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Original Article

Development and Evaluation of the Physicochemical Properties of Fenugreek Energy Bars and Their Relationship with Polycystic Ovary Syndrome

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ABSTRACT

Background: Polycystic ovary syndrome (PCOS) is a heterogeneous reproductive and metabolic disorder in which healthy lifestyle and dietary management are important components of care. Fenugreek contains fiber and bioactive compounds that have attracted interest in metabolic nutrition, but incorporation into foods requires simultaneous consideration of composition and palatability. Objective: To develop fenugreek-containing energy bars and evaluate their physicochemical, total phenolic, and sensory characteristics as a preliminary functional-food formulation potentially relevant to dietary strategies for women with PCOS. Methods: Four formulations were prepared: a peanut-butter-containing control (T0) and three fenugreek formulations containing 5% (T1), 10% (T2), or 15% (T3) fenugreek powder. Moisture, protein, fat, fiber, ash, carbohydrate, and total phenolic content were evaluated. Fifteen panelists aged 20–35 years assessed appearance, taste, aroma, texture, and overall acceptability using a 9-point hedonic scale. Results: Moisture, protein, fiber, ash, and total phenolic content increased across T0–T3, while fat decreased modestly. T3 had the highest fiber (2.90±0.11%), ash (1.56±0.07%), and total phenolic content (57.4±1.6 mg GAE/100 g). Corrected carbohydrate-by-difference values were 61.15%, 59.87%, 59.83%, and 59.04% for T0–T3, respectively. Sensory distributions showed T0 as the most highly rated overall formulation; among fenugreek-containing bars, T2 had the greatest overall acceptability, while T3 had markedly poorer ratings. Conclusion: Fenugreek-containing bars with measurable fiber and phenolic content were successfully formulated. A 10% fenugreek formulation provided the best sensory balance among the fenugreek-enriched products. Clinical effects in PCOS were not evaluated and require dedicated intervention studies. Keywords: PCOS; Fenugreek; Energy Bar; Functional Food; Physicochemical Properties; Fiber; Polyphenols; Sensory Evaluation.

INTRODUCTION

Polycystic ovary syndrome is one of the most common endocrine-metabolic disorders affecting reproductive-age women. It is heterogeneous in presentation and may involve ovulatory dysfunction, hyperandrogenism, metabolic abnormalities, psychological burden, and increased long-term cardiometabolic risk. International evidence-based guidance emphasizes accurate diagnosis, healthy lifestyle, emotional wellbeing, management of metabolic risk, and individualized pharmacological or fertility treatment according to clinical need (1).

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Reported PCOS prevalence varies according to population, region, and diagnostic criteria. Recent global synthesis and community-based studies demonstrate that prevalence estimates change substantially according to whether Rotterdam, National Institutes of Health, Androgen Excess-PCOS, or other diagnostic definitions are applied (2,3). This heterogeneity is relevant when evaluating nutritional interventions because women with PCOS do not represent a metabolically uniform population.

Insulin resistance and compensatory hyperinsulinemia are prominent features in many women with PCOS and may contribute to ovarian androgen production and metabolic dysfunction. These processes can occur in women across different body-weight categories, although obesity and central adiposity may amplify metabolic risk. Low-grade inflammation, dyslipidemia, oxidative stress, and adipose-tissue dysfunction also contribute to the complex metabolic phenotype (4–7).

Lifestyle management remains a central component of PCOS care. Contemporary guidance supports sustainable healthy eating, physical activity, prevention of excess weight gain, management of weight where appropriate, and attention to psychological and behavioral barriers. Importantly, evidence comparing dietary approaches remains heterogeneous, and no single food product or dietary composition has been demonstrated to treat the full PCOS phenotype; dietary interventions should therefore be considered within an overall healthy lifestyle pattern (1,8,9).

Functional foods are foods developed or selected to provide nutritional characteristics beyond basic energy provision, often through fiber, unsaturated fats, phytochemicals, or other bioactive components. They are of interest in metabolic nutrition because they may provide a practical means of modifying dietary quality, although claims regarding disease treatment require direct clinical testing rather than extrapolation from laboratory nutrient composition (10,11).

Fenugreek (Trigonella foenum-graecum) contains soluble and insoluble fiber together with saponins, alkaloids including trigonelline, steroidal sapogenins, and phenolic compounds (12,13). Fenugreek has been investigated for possible metabolic effects, particularly glucose and lipid regulation (12–14). Meta-analysis of randomized trials in type 2 diabetes and prediabetes indicates that fenugreek preparations can affect several glycemic and lipid outcomes, although formulation, dose, study quality, and target population vary considerably (14).

Clinical evidence involving PCOS is more limited. A recent randomized comparison of fenugreek with metformin reported changes in clinical and metabolic outcomes in women with PCOS but concluded that fenugreek should not be regarded as a replacement for metformin, although it may warrant further investigation as an adjunct in selected settings (15). These clinical data concern defined fenugreek interventions and cannot be assumed to apply automatically to a composite food product containing a smaller dietary quantity of fenugreek (14,15).

The other ingredients used in the present formulations were oats, almonds, honey, and, in the control formulation, peanut butter. Oats provide carbohydrate and β-glucan-containing fiber, while almonds contribute substantial lipid, protein, and other nutrient fractions (16,17). Honey serves as a sweetening and binding ingredient. The inclusion and relative proportions of these ingredients influence both the nutritional composition and sensory characteristics of the final food product.

Convenience, behavioral feasibility, and consumer acceptance can influence adherence to dietary strategies (8,11). Ready-to-eat foods may be useful when they replace less nutritionally appropriate snack choices, provided their ingredients, energy density, portion size, and sensory characteristics are compatible with the individual's overall dietary pattern. A functional snack designed for a metabolic-health context should therefore achieve both an acceptable nutritional profile and sufficient palatability for practical consumption (11).

Food-product development involves a balance between functional ingredients and sensory acceptance. Increasing the concentration of an ingredient may improve one nutritional characteristic while adversely affecting taste, aroma, appearance, or texture. Fenugreek is particularly relevant in this respect because its characteristic flavor and phytochemical profile can affect sensory attributes as incorporation levels increase (13,18).

The development of culturally familiar, locally producible functional foods may have particular relevance in South Asian settings because PCOS burden varies across regions and product acceptance is strongly influenced by food context and consumer factors (2,11). However, laboratory formulation research should be distinguished from clinical efficacy research.

The present study therefore developed four energy-bar formulations containing oats, almonds, honey, peanut butter or fenugreek in different proportions and evaluated their physicochemical composition, total phenolic content, and sensory acceptability. The relationship to PCOS is conceptual and nutritional:

the study examined whether a palatable fenugreek-containing product could be formulated as a candidate for future clinical dietary research, not whether the product improves PCOS outcomes.

MATERIALS AND METHODS

Study Design

An experimental laboratory food-product development study was conducted to formulate energy bars and evaluate their physicochemical, phytochemical, and sensory characteristics.
The work comprised three principal phases: formulation and preparation of the control and fenugreek-containing bars; laboratory analysis of proximate composition and total phenolic content; and sensory assessment using a structured hedonic scale.

Study Setting

Laboratory development and analysis were conducted in the Food Science and Technology Laboratory, The Superior University, Lahore. Sensory assessment was conducted within the department under controlled conditions.
Ingredients
The principal ingredients were powdered fenugreek seeds, oats, almonds, honey, and peanut butter.
Fenugreek powder was incorporated into treatment formulations T1, T2, and T3. Oats formed the principal base of all four formulations. Almonds were included in all formulations, honey was used as a sweetening and binding ingredient, and peanut butter was used only in the control formulation.
Formulation Composition
The four formulations were compositionally distinct.

Table 1. Ingredient Composition of the Four Energy-Bar Formulations

Ingredient, %	T0 Control	T1 5% Fenugreek	T2 10% Fenugreek	T3 15% Fenugreek
Oats	50	50	50	50
Almonds	20	20	15	10
Honey	10	25	25	25
Peanut butter	20	0	0	0
Fenugreek powder	0	5	10	15
Total	100	100	100	100

Thus, comparisons between the control and fenugreek formulations reflected several ingredient changes. Within T1–T3, increasing fenugreek concentration was accompanied by a corresponding reduction in almond content.
Preparation Procedure
All ingredients were weighed using an electronic balance.
Oats, fenugreek powder where applicable, and crushed almonds were combined. Honey was used in all preparations, while peanut butter was included in the control formulation. The wet binding ingredients were slightly heated to facilitate mixing.
Dry and wet components were mixed until a homogeneous dough-like consistency was obtained. The mixture was shaped into rectangles and compressed. Prepared bars were refrigerated for approximately two hours, divided into equal-sized pieces, wrapped in food-grade material, and labelled according to formulation.
Physicochemical Analysis
The study used laboratory procedures described as based on AOAC methods (19).
Moisture content was determined by oven drying. Approximately 2–5 g of sample was weighed in a tared dish, dried at 105°C to constant weight, cooled in a desiccator, and reweighed.
Protein was determined using the Lowry method (20). One gram of sample was macerated in 10 mL distilled water with 3–4 drops of Triton X-100 for 30 minutes and centrifuged at 2700 rpm for 10 minutes. A 0.1-mL aliquot of supernatant was diluted to 1 mL. Reagent C was added, followed by Folin-Ciocalteu reagent. After 30 minutes at room temperature, absorbance was read at 600 nm. Bovine serum albumin

standards ranging from 100 to 1000 µg/mL were used to construct the calibration curve. The protein assay was performed in triplicate.

Total lipid was assessed using Soxhlet extraction. Fifteen grams of powdered sample were placed in a thimble and macerated in petroleum ether before hot extraction at approximately 40–60°C. The extract was subsequently dried and lipid content determined gravimetrically.

Crude fiber was determined by sequential digestion of defatted material with dilute sulfuric acid and dilute sodium hydroxide, followed by filtration, drying, weighing, and ashing. Fiber was calculated from weight loss following ashing.

Total ash was determined by incinerating approximately 2–4 g of sample at 500–600°C in a muffle furnace until carbon-free residue was obtained. Samples were cooled in a desiccator and reweighed to constant mass.

Carbohydrate was calculated by difference from the reported proximate components.

Total Phenolic Content

Total phenolic content was determined using a Folin-Ciocalteu procedure, with gallic acid used for preparation of the standard calibration curve (21).

Sample and gallic-acid stock solutions were prepared in methanol. Aliquots were diluted, reacted with Folin-Ciocalteu reagent, followed by 15% sodium carbonate, and incubated for two hours at room temperature. Absorbance was measured at 760 nm.

Results were expressed as milligrams of gallic acid equivalents per 100 g of product.

Sensory Evaluation

Fifteen panelists aged 20–35 years were purposively selected. Eligibility required absence of known allergy to fenugreek, oats, almonds, honey, or peanuts and willingness to participate in repeated tasting. Each panelist evaluated all four formulations, resulting in 60 formulation-level evaluation forms.

A 9-point hedonic scale was used to characterize food acceptability (22):

1 = dislike extremely;
2 = dislike very much;
3 = dislike moderately;
4 = dislike slightly;
5 = neither like nor dislike;
6 = like slightly;
7 = like moderately;
8 = like very much;
9 = like extremely.

Appearance, taste/flavor, aroma/smell, texture/consistency, and overall acceptability were evaluated.

The available sensory output consisted of aggregated response distributions for each formulation and attribute. Weighted descriptive mean hedonic scores were therefore calculated from these categorical distributions. Participant-level paired sensory scores were not reconstructed, and no repeated-measures inferential statistic was generated from the aggregated data.

Statistical Analysis

Data were processed using IBM SPSS Statistics version 25 and Microsoft Excel 2021.

Physicochemical and phenolic measurements were summarized as reported means and standard deviations.

Sensory response distributions were summarized descriptively. Weighted mean hedonic scores were calculated using the score assigned to each response category.

Because the original food-composition analysis specified carbohydrate by difference, carbohydrate values were checked arithmetically against the reported moisture, protein, fiber, ash, and fat values.

Ethical Considerations

The study protocol was reviewed and approved by the Ethics Committee of The Superior University, Lahore. Informed consent was obtained from sensory participants, and confidentiality was maintained.

RESULTS

Physicochemical Composition

Moisture increased progressively from 9.25±0.12% in T0 to 10.15±0.18% in T3. Protein showed a smaller increase from 11.50±0.22% in T0 to 12.45±0.25% in T3.
Fiber increased from 2.10±0.08% in T0 to 2.90±0.11% in T3, while ash increased from 1.20±0.05% to 1.56±0.07%.
Fat decreased from 14.80±0.28% in the control to 13.90±0.24% in T3.
The source table reported carbohydrate values of 50.87%, 50.23%, and 50.04% for T1–T3. These values were incompatible with the stated difference method. Subtracting moisture, protein, fiber, ash, and fat from 100% produced corrected carbohydrate values of 59.87%, 59.83%, and 59.04%, respectively. The control value of 61.15% was internally consistent.
Total phenolic content increased across formulations from 38.5±1.2 mg GAE/100 g in the control to 57.4±1.6 mg GAE/100 g in T3.

Table 2. Physicochemical and Total Phenolic Characteristics of Energy-Bar Formulations

Parameter	T0 Control	T1 5% Fenugreek	T2 10% Fenugreek	T3 15% Fenugreek
Moisture, %	9.25±0.12	9.80±0.15	9.90±0.17	10.15±0.18
Protein, %	11.50±0.22	12.10±0.24	12.15±0.19	12.45±0.25
Fiber, %	2.10±0.08	2.65±0.09	2.68±0.08	2.90±0.11
Ash, %	1.20±0.05	1.38±0.06	1.44±0.06	1.56±0.07
Fat, %	14.80±0.28	14.20±0.26	14.00±0.25	13.90±0.24
Carbohydrate by difference, %	61.15	59.87	59.83	59.04
Total phenolic content, mg GAE/100 g	38.5±1.2	49.8±1.4	55.0±1.3	57.4±1.6

The compositional pattern demonstrates progressively higher measured fiber, ash, and total phenolic content across the four formulations. Because multiple ingredient proportions changed simultaneously, these trends represent formulation-associated differences rather than an isolated experimental effect of fenugreek alone.
Sensory Evaluation
All 15 panelists evaluated the four formulations for five sensory attributes.
The original sensory table contained values outside the possible range of the 9-point hedonic instrument. The internally coherent sensory information was contained in the formulation-specific category distributions.
Weighted means calculated from those distributions showed consistently high scores for the control formulation, intermediate-to-high scores for T2, lower but positive scores for T1, and poor scores for the 15% fenugreek T3 formulation.
For overall acceptability, the reconstructed weighted means were 8.27 for T0, 6.67 for T1, 7.93 for T2, and 1.80 for T3. Thus, T0 was the most highly rated formulation overall, while T2 was the most highly rated among the fenugreek-containing formulations.

Table 3. Sensory Evaluation Derived From the 9-Point Hedonic Response Distributions

Attribute	T0 Control	T1 5% Fenugreek	T2 10% Fenugreek	T3 15% Fenugreek
Appearance	8.27	6.67	7.93	2.67
Taste/flavor	8.60	6.47	7.87	1.87
Aroma/smell	8.53	6.73	7.73	1.60
Texture/consistency	8.27	6.47	7.93	2.07
Overall acceptability	8.27	6.67	7.93	1.80

Values are weighted descriptive means on the 1–9 hedonic scale reconstructed from the formulation-specific categorical response distributions of 15 panelists.

The underlying category distributions further showed that all T0, T1, and T2 overall responses were in positive hedonic categories ranging from "like slightly" to "like extremely," whereas T3 overall responses were confined to negative categories.
T3 also showed markedly poorer appearance, taste, aroma, and texture responses than the lower-fenugreek formulations.

DISCUSSION

The present study successfully developed a control energy bar and three fenugreek-containing formulations and characterized their physicochemical, phenolic, and sensory properties. Increasing formulation number from T0 through T3 was accompanied by modest increases in moisture and protein, larger relative increases in fiber and ash, an increase in total phenolic content, and a small decline in fat. These changes cannot, however, be interpreted as a pure fenugreek dose-response experiment. The formulations did not differ only in fenugreek concentration. The control contained 20% peanut butter and only 10% honey, whereas all fenugreek formulations contained 25% honey and no peanut butter. Within T1–T3, fenugreek increased from 5% to 15% while almond content declined from 20% to 10%. Nutrient differences therefore reflect the combined consequences of these formulation changes.
This distinction is particularly important for fat content. The control had the highest fat value and was the only formulation containing peanut butter. Consequently, the observed reduction in fat across treatment formulations cannot be attributed solely to the addition of fenugreek.
Likewise, the modest rise in protein may reflect changing contributions from fenugreek, almonds, and removal of peanut butter rather than fenugreek alone. The analytical results are nevertheless useful for characterizing the final products themselves, which is the central objective of a product-development study.
Fiber increased from 2.10% in the control to 2.90% in T3. Fenugreek is recognized as a fiber-containing food ingredient and has been studied for potential effects on glycemic and lipid metabolism (12–14). However, the fiber values measured in the current product characterize the food; they do not demonstrate reduced blood glucose, improved insulin resistance, weight reduction, or hormonal change in consumers.
Total phenolic content also increased, reaching 57.4 mg GAE/100 g in T3. Fenugreek seeds contain multiple phytochemical constituents, including phenolic compounds, and experimental food and phytochemical research has reported antioxidant-related activity (12,13,18). The present Folin-Ciocalteu assay establishes a higher measurable phenolic-equivalent content in the enriched formulations but does not directly demonstrate antioxidant effects in vivo.
The carbohydrate results required numerical reconciliation. Because the stated analytical method defined carbohydrate by difference, the initially reported T1–T3 values were mathematically incompatible with the other measured components. Corrected values were 59.87%, 59.83%, and 59.04%, respectively. These values show only a modest decline in estimated carbohydrate content across the fenugreek formulations rather than the much larger decline implied by the original table.
The sensory evaluation revealed a clear formulation trade-off. The control had the highest weighted scores across appearance, taste, aroma, texture, and overall acceptability. This is important because a control containing familiar ingredients such as peanut butter and a lower honey proportion is not sensory-equivalent to a fenugreek formulation.
Among the fenugreek-containing products, T2 containing 10% fenugreek had the strongest sensory performance, with an overall weighted score of approximately 7.93 on the 9-point hedonic scale. T1 remained positively rated but scored lower, while T3 showed marked deterioration across all sensory domains.
The poor T3 ratings are compatible with food-product literature showing that increasing fenugreek incorporation can alter color, aroma, flavor, and texture and that higher levels may require processing or flavor-management strategies to maintain consumer acceptance (13,18). The present results similarly indicate that maximizing the concentration of a functional ingredient does not necessarily optimize the final product.
T2 therefore represents the most promising fenugreek-containing formulation within the formulations tested. It achieved higher measured fiber and total phenolic content than T1 while maintaining substantially greater sensory acceptance than T3. This provides a rational formulation for subsequent development work.

The relationship of these findings to PCOS requires careful distinction between nutritional rationale and clinical evidence. PCOS is associated with important metabolic features, and international guidelines and contemporary evidence syntheses emphasize sustainable healthy lifestyle and dietary management (1,8,9). Fenugreek itself has been investigated clinically in metabolic disease and PCOS (14,15), but the current experiment did not enroll women with PCOS, administer the bars as a dietary intervention, or measure insulin, glucose tolerance, lipid profile, androgen concentrations, ovulation, menstrual regularity, body weight, inflammatory biomarkers, or quality of life.

Consequently, the present study cannot establish that these bars treat PCOS, improve insulin resistance, balance reproductive hormones, reduce inflammation, or normalize menstrual cycles. The scientifically supportable conclusion is narrower: the study produced a fenugreek-containing snack with measurable nutritional and phytochemical characteristics and identified a formulation with comparatively favorable sensory acceptability.

This distinction is important for functional-food development. A biologically plausible ingredient does not confer demonstrated therapeutic efficacy on every food containing that ingredient. Dose, bioavailability, food matrix, total dietary intake, participant phenotype, adherence, and intervention duration all influence the translation of compositional characteristics into clinical effects (11).

The current study is therefore best viewed as the preclinical food-development stage of a potential PCOS-related nutrition research program. A subsequent pilot trial could determine whether the selected formulation is acceptable to women with PCOS during repeated consumption and whether it can be incorporated into a defined diet without increasing total energy intake undesirably (1,9,11).

Future clinical testing should use a clearly specified intervention dose and comparator and prospectively measure relevant outcomes. Depending on the intended claim, these could include fasting glucose, fasting insulin, HOMA-IR, lipid profile, body weight and waist circumference, appetite or satiety measures, menstrual-cycle characteristics, androgen-related outcomes, and validated quality-of-life measures (1,9,15).

The study also requires further food-science development before therapeutic testing. Shelf-life was not measured, and moisture content alone cannot establish microbiological stability because water activity, storage conditions, and packaging materially influence product stability and microbial growth (23,24). Water activity, microbial counts, oxidative stability, packaging conditions, storage temperature, and sensory change over time should therefore be evaluated.

Product composition also requires optimization. The current control and treatment bars differed in several ingredients simultaneously. A more rigorous dose-response experiment would keep oats, honey, almonds, peanut butter or another base composition constant while replacing a defined component progressively with fenugreek. This would permit physicochemical changes to be attributed more specifically to fenugreek concentration.

Sensory methodology could also be strengthened. The same 15 individuals evaluated all four formulations, creating repeated observations. Future statistical analysis should therefore preserve participant-level paired scores and use a repeated-measures method rather than treating the 60 forms as independent observations.

The small panel is appropriate for preliminary formulation screening but not for population-level consumer acceptance claims. A larger blinded consumer panel representing the intended users, including women with PCOS if that is the target market, would provide stronger acceptability evidence.

Several strengths remain. The study tested four clearly identifiable formulations, used laboratory assays to characterize multiple proximate components, measured total phenolic content, and collected multidimensional sensory responses from all panelists for each formulation. The embedded sensory distributions also permit direct comparison of consumer preference without reliance on unsupported clinical extrapolation.

CONCLUSION

Fenugreek-containing energy bars were successfully developed and characterized for physicochemical composition, total phenolic content, and sensory acceptability.

Higher-fenugreek formulations were associated with greater measured fiber, ash, and total phenolic content, although the formulation design changed several ingredients simultaneously and therefore does not isolate a fenugreek-specific causal effect.

Sensory evaluation identified the control as the most highly rated formulation overall. Among the fenugreek-containing bars, the 10% fenugreek formulation (T2) provided the most favorable balance between compositional enrichment and sensory acceptance, whereas the 15% formulation was poorly accepted.

The study provides a foundation for further functional-food development relevant to PCOS nutrition, but it does not establish therapeutic effects on insulin resistance, hormones, menstrual function, inflammation, fertility, or other PCOS outcomes. Such claims require prospective clinical testing in women with PCOS.

RECOMMENDATIONS

The T2 formulation should be prioritized for further product optimization because it achieved the strongest overall sensory acceptance among the fenugreek-containing formulations while retaining higher fiber and phenolic content than T1.

Future formulation experiments should alter fenugreek concentration while holding other ingredients constant to separate fenugreek-specific effects from changes in almonds, honey, and peanut butter.

Independent production batches should be tested to distinguish analytical repeatability from batch-to-batch variability.

Shelf-life studies should evaluate water activity, microbial stability, oxidative changes, packaging, and storage conditions rather than inferring stability from moisture content alone (23,24).

Future sensory studies should retain participant-level repeated ratings and use an appropriate within-subject statistical analysis. A larger target-consumer panel should subsequently evaluate acceptance.

Clinical research in women with PCOS should be conducted before therapeutic claims are made. Such studies should prespecify dosage, intervention duration, comparator diet, adherence, energy intake, and metabolic, reproductive, anthropometric, and patient-reported outcomes (1,9,15).

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