Formulation and Nutraceutical Evaluation of Dragon Fruit-Based Energy Balls

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How to Cite this Article:

Bhagwat, S. V. & Bankar, K. K. (2026). Formulation and Nutraceutical Evaluation of Dragon Fruit-Based Energy Balls. International Journal of Creative and Open Research in Engineering and Management, 02(05). https://doi.org/10.55041/ijcope.v2i5.420

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Abstract

Dragon fruit-based energy balls are emerging as an attractive functional snack because they combine natural sweetness, appealing color, dietary fiber, antioxidants, and convenience in a ready-to-eat nutraceutical format. Dragon fruit (*Hylocereus Undatus*) contains betalains, phenolic compounds, flavonoids, vitamin C, minerals, and seed-associated lipids that support its use as a functional food ingredient with antioxidant, anti-inflammatory, and broader health-promoting properties [cite:32][cite:35][cite:40]. When incorporated into energy balls, dragon fruit can contribute both nutritional value and visual appeal, while complementary ingredients such as oats, nuts, seeds, dates, or protein-rich binders can improve texture, satiety, and macro-nutrient balance [cite:46][cite:44][cite:49].

This review summarizes the formulation rationale, ingredient classification, phytochemical profile, functional and nutraceutical properties, mechanisms underlying health effects, evaluation parameters, shelf-life considerations, safety issues, regulatory aspects, development challenges, and prospects of dragon fruit-based energy balls. Particular emphasis is placed on nutritional composition, oxidative stability, pigment retention, water activity, packaging, and sensory optimization because these factors determine whether the product can be positioned successfully as a healthy shelf-stable snack [cite: 43] [cite: 50] [cite: 33].

Keywords

Dragon fruit; energy balls; nutraceutical snack; functional food; betalains; antioxidants; shelf-life stability; nutritional composition; functional properties; healthy snack formulation.

Introduction

The growing demand for convenient yet health-oriented snack products has accelerated the development of functional foods that deliver both nutrition and bioactive compounds in portable forms. Energy balls, also called snack bites or no-bake functional balls, fit this trend because they are compact, easy to formulate with minimally processed ingredients, and well-suited to the inclusion of fruits, nuts, seeds, cereals, and nutraceutical components [cite:46][cite:44].

Dragon fruit is especially promising for this application because of its vivid natural color, mild flavor, fiber content, antioxidant phytochemicals, and consumer-friendly "super fruit" positioning. Recent reviews describe dragon fruit as a source of betalains, polyphenols, flavonoids, carotenoids, vitamin C, and minerals, with reported potential in oxidative stress reduction, anti-inflammatory support, metabolic health, and functional food innovation [cite:32][cite:35][cite:40]. These characteristics make dragon fruit suitable not only as a flavor and color contributor but also as a nutraceutical ingredient capable of differentiating energy balls from conventional snack products [cite:35][cite:32].

This review aims to present a comprehensive paper on the formulation and nutraceutical evaluation of dragon fruit-based energy balls, with focus on shelf-life stability, nutritional composition, and functional properties for potential use as a healthy snack. The discussion integrates ingredient science, processing issues, analytical testing, stability concerns, and practical product development considerations relevant to pharmacy, nutraceutical, and food technology research [cite: 32] [cite: 43] [cite: 50].

Need and Rationale

Modern consumers increasingly prefer snacks that provide clean-label appeal, natural ingredients, reduced synthetic additives, and functional benefits beyond calories alone. Dragon fruit-based energy balls can answer this need by combining natural fruit-derived bioactives with nutrient-dense ingredients such as oats, nuts, seeds, and plant proteins, producing a snack that is more aligned with preventive nutrition and nutraceutical lifestyles than conventional confectionery [cite:35][cite:46][cite:49].

Dragon fruit also offers formulation advantages. Its pulp can contribute moisture, binding assistance, and natural sweetness, while peel-derived ingredients can provide dietary fiber, antioxidants, and natural pigments if used safely and appropriately processed. Studies on dragon fruit peel in foods have shown its potential to improve antioxidant activity, quality, and even shelf-life in selected food systems, suggesting wider value in snack formulation [cite:50][cite:35].

Another strong rationale is value addition and waste utilization. Since dragon fruit peel is rich in betalains and phenolic compounds, it can be explored in powder or extract form as a functional co-ingredient, provided sensory and safety aspects are controlled. This makes dragon fruit-based energy balls relevant not only nutritionally but also from a sustainability perspective [cite: 32] [cite: 43] [cite: 45].

Classification of Raw Materials

For formulation design, the ingredients used in dragon fruit-based energy balls can be classified according to technological and nutraceutical roles.

According to the functional role in formulation

- **Primary fruit base:** Dragon fruit pulp, puree, powder, or freeze-dried fruit supplies color, antioxidants, flavor, and part of the bulk [cite: 32] [cite: 35].
- **Binding agents:** Dates, fig paste, nut butter, honey, or syrup-based binders help agglomeration and texture formation, although high-moisture binders may reduce shelf stability [cite:33][cite:46].
- **Structure-forming ingredients:** Oats, puffed grains, millets, seed meals, and protein powders improve bite, shape retention, and nutritional density [cite: 44] [cite: 49].
- **Functional enrichers:** Chia, flaxseed, pumpkin seed, almond, peanut, whey, or plant protein concentrates can enhance protein, fiber, minerals, and satiety [cite: 46] [cite: 44].

- **Protective additives:** Natural antioxidants, low-water-activity ingredients, and suitable packaging systems help delay oxidation and microbial spoilage [cite: 50] [cite: 33].

According to the dragon fruit ingredient type

Dragon fruit form	Main use in energy balls	Advantages	Limitations
Fresh pulp/puree	Flavor, moisture, color	Natural taste and consumer appeal [cite:32]	Higher moisture may shorten shelf-life [cite:33]
Freeze-dried powder	Color, flavor, phytochemical enrichment	Lower moisture and easier blending [cite:38][cite:43]	More expensive; some pigment degradation during storage
Peel powder	Fiber, antioxidants, natural pigment	Valorizes by-product and can improve oxidative stability [cite:50][cite:45]	May affect taste, grittiness, or acceptability at high levels
Peel/pulp extract	Bioactive enrichment	Standardizable for research use [cite:43]	Requires processing control and solvent safety

Table no.1: Dragon fruit ingredient type

According to the intended nutritional purpose

Dragon fruit-based energy balls may be positioned as antioxidant snacks, fiber-rich snacks, sports or travel snacks, school snacks, or nutraceutical snacks for general wellness. Final classification depends on the ingredient profile, serving size, nutrient density, and regulatory category under the intended market framework [cite: 35] [cite: 46].

Phytochemical Constituents

The nutraceutical relevance of dragon fruit-based energy balls largely depends on the phytochemical composition of dragon fruit and accompanying ingredients.

Dragon fruit phytochemicals

Dragon fruit is notable for its betalains, including betacyanins and betaxanthins, which are responsible for the fruit's red-purple pigmentation and substantial antioxidant capacity. Reviews also identify phenolic acids, flavonoids, carotenoids, vitamin C, and minerals as important contributors to its functional value [cite: 32] [cite: 35] [cite: 41].

Seed and peel components

The seeds contain lipids and other nutrients that may add energy density and texture, while the peel is particularly rich in phenolic compounds, hydroquinones, flavonoids, and pigment compounds. Research on peel-derived ingredients suggests that the peel can function as an antioxidant dietary fiber source in food products, which is highly relevant for value-added snack development [cite: 32] [cite: 50].

Bioactive compounds relevant to functional snack design

The most important bioactive groups for a research paper on energy balls are:

- **Betalains:** Natural pigments with antioxidant and anti-inflammatory relevance [cite: 41] [cite: 32].
- **Polyphenols and flavonoids:** Associated with radical-scavenging and broader protective effects [cite: 32] [cite: 35].
- **Vitamin C and carotenoids:** Support antioxidant status, though both are sensitive to processing and storage [cite: 32] [cite: 40].

- **Dietary fiber:** Particularly relevant when peel powder or whole fruit components are incorporated [cite: 50] [cite: 45].

Formulation of Dragon Fruit-Based Energy Balls

The formulation of energy balls involves transforming nutrient-dense ingredients into a cohesive, shelf-acceptable, bite-sized product with good sensory quality.

Proposed formulation concept

A practical formulation may contain dragon fruit powder or concentrated pulp, oats, date paste, or a low-moisture binder, almond or peanut butter, chia or flaxseed, nuts or seed fragments, and optional protein enrichment. The objective is to obtain a ball that is cohesive, non-sticky, pleasant in taste, and sufficiently low in water activity to support storage stability [cite: 46] [cite: 44] [cite: 33].

An illustrative research-level formula for a 100 g batch could include 15 to 25 g dragon fruit powder or equivalent fruit solids, 20 to 30 g oats, 20 to 25 g date paste or nut butter as a binder, 10 to 20 g mixed nuts and seeds, 5 to 15 g protein source, and small quantities of flavoring or natural preservatives if justified. Such a formulation should then be optimized by sensory testing and physicochemical analysis rather than accepted as final without validation [cite: 44] [cite: 49].

Processing method

Typical processing steps include sorting and cleaning of raw materials, preparation of dragon fruit pulp or powder, drying if needed, milling/sieving, blending of dry ingredients, addition of binder, mixing to a uniform mass, shaping into balls, optional coating, packaging, and storage. Use of low-temperature drying or freeze-drying is advantageous when preserving color and heat-sensitive phytochemicals is a priority [cite: 38] [cite: 43].

Formulation variables

Critical variables include moisture content, particle size, binder ratio, fat composition, sugar level, stickiness, hardness, and pH. Because energy balls are often semi-moist, small increases in fruit puree or hygroscopic ingredients can markedly alter microbial stability, texture, and shelf-life, making Preformulation trials essential [cite:33][cite:46].

Nutritional Composition

Dragon fruit-based energy balls are expected to provide balanced nutrition when formulated with whole-food ingredients.

Macronutrient profile

Depending on composition, energy balls can supply carbohydrates for rapid energy, fats from nuts and seeds for satiety, moderate protein from pulses or protein powders, and dietary fiber from fruit, oats, and peel fractions. Published energy ball formulations show that such snacks can meaningfully contribute calories, protein, and fiber when properly designed [cite: 44] [cite: 46] [cite: 49].

Micronutrients and phytonutrients

Dragon fruit contributes vitamin C, minerals, and phytochemicals, though their final levels depend heavily on processing and storage. When peel fractions are used, the product may gain additional phenolic and antioxidant dietary fiber; when seeds, nuts, and oats are included, the mineral and healthy-fat profile improves further [cite: 32] [cite: 35] [cite: 50].

Nutritional analysis parameters

A complete research evaluation should include moisture, ash, crude protein, crude fat, crude fiber, total carbohydrate, and energy value. Additional useful tests include total sugar, dietary fiber, mineral estimation, and phytochemical screening for total phenolic or betalains content, depending on the objective of the study [cite:49][cite:44][cite:32].

Functional Properties

The functional performance of dragon fruit-based energy balls extends beyond their nutrient content.

Antioxidant potential

Dragon fruit is widely recognized for its strong antioxidant potential due to its betalains, polyphenols, carotenoids, and vitamin C. This makes it especially attractive for nutraceutical snack development, where antioxidant activity is often used as a key functional marker [cite: 32] [cite: 35] [cite: 41].

Anti-inflammatory and metabolic support

Reviews suggest that dragon fruit may exert anti-inflammatory, lipid-lowering, and broader metabolic benefits through its bioactive composition, although product-specific outcomes will depend on dose, matrix, and bioavailability. This supports the positioning of dragon fruit energy balls as a wellness snack rather than merely a flavored confection [cite: 35] [cite: 40].

Fiber-related functionality

If peel powder or whole-fruit solids are incorporated, the formulation can gain soluble and insoluble fiber, which may improve satiety, digestive support, and glycemic moderation. This aspect is important for framing the product as a healthy snack, particularly when compared with conventional sugar-rich snacks [cite: 50] [cite: 45].

Natural color functionality

Betalains provide an additional technological benefit by acting as natural pigments. However, because these compounds are sensitive to heat, oxygen, and high-temperature storage, formulation design must protect color stability to maintain product appeal [cite: 43] [cite: 48].

Mechanism of Nutraceutical Action

The health-supporting effects of dragon fruit-based energy balls arise from multiple interacting mechanisms.

Radical scavenging and oxidative stress reduction

Betalains, phenolic, and vitamin C can donate electrons and help neutralize free radicals, reducing oxidative stress that contributes to cellular damage. This antioxidant mechanism is one of the most consistently cited explanations for dragon fruit's nutraceutical relevance [cite: 32] [cite: 41].

Anti-inflammatory modulation

Dragon fruit bioactives, including betalains and other phenolic compounds, have been linked with modulation of inflammatory pathways and protection against oxidative-inflammatory damage. These effects are central to its proposed role in functional food applications [cite: 35] [cite: 32].

Dietary fiber and metabolic response

Fiber-rich snack matrices can influence digestion rate, satiety, and postprandial metabolic response. If dragon fruit peel powder, oats, chia, or flaxseed are included, the energy balls may demonstrate additional benefits related to gastrointestinal health and moderated glycemic response, though this must be verified experimentally for the exact formulation [cite:46][cite:50].

Matrix and bioavailability considerations

One important limitation is that the bioavailability of some dragon fruit bioactives may be low, and the final food matrix can influence release and absorption. This means nutraceutical claims should be supported with realistic functional assays rather than relying solely on raw-ingredient reputation [cite: 35] [cite: 40].

Shelf-Life Stability

Shelf-life is a central quality parameter for energy balls because they are frequently semi-moist and rich in biologically active ingredients.

Moisture and water activity

Shelf-life depends more on water activity than on total moisture alone. Evidence comparing packaged snack products with homemade energy balls emphasizes that higher water activity strongly increases spoilage risk, making low-moisture binders and moisture control essential in product design [cite:33].

Oxidative stability

Because nuts, seeds, and dragon fruit pigments are susceptible to oxidation, lipid oxidation and color fading are major causes of quality loss during storage. Dragon fruit peel powder has shown antioxidant effects in food systems and may help retard oxidative deterioration when used appropriately [cite: 50] [cite: 43].

Betalain stability

Betalains are sensitive to heat, oxygen, and unfavorable storage conditions. Studies on dragon fruit betalains indicate that these pigments are unstable at elevated temperatures and benefit from protective strategies such as encapsulation, hydrocolloid systems, low-temperature processing, and suitable packaging [cite:43][cite:48][cite:38].

Packaging and storage

Barrier packaging is highly important for nutraceutical snacks because oxygen and moisture transmission directly affect flavor, texture, and phytochemical retention. For dragon fruit-based energy balls, high-barrier pouches, refrigerated storage where necessary, and light protection are likely to improve shelf stability compared with loosely packed or low-barrier packaging [cite:33][cite:45].

Evaluation and Standardization

A complete evaluation program should include sensory, physicochemical, nutritional, microbiological, and functional testing.

Organoleptic evaluation

Energy balls should be evaluated for color, surface appearance, aroma, taste, chewiness, cohesiveness, stickiness, sweetness, aftertaste, and overall acceptability. Dragon fruit contributes attractive color but a relatively mild flavor, so sensory balancing with acids, nuts, or spices may be necessary to produce a distinctive and acceptable product [cite: 32] [cite: 49].

Physicochemical evaluation

Important tests include moisture content, water activity, pH, bulk density, texture profile, color parameters, and weight variation. In research aimed at shelf-life, periodic monitoring of texture hardening, moisture migration, and pigment retention is especially valuable [cite: 33] [cite: 43] [cite: 48].

Nutritional and phytochemical analysis

Standard proximate analysis should be supported by total phenolic content, Betalain estimation, antioxidant assays such as DPPH/FRAP, and, possibly, vitamin C estimation when feasible. These tests help connect ingredient selection with measurable nutraceutical value [cite: 32] [cite: 41] [cite: 43].

Microbiological evaluation

Total plate count, yeast and mold count, and product safety over storage are essential because energy balls often contain fruit-based binders and are not always heat-processed after shaping. Shelf-life claims are weak without microbiological evidence [cite: 33] [cite: 45].

Safety and Toxicity

Dragon fruit is generally recognized as a safe food and is widely consumed in many countries, with most concerns relating not to the toxicity of the fruit itself but to processing hygiene, ingredient compatibility, and spoilage control [cite:32][cite:35]. If peel-derived ingredients are used, they should be prepared from clean, food-grade material and assessed for contaminants, pesticide residues, and sensory acceptability because the peel is not always consumed directly in conventional diets [cite:45][cite:50].

Safety also depends on the co-ingredients used in the energy balls. Nuts, seeds, dairy proteins, and certain flavoring ingredients may introduce allergen concerns, while high-moisture formulations may present greater microbial risk if stored improperly. Therefore, product labeling, hygienic preparation, and stability validation are essential [cite: 46] [cite: 33].

Regulatory Aspects

The regulatory classification of dragon fruit-based energy balls depends on jurisdiction, ingredient claims, and label language. In most cases, they would be positioned as functional foods or nutraceutical snacks rather than therapeutic products, unless drug-like claims are made [cite: 35] [cite: 40].

This distinction is important because phrases such as “rich in antioxidants,” “source of fiber,” or “contains dragon fruit bioactive” are generally more appropriate than disease-treatment statements. Any claims regarding anti-inflammatory, metabolic, or preventive health effects should be framed carefully and supported by legally acceptable evidence under the relevant food regulations [cite:35][cite:32].

Challenges in Formulation

One of the main challenges is balancing shelf stability with the desirable softness and moist mouthfeel of energy balls. Fresh dragon fruit pulp improves naturalness but may increase water activity and reduce storage life, whereas powders improve stability but can alter flavor authenticity and cost [cite: 33] [cite: 38].

A second challenge is Betalain stability. The same pigments that make dragon fruit visually attractive are also prone to degradation during processing and storage, especially under heat and oxygen exposure [cite: 43] [cite: 48]. This creates a trade-off between vibrant appearance and long-term stability.

Other challenges include stickiness, shape retention, oil separation from nut-rich systems, microbial stability, nutritional variability among raw materials, and the absence of widely standardized methods specifically tailored to energy ball products. These issues make optimization and repeated batch validation necessary for credible research outcomes [cite: 44] [cite: 49] [cite: 33].

Future Prospects

Dragon fruit-based energy balls have strong future potential as natural-color, antioxidant-rich, premium healthy snacks. The rising interest in super fruits, functional snacking, clean-label products, and by-product valorization aligns well with the use of dragon fruit pulp and peel in compact nutraceutical formats [cite: 35] [cite: 45] [cite: 32].

Future work should explore optimized drying systems, microencapsulation of betalains, controlled water activity, sugar-free variants, protein-enriched versions, sports-nutrition positioning, and comparative stability studies under different packaging systems. Product-specific clinical or postprandial studies would also strengthen claims around satiety, metabolic response, or antioxidant functionality [cite: 43] [cite: 46] [cite: 40].

There is also scope for developing region-specific formulations using millets, seeds, jaggery alternatives, or plant proteins to produce culturally relevant and economically practical nutraceutical snacks. Such innovation could make dragon fruit-based energy balls suitable for both premium retail and academic product-development projects [cite: 44] [cite: 49].

Conclusion

Dragon fruit-based energy balls are a promising nutraceutical snack system because they unite convenience, natural color, antioxidant phytochemicals, fiber, and flexible formulation possibilities. Dragon fruit contributes betalains, phenolic, and other functional compounds, while complementary ingredients such as oats, nuts, seeds, and protein sources can improve nutritional density and consumer acceptability [cite:32][cite:35][cite:46].

The success of this product category depends on careful control of moisture, water activity, oxidation, pigment stability, and sensory quality. Strong product development, therefore, requires systematic formulation optimization, proximate analysis, antioxidant testing, microbiological assessment, and realistic shelf-life studies under defined packaging and storage conditions [cite: 33] [cite: 43] [cite: 48]. With appropriate standardization, dragon fruit-based energy balls have clear potential as a healthy functional snack for nutraceutical and wellness markets [cite: 40] [cite: 35].

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