micronutrients, including a broad spectrum of vitamins (A, C, E, K, and the B-complex) and critical minerals such as iron, zinc, magnesium, and calcium (Gaur et al., 2010). Chickpeas are particularly distinguished by a protein content of 20-25%, complemented by significant levels of dietary fiber, and bioactive compounds like phenolic acid (Hall et al., 2017). This nutritional versatility, coupled with superior functional properties, positions chickpea-derived ingredients as ideal candidates for plant-based cheese analogues. Specifically, chickpea proteins exhibit high efficiency in emulsification and gelling-traits largely attributed to the structural complexity of globulins and the hydrophobic interactions that drive their functionality (Kaur & Singh, 2007; Withana-Gamage et al., 2011).

Turmeric (*Curcuma longa* L.) is an ancient spice and traditional remedy used as a medicine, condiment, and dye, originating from the tropical regions of South Asia as a rhizomatous herbaceous perennial of the *Zingiberaceae* family (Prasath et al., 2024). Its yellow colour and medicinal properties are derived from curcuminoids, a group of polyphenolic compounds, among which curcumin stands out as the primary constituent evaluated for its health-promoting activities. Beyond these, turmeric contains sugars, proteins, resins, and volatile oils - such as turmerone, atlantone, and zingiberene - some of which may also exhibit bioactivity. Consequently, numerous preclinical investigations have identified a wide range of potential health benefits, including treatments for heart disease, arthritis, Alzheimer's, gastrointestinal disorders, and metabolic syndrome (Hay et al., 2019; Singletary, 2020).

Due to their highly perishable nature, tomatoes (*Solanum lycopersicum*) are frequently subjected to dehydration processes to extend shelf life and facilitate their use as versatile raw materials in the production of functional foods, nutraceuticals, and diverse processed commodities (Pravitha et al., 2024). These fruits are characterized by a dense micronutrient profile, notably providing an average of 20 mg/100 g of vitamin C, representing approximately 40% of the recommended daily intake - alongside a complex matrix of phenolic acids, flavonoids, and carotenoids that underpin their significant antioxidant capacity. Furthermore, the concentration of soluble sugars and organic acids within the dry matter fraction is a critical determinant of palatability, as these constituents govern the organoleptic balance between sweetness and acidity (Bakir et al., 2023). Empirical evidence suggests that thermal processing at a controlled temperature of 60°C optimizes the retention of these bioactive compounds, ensuring superior phytochemical stability both immediately post-dehydration and during subsequent storage periods (Kaur et al., 2020).

The aim of this work is to formulate and characterize three chickpea-based vegan cheese variants: a plain control and two enriched versions (turmeric/black pepper/oregano and sun-dried tomato/basil). The study assesses their nutritional and sensory attributes, alongside their antioxidant activity and total polyphenol content.

MATERIALS AND METHODS

Chickpea-based vegan cheese alternatives preparation

Three chickpea-based cheese alternatives (C, VC1 and VC2) were developed using raw materials sourced from the Romanian market (Figure 1), following the specific formulations detailed in Table 1.

In the preparation of the three chickpea-based cheese analogues, ingredients were precisely weighed in accordance with the established formulations. The mixture underwent homogenization until a uniform consistency was achieved, followed by thermal treatment (boiling) until the desired viscosity was

reached. The resulting hot matrix was transferred into molds pre-treated with a thin film of vegetable oil. Upon cooling, the samples were refrigerated for a duration of 2 hours, subsequently vacuum-sealed, and maintained under strictly controlled refrigeration conditions.

Table 1. Recipes for chickpea-based vegan cheese alternatives

Product / Materials (%)	C	VC1	VC2
Chickpea flour	30	29	29
Extra virgin olive oil	3	3	3
Lemon juice	3	3	3
Garlic powder	0.5	0.5	0.5
Onion flasks	0.5	0.5	0.5
Nutritional yeast flakes	1.5	2	2
Water	60	59	59
Turmeric powder		0.5	
Black pepper grounded		0.5	
Dried oregano		0.5	
Dried tomato flakes			1
Dried basil			0.5
Salt	1.5	1.5	1.5



C VC1 VC2

Figure 1. The three types of chickpea-based vegan cheese alternatives (own source)

Total polyphenol content evaluation

The total phenolic content (TPC) of the raw materials and the resulting chickpea-based cheese analogues was quantified via the Folin-Ciocalteu spectrophotometric assay. Samples were subjected to extraction using 70% (v/v) ethanol. The analytical protocol was executed according to the methodology described by Dumbrava et al. (2020). Quantitative results were calculated using a gallic acid calibration curve and expressed as milligrams of gallic acid equivalents per 100 grams (mg GAE/100g).

Antioxidant activity evaluation

The antioxidant capacity of both the raw materials and the finished chickpea-based cheese analogues was quantified via the Cupric Ion Reducing Antioxidant Capacity (CUPRAC) assay. To maintain methodological uniformity across all spectrophotometric measurements, the analysis was conducted on the previously prepared 70% (v/v) ethanolic extracts, strictly adhering to the protocol described by Dumbrava et al. (2020). Quantitative data were reported in milligrams of Trolox equivalents per gram of sample (mg TE/g).

Antiradical activity evaluation

The antiradical capacity of the raw materials and the resultant chickpea-based cheese analogues was quantified by determining their 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging activity (RSA). The analytical procedure was conducted in accordance with the methodology previously presented by Poiana et al. (2022), ensuring technical consistency across the experimental framework.

Proximate composition and energy value determination

The proximate composition of the chickpea-based cheese analogues was determined in accordance with standardized methods established by the International Organization for Standardization (ISO). Specifically, the crude protein content was quantified according to SR ISO 937:2007, total lipids were extracted per SR ISO 1443:2008, and mineral (ash) content was determined via SR ISO 936:2009. Sugars and fiber concentrations were assessed following SR ISO 91-2007 and ISO 13906:2007, respectively. Moisture content was evaluated using a FOSS Fibertec 2010 M6 system (Sweden) following SR ISO 1442:2010. The total carbohydrate content was derived by difference, subtracting the combined percentages of protein, lipids, dietary fiber, minerals, and moisture from 100%. Finally, the energy value (kcal/100 g) was estimated by applying the Atwater conversion factors: 9 kcal/g for lipids and 4 kcal/g for both proteins and carbohydrates

Statistical data processing

Quantitative data, derived from triplicate determinations of total phenolic content (TPC), antioxidant capacity, antiradical activity, and proximate composition, were subjected to

statistical analysis. Data processing and descriptive statistics were performed using Microsoft Excel 2010 (Microsoft Corp., Redmond, WA, USA), with results expressed as the mean value ± standard deviation (SD) to ensure analytical reproducibility.

Sensory analysis

The organoleptic properties of the chickpea-based analogues were evaluated in accordance with the ISO 4121:2002 standard. The sensory panel comprised 20 semi-trained evaluators (balanced by gender, aged 21-60 years). Assessments were conducted using a 5-point hedonic scale, where scores ranged from 1 (dislike extremely) to 5 (like extremely), encompassing six key sensory descriptors: external appearance, appearance in section, smell, taste, flavour, texture, and overall acceptability. Ethical compliance was maintained through the acquisition of written informed consent from all participants, adhering to European Union research guidelines (Alfonsi et al., 2012). To ensure reproducibility, the evaluation was performed under controlled environmental conditions, with score interpretations and acceptability thresholds aligned with the methodology established by Lim (2011).

RESULTS AND DISCUSSIONS

Total polyphenol content

TPC data for the raw materials and chickpea-based vegan cheese analogues are presented in Table 2.

The assessment of the TPC within the raw ingredients reveals that turmeric powder yielded the most significant phenolic concentration (4147.25 ± 11.06 mg GAE/100 g), substantially surpassing dried oregano (1014.18 ± 9.28 mg GAE/100 g) and dried basil (741.82 ± 5.22 mg GAE/100 g). Conversely, the lowest concentration was identified in the chickpea flour (59.63 ± 1.06 mg GAE/100 g).

In a study of 40 chickpea genotypes, Gupta et al. (2017) observed lower TPC concentrations than those found in the present study, with values ranging from 4.70±0.10 to 35.40 ± 0.20 mg GAE/100 g. For commercial onion powder, a comparable value of 386.60±10.02 mg GAE/100 g DM was reported by Bamba et al. (2020). Bieżanowska-Kopeć et al. (2022) observed TPC levels in commercial dried thyme (632.09 ± 17.68 to 867.57 ± 18.16), basil (548.99 ± 12.90 to 707.43 ± 10.51), and black pepper (443.24 ± 18.16 to 610.14±0.96 mg GAE/100 g) that are consistent with our results. For dried tomatoes, the TPC values obtained in this study fall within the range reported by Toor și Savage (2006), which varied from 235 ± 23.6 to 387 ± 19.8 mg GAE/100 g.

Table 2. TPC in chickpea-based vegan cheese analogues and their constituent raw materials

Sample	TPC (mg GAE/100 g)
Chickpea flour	59.63 ± 1.06
Lemon juice	61.48 ± 0,81
Garlic powder	502.27 ± 4.21
Onion flasks	358.14 ± 3.12
Turmeric powder	4147.25 ± 11.06
Black pepper grounded	608.42 ± 4.18
Dried oregano	1014.18 ± 9.28
Dried tomato flakes	288.61 ± 3.11
Dried basil	741.82 ± 5.22
C	31.16 ± 0.62
VC1	48.61 ± 1.04
VC2	40.44 ± 0.83

For the chickpea-based vegan cheese analogues, the results highlighted that the lowest TPC was recorded for the control sample (C) (31.16±0.62 mg GAE/100 g). In the VC1 (48.61±1.04 mg GAE/100 g) and VC2 (40.44±0.83 mg GAE/100 g) formulations, the TPC values were higher than the control by 54.83% and 29.03%, respectively.

With respect to the total polyphenol content (TPC) in various dairy-based matrices, Sik et al. (2023) reported values of 19.01 mg GAE/100 g for Jersey ricotta, whereas Holstein ricotta exhibited the lowest concentration, at 10.55 mg GAE/100 g. Comparable TPC levels were documented for Simmental and Saanen goat ricotta samples, both quantified at 15.42 mg GAE/100 g. Notably, all of these dairy-derived values are substantially lower than the polyphenol concentrations determined in the present study for the chickpea-based vegan cheese analogues. Similarly, in the case of cottage cheese, Farrag et al. (2020) reported a TPC of 32.29 mg GAE/100 g, which also remains below the concentrations measured in the current investigation for the VC1 and VC2 vegan formulations. These findings underscore the superior antioxidant potential of the VC1 and VC2 formulations developed in the present

study. The elevated polyphenol concentrations observed in these chickpea-based matrices signify a robust capacity for free-radical scavenging, thereby positioning these vegan cheese analogues as functional dietary interventions with high biological value.

Antioxidant and antiradical activities

Antioxidant activity assessments of the raw materials and final products, conducted using the CUPRAC assay, resulted in the data summarized in Table 3.

The experimental data reveal a distinct hierarchy in antioxidant potency among the primary substrates: black pepper manifested the highest antioxidant and respectively DPPH free-radical scavenging capacity (60.11±0.90 mg TE/g, 96.42 ± 0.72%), followed by turmeric powder (57.25 ± 0.94 mg TE/g, 95.86 ± 0.81%), while chickpea flour (2.18 ± 0.14 mg TE/g, 34.28 ± 0.36%) yielded the lowest recorded values.

In comparison to the results reported by Bieżanowska-Kopeć et al. (2022) for commercial dehydrated basil and thyme (0.36 mg TE/g, ABTS assay), the present study yielded higher antioxidant values using the CUPRAC method. This discrepancy potentially reflects the distinct reaction mechanisms of these two analytical approaches. Specifically, the elevated results observed here may be attributed to the superior sensitivity of the CUPRAC assay toward the unique phenolic profile of these aromatic herbs compared to the ABTS radical scavenging method (Apak et al., 2006; Apak et al., 2007). This is particularly relevant as CUPRAC has been shown to correlate more strongly with total polyphenolic content in *Lamiaceae* species than the ABTS assay (Özyürek et al., 2008). Notably, the antioxidant capacities determined in the present study via the CUPRAC assay are in close agreement with the range (3.89-4.60 mg TE/g) reported by Toor and Savage (2006) for various tomato cultivars using the ABTS method. While these assays employ different reactive species, their mutual reliance on Single Electron Transfer (SET) mechanisms facilitates a meaningful comparison. These consistent findings suggest that the polyphenols and carotenoids, such as lycopene, within the dehydrated tomato matrix are equally proficient at reducing metallic ions and scavenging free radicals. Moreover, the capacity of the CUPRAC assay to simultaneously evaluate both hydrophilic and lipophilic antioxidants likely underpins the observed consistency with established literature. Furthermore, a comparative evaluation of multiple turmeric species and cultivars conducted by Akter et al. (2019) using the Oxygen Radical Absorbance Capacity (ORAC) assay revealed antioxidant capacities between 420.0 and 3522.5 mg TE/g - substantially exceeding those determined herein via the CUPRAC method. Regarding chickpeas, Jogihalli et al. (2017) reported a radical scavenging activity (RSA) of 22.85 ± 0.25%, a value lower than that observed in the present study.

For the three chickpea-based vegan cheese analogues, variants VC1 and VC2 demonstrated higher antioxidant activity and RSA values compared with the control sample. The incorporation of turmeric, black pepper, and dried thyme in variant VC1 resulted in an antioxidant activity of 1.68 ± 0.10 mg TE/g and an RSA of 32.16 ± 0.21%, corresponding to increases of 58.49% and 58.19%, respectively, relative to the control. Conversely, the addition of dried tomatoes and dried basil in variant VC2 produced an antioxidant activity of 1.14 ± 0.05 mg TE/g and an RSA of 25.28 ± 0.18%, representing increases of 7.55% and 24.23% compared with the control (1.06 ± 0.08 mg TE/g and 20.35 ± 0.12%, respectively).

Table 3. Antioxidant and antiradical activities of chickpea-based vegan cheese analogues and their constituent raw materials

Sample	Antioxidant activity (mg TE/g)	RSA (%)
Chickpea flour	2.18 ± 0.14	34.28 ± 0.36
Lemon juice	10.62 ± 0.24	90.74 ± 0.62
Garlic powder	12.62 ± 0.30	92.16 ± 0.53
Onion flasks	9.23 ± 0.28	83.86 ± 0.46
Turmeric powder	57.25 ± 0.94	95.86 ± 0.81
Black pepper grounded	60.11±0.90	96.42 ± 0.72
Dried oregano	11.33 ± 0.22	92.35 ± 0.48
Dried tomato flakes	4.34 ± 0.16	84.18 ± 0.38
Dried basil	7.53±0.61	83.68 ± 0.46
C	1.06 ± 0.08	20.35 ± 0.12
VC1	1.68 ± 0.10	32.16 ± 0.21
VC2	1.14 ± 0.05	25.28 ± 0.18

Proximate composition and energy value of chickpea-based vegan cheese analogues

The results concerning the proximate composition and energetic values of the three chickpea-based vegan cheese analogues are detailed in Table 4.

Table 4. Proximate composition and energy value of chickpea-based vegan analogues

Parameters	C	VC1	VC2
Proteins (g/100 g)	10.00±0.10	10.07±0.08	10.35±0.11
Lipids (g/100 g)	5.43±0.06	5.39±0,04	5.39±0,06
Saturated fatty acids (g/100 g)	0.57±0.02	0.57±0.01	0.57±0.01
Carbohydrates (g/100 g)	32.64	32.98	32.93
Sugar (g/100 g)	0.43±0.03	0.43±0.02	0.99±0.06
Dietary fiber (g/100 g)	7.71±0.12	8.37±0.13	8.09±0.11
Moisture (g/100 g)	42.86±0.31	41.84±0.28	41.84±0.32
Mineral substances (g/100 g)	1.36±0.04	1.35±0.05	1.40±0.03
Energy value (kcal/100 g)	221.07	220.71	221.63

As evidenced by the data, the proximate compositions of the three formulations exhibit a high degree of uniformity; nevertheless, the VC2 analogue demonstrates a marginal but statistically relevant superiority in protein content. Specifically, the protein concentration of VC2 (10.35 ± 0.11 g/100 g) exceeds that of VC1 (10.07 ± 0.08 g/100 g) and the control C (10.00 ± 0.10 g/100 g) by 2.78% and 3.5%, respectively. Furthermore, the sugar content, although low across all three formulations, was 2.30 times higher in VC2 (0.99 ± 0.06 g/100 g) compared to VC1 (0.43 ± 0.02 g/100 g) and C (0.43 ± 0.03 g/100 g). Additionally, the analysed formulations are distinguished by a significant dietary fiber profile; the highest concentration was identified in the VC1 analogue (8.37 ± 0.13 g/100 g), whereas the control sample (C) exhibited the lowest fiber content (7.71 ± 0.12 g/100 g).

Compared to the analogues presented in this work, the Romanian cow's milk cheeses analysed by Ibric et al. (2024) exhibited higher concentrations of moisture, crude protein, and total lipids, with maximum values reaching 57.71 ± 2.05 g/100 g (all proximate constituents were calculated based on the wet weight of the samples as analyzed, with values expressed in g/100 g of the total product weight), 17.50 ± 0.61 g/100 g, and 27.93 ± 0.95 g/100 g, respectively. Conversely, total carbohydrates showed a marked reduction (0.53 ± 0.01 to 1.44 ± 0.04 g/100 g), with no dietary fibre being reported.

In a study of vegan cheese analogues based on fava bean and respectively yellow pea flours, Ferawati et al. (2021) reported lower protein concentrations (4.2-4.4 g/100 g and 6.2-6.6 g/100 g, respectively) and total lipid contents (10.4-10.6 g/100 g and 9.9-10.8 g/100 g, respectively) compared to the formulations in the present work. Furthermore, while the total carbohydrate levels (3.3-8.3 g/100 g) were also reduced, the dietary fiber values (6.5-7.7 g/100 g) were found to be comparable to those observed in our current investigation.

Sensory analysis

The sensory evaluation of the three chickpea-based cheese analogues yielded the comparative data illustrated in Figure 2.

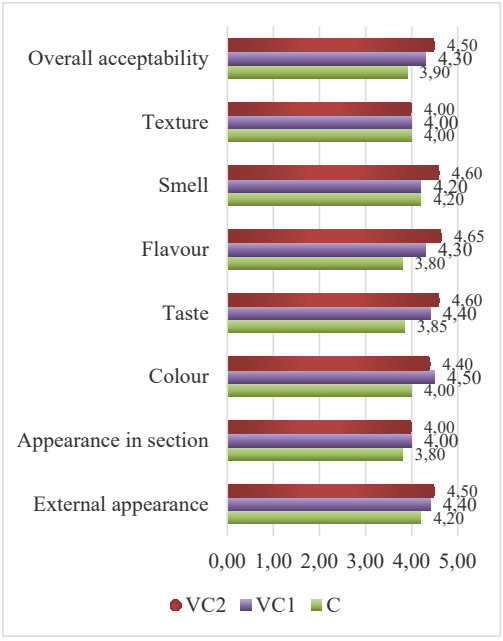

Figure 2. Comparative sensory profile and overall acceptability of chickpea-based cheese analogues

These results reflect the organoleptic performance of the formulations, assessed across various descriptors to determine consumer

acceptability and textural attributes. Although a uniform score of 4.00 was recorded for texture across all three samples, significant variations were observed in the remaining sensory attributes, with a distinct preference for the VC1 and, more prominently, VC2 variants. Specifically, VC2 exhibited superior performance, achieving "very good" ratings for external appearance (4.50), taste (4.60), flavour (4.65), smell (4.60), and overall acceptability (4.50), while VC1 followed with respective scores of 4.40, 4.40, 4.30, 4.20, and 4.30. In contrast, the control sample (C) yielded lower values for these parameters (4.20, 3.85, 3.80, 4.20, and 3.90, respectively); furthermore, while VC1 attained the highest acceptability for colour (4.50), followed by VC2 (4.40) and C (4.00), the cross-sectional appearance was rated equally for both VC1 and VC2 (4.00), surpassing the inferior score of 3.80 attributed to the control.

CONCLUSIONS

This research details the formulation and systematic evaluation of three distinct chickpea-based plant-derived cheese alternatives. These include a plain variant, a second variant fortified with turmeric, dried thyme, and black pepper, and a third variant incorporating dried tomatoes and dried basil.

The raw ingredients analysis identifies turmeric powder as the primary contributor to the total phenolic content, significantly outperforming the other botanical components and the leguminous base. The resulting chickpea-based analogues demonstrate a markedly superior antioxidant profile compared to the control sample, with the enriched formulations exhibiting a substantial increase in polyphenol concentration. Most notably, when benchmarked against traditional dairy matrices such as ricotta and cottage cheese, the developed vegan analogues consistently show higher phenolic levels. These findings highlight the formulations' robust capacity for free-radical scavenging and their potential as high-biological-value functional alternatives to conventional dairy products.

The research highlights a clear hierarchy in antioxidant potency among the utilized substrates, with black pepper and turmeric manifesting the most pronounced free-radical scavenging properties. Integrating these ingredients into the cheese analogue formulations optimized the antioxidant activity of the final products. Consequently, the addition of spices and herbs represents an effective strategy for improving the oxidative stability and nutritional quality of chickpea-based food matrices.

The developed formulations demonstrate a highly consistent proximate composition, with the VC2 analogue offering a marginal advantage in protein content. The primary distinguishing factor of these analogues is their robust dietary fiber profile, which significantly surpasses that of traditional dairy counterparts. While conventional Romanian cheeses and Gouda exhibit higher protein and lipid concentrations, the formulations presented in this work successfully address the nutritional limitations of traditional dairy products by providing a superior fibre-to-carbohydrate ratio. When compared to other pulse-based alternatives such as fava bean and yellow pea analogues, the chickpea formulations developed in this study exhibit a superior nutritional density, characterized by markedly higher protein and total lipid concentrations. While the dietary fibre profiles remain consistent across different leguminous sources, the elevated macronutrient levels in our formulations suggest a more robust nutritional profile than previously reported alternatives.

Sensory evaluation indicates that while texture remained consistent across all samples, the inclusion of functional ingredients positively influenced the remaining attributes. The enriched variants were markedly superior to the control, with the tomato and basil formulation being the most highly rated for taste, flavour, and overall acceptability. Simultaneously, the turmeric variant achieved the highest appreciation for colour, demonstrating that nutritional optimization through spice supplementation concurrently enhances the organoleptic properties of the products.

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