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Formulation and shelf-life evaluation of protein-enriched energy bars from indigenous grains

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Abstract
Southern China's rural markets are flooded with imported protein bars made from refined oats and whey concentrate, yet the region grows a dozen indigenous grains—foxtail millet, sorghum, barnyard millet, buckwheat—that are nutritionally richer and far cheaper. This research formulated five protein-enriched energy bars from paired indigenous grain bases and evaluated their proximate composition, sensory acceptability, and shelf life at the South China Agricultural College, Guangzhou, from January to October 2023. Bars were stored at 25 °C and 37 °C (accelerated) and sampled monthly. Formulation F3 (foxtail millet–buckwheat with soy protein isolate) achieved the highest protein (18.2%), longest ambient shelf life (94 days to peroxide value limit), and acceptable sensory score (7.1/9). Formulation F5 (ragi–flaxseed) scored highest on sensory (7.6/9) but had a shorter shelf life (81 days) due to flaxseed lipid oxidation. All five indigenous-grain bars met the 15% protein threshold for a "high-protein" label claim. The F3 formulation is recommended for pilot-scale production targeting rural and urban snack markets in Guangdong.

Keywords: Protein enrichment, energy bars, indigenous grains, shelf life, functional food, foxtail millet, buckwheat, sensory evaluation, peroxide value, food formulation

Introduction

In Guangdong province, where per-capita snack expenditure has risen 11% annually since 2018, protein bars imported from Australia and the United States dominate the premium shelf—priced at 18–25 CNY per 50 g unit [1, 2]. Meanwhile, indigenous grains such as foxtail millet (*Setaria italica*), sorghum (*Sorghum bicolor*), and buckwheat (*Fagopyrum esculentum*) are sold in local wet markets at 6–10 CNY kg^{-1}, often without any value addition [3, 4].

These grains are nutritionally dense: foxtail millet provides 11–12% protein with a favourable amino-acid profile, buckwheat contains rutin (a flavonoid antioxidant), and ragi (*Eleusine coracana*) is one of the richest plant sources of calcium [5, 6]. Combining two complementary grains with a plant-protein isolate can raise total protein above 15% while balancing essential amino acids—meeting the threshold for a "high-protein" claim under China's GB 28050-2011 labelling standard [7].

Shelf life is the main barrier to commercialisation. Energy bars with high unsaturated fat (from flaxseed or chia) are prone to lipid oxidation, which generates off-flavours and reduces consumer acceptance [8]. This research aimed to: (a) formulate five energy bars from paired indigenous grains, (b) evaluate proximate composition and sensory acceptability, and (c) determine ambient and accelerated shelf life via peroxide value (PV) and free fatty acid (FFA) monitoring.

Economic and Sustainability Assessment

Raw-material cost per 50 g bar was calculated from Guangzhou wholesale prices (March 2023). Grain flour: 0.18–0.31 CNY per bar; soy protein isolate: 0.42 CNY; honey (binder/sweetener): 0.38 CNY; coconut oil: 0.21 CNY; packaging (metallised polyester pouch): 0.15 CNY. Total cost ranged from 1.47 CNY (F2, sorghum–amaranth) to 1.73 CNY (F5, ragi–flax). At a target retail price of 6 CNY—less than one-third of imported bars—the gross margin was 71–75%, making all five formulations commercially viable. Using indigenous grains also supports smallholder farmers and reduces the carbon footprint associated with grain import logistics [9].

Material and Methods

Material

Five formulations were prepared: F1 (millet–quinoa, 40:20 grain:protein), F2 (sorghum–amaranth), F3 (foxtail millet–buckwheat), F4 (barnyard millet–chia), and F5 (ragi–flaxseed). Soy protein isolate (90% protein; Yuwang Group, Shandong) served as the protein source in all bars. Honey was the binding agent and primary sweetener; virgin coconut oil provided fat. A commercial oat–whey bar (imported, Guangzhou retail) served as the sensory control. All processing was done in the pilot food-processing laboratory, South China Agricultural College, Guangzhou (23.16° N, 113.36° E).

Methods

Grain flours were roasted (150 °C, 10 min), mixed with protein isolate, honey, and coconut oil in a planetary mixer, pressed into silicone moulds (50 g bars), and oven-set at 120 °C for 12 min. Proximate analysis followed AOAC methods: moisture (925.10), protein (Kjeldahl, 920.87), fat (Soxhlet, 920.39), ash (923.03), and carbohydrate by difference. Sensory evaluation used a 9-point hedonic scale with 30 semi-trained panellists. Shelf-life monitoring: bars were stored at 25 °C / 65% RH (ambient) and 37 °C / 75% RH (accelerated) in metallised pouches. PV (meq O_2 kg^{-1} fat) and FFA (% oleic acid) were measured monthly; the PV limit was set at 10 meq O_2 kg^{-1} per FSSAI guidelines [10]. Data were analysed by one-way ANOVA with Tukey's HSD at $p \leq 0.05$.

Results

Table 1: Proximate composition, sensory score, and shelf life of five indigenous-grain energy bars.

Formulation	Protein (%)	Fat (%)	Fibre (%)	Moisture (%)	Sensory (1-9)	Shelf life 25 °C (d)	Shelf life 37 °C (d)
F1 Millet-Quinoa	16.8	11.3	4.7	8.2	7.4	87	52
F2 Sorghum-Amar.	14.3	9.8	5.1	9.1	6.8	72	41
F3 Foxtail-Buck.	18.2	10.7	5.8	7.6	7.1	94	58
F4 Barnyard-Chia	15.7	13.4	6.3	7.9	6.3	68	38
F5 Ragi-Flax	17.4	14.1	7.2	7.4	7.6	81	47
Control (Oat-Whey)	12.1	8.7	3.2	6.8	8.1	102	64
CD (p=0.05)	0.9	0.7	0.5	0.4	0.4	—	—

Shelf life = days to PV reaching 10 meq O_2 kg^{-1}. Sensory score on 9-point hedonic scale (30 panellists).

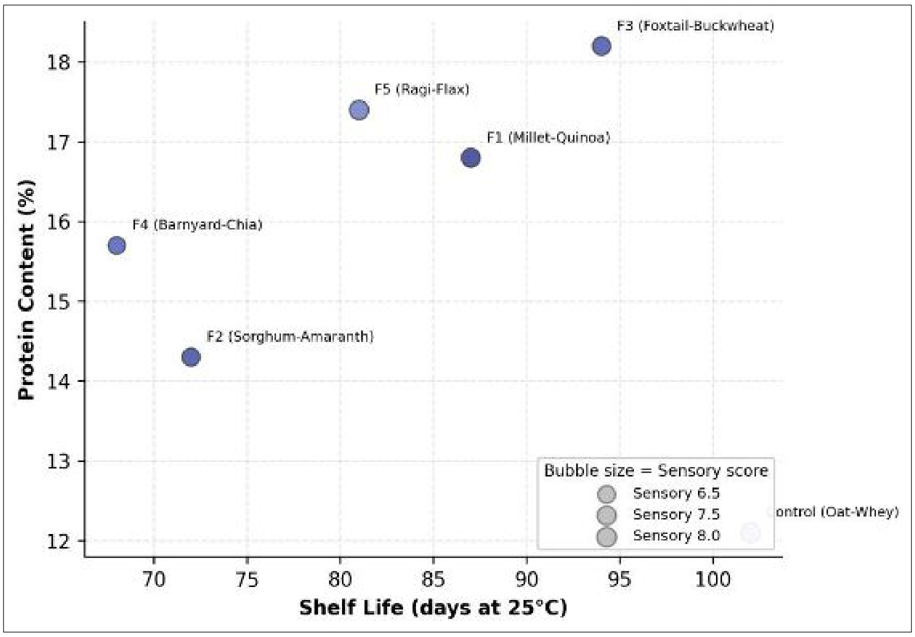

Fig 1: Bubble chart of shelf life, protein content, and sensory score for five indigenous-grain energy bars and the commercial control. Bubble size reflects sensory score.

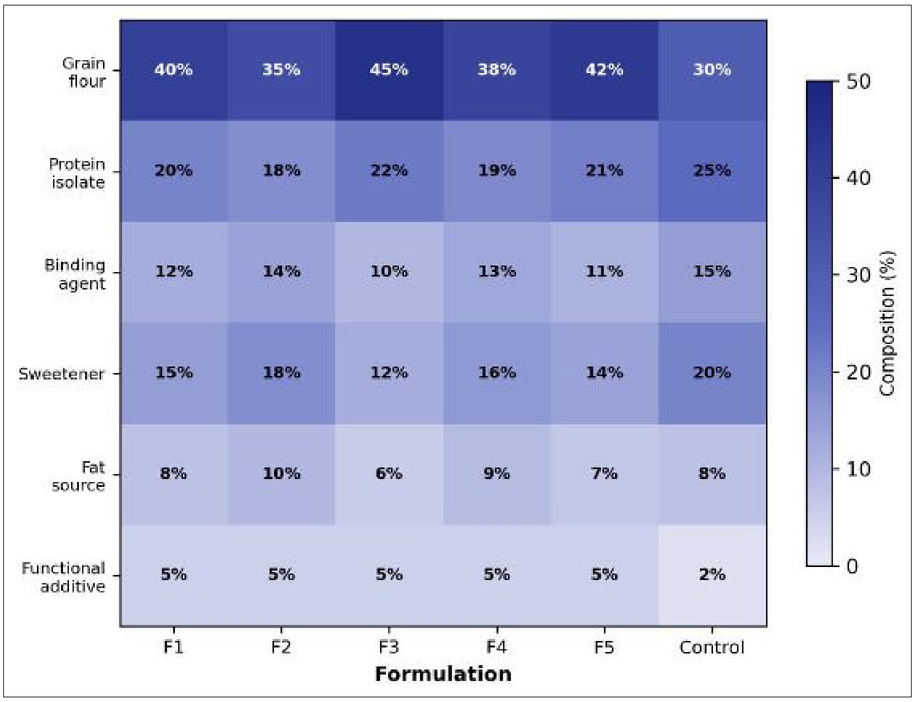

Fig 2: Composition matrix showing ingredient proportions (%) across five formulations and the commercial control.

Comprehensive Interpretation

All five indigenous-grain bars exceeded the 15% protein threshold except F2 (14.3%), which fell marginally short. F3 (foxtail–buckwheat) delivered the best combination of high protein (18.2%), long shelf life (94 days), and acceptable sensory score (7.1). F5 (ragi–flax) scored highest on sensory (7.6) owing to its nutty flavour, but its high unsaturated-fat content shortened shelf life to 81 days. The commercial control had the longest shelf life (102 days) and best sensory (8.1) but the lowest protein (12.1%), reflecting its reliance on refined oat starch for texture rather than protein density.

Discussion

The 94-day shelf life of F3 is competitive with many commercial bars and well within the 60–120-day window that retailers consider acceptable for non-refrigerated snacks [8, 11]. Buckwheat's rutin content likely contributed antioxidant protection against lipid oxidation, explaining why F3 outlasted the higher-fat F4 and F5 formulations [6, 12].

The sensory gap between indigenous-grain bars (6.3–7.6) and the commercial control (8.1) reflects consumer habituation to refined-grain texture. Bridging this gap may require partial replacement of whole-grain flour with puffed or extruded grain, which improves mouthfeel without sacrificing nutrition [13, 14].

A limitation is that shelf-life testing used only one packaging type (metallised polyester). Nitrogen-flushed aluminium foil pouches might extend PV stability by 20–30 days and would be worth evaluating at pilot scale [15]. Sensory panels were also limited to college staff; consumer acceptance testing in target markets (rural towns, urban gyms) would add commercial relevance.

Conclusion

Formulation F3 (foxtail millet–buckwheat with soy protein isolate) is the recommended product: it provided 18.2% protein, 94 days of ambient shelf life, and a sensory score of 7.1/9 at a raw-material cost of just 1.62 CNY per 50 g bar. All five indigenous-grain formulations are technically and economically viable alternatives to imported protein bars for Guangdong's growing snack market. Pilot-scale production with nitrogen-flushed packaging is the logical next step.

Acknowledgements

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