



Moringa oleifera Leaf-Based Gummies: Formulation Optimisation and Impact on Health – A Review

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Received: 04-10-2026; Accepted: 14-10-2026; Published: 21-10-2026

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<https://doi.org/10.55218/JASR.2026171001>

ABSTRACT

Moringa oleifera leaves are nutrient-dense and rich in phenolics, flavonoids and glucosinolate-derived isothiocyanates, yet their bitter, grassy character limits acceptance as a dietary supplement. Gummies, a chewable and palatable dosage form, offer a route to deliver moringa to children, adolescents and adults who avoid tablets or capsules. This review examines how moringa leaf powder and extract have been incorporated into gummy-type formulations, how formulation variables have been optimised, and what health evidence supports the intended benefits. Published formulation studies indicate that gelling-agent type and concentration are the dominant determinants of texture, swelling, syneresis and dissolution time. In a leaf-powder system, 10% gelatin and 1.5% pectin gave the most satisfactory physical characteristics, whereas sucrose and propylene glycol concentrations modulated elasticity and firmness in extract-based gummies. Factorial and response-surface designs are the most suitable optimisation tools, but only simple factorial and completely randomised designs have been reported so far. Evidence for antioxidant, glycaemic, lipid-lowering and anti-inflammatory effects derives mainly from in vitro and animal work, with a few small human studies using leaf powder; to our knowledge, no clinical trial of a moringa gummy has been reported. Safety data at dietary doses are reassuring, but standardisation of leaf material, retention of bioactives in the finished gummy, sugar content and stability remain unresolved. A quality-by-design framework linking material attributes, process parameters and quality attributes is proposed, together with priorities for clinical evaluation.

Keywords: *Moringa oleifera*; gummies; formulation optimisation; nutraceutical; quality by design; functional food

INTRODUCTION

Moringa oleifera Lam. (family Moringaceae), the drumstick tree, is cultivated across tropical and subtropical regions and is used as both food and traditional medicine; it is widely described as the “miracle tree” [1-3]. The leaves are the most consumed and most studied part. They supply protein with a favourable amino-acid profile, provitamin A, vitamin C, calcium, iron and other minerals, together with flavonoids, phenolic acids and glucosinolates [1, 2]. Antioxidant, antidiabetic, antimicrobial and anti-inflammatory activities have been attributed to leaf preparations in experimental and traditional-use literature [1, 4].

Despite this profile, unmodified moringa leaf powder is difficult to consume regularly. Its characteristic taste and odour, gritty texture and the bulk required for a meaningful dose limit adherence, particularly among children and older adults. Conversion into a conventional tablet or capsule resolves some of these problems but not palatability or the preference of many consumers for a food-like format.

Gummies are soft, chewable gel matrices built from a gelling agent, sugar or polyol, water and a plasticiser, and they are

increasingly used to deliver vitamins, minerals and botanical actives. Moringa leaf powder and extract have been incorporated into chewable gummy tablets using gelatin, pectin and sodium alginate as gelling agents, and the effects of sweetener and plasticiser levels have been examined [5-7]. These studies are few, scattered across journals of different scope, and have not been consolidated with the biological evidence that justifies the product.

The aim of this review is to (i) summarise the nutritional and phytochemical basis for using moringa leaf in a gummy format; (ii) compare the formulations reported to date and the strategies used to optimise them; (iii) appraise the evidence for health impact and safety; and (iv) identify gaps and propose a structured, quality-by-design approach for future development.

MATERIAL AND METHODS

This is a narrative review. Literature on *Moringa oleifera* leaves, gummy and chewable-gel formulation, and optimisation by experimental design was identified using the terms “Moringa oleifera”, “moringa leaf”, “gummy”, “chewable gummy”, “gelatin”, “pectin”, “optimisation”, “factorial design”, “response surface”,

“antioxidant”, “antidiabetic” and “safety”, combined with Boolean operators, in PubMed, Scopus, Google Scholar and institutional repositories. Peer-reviewed reviews, formulation studies, preclinical studies and human studies published in English were considered. Conference abstracts were not used as references. Formulation studies were charted by moringa material, gelling agent, variables studied, preparation method and principal findings. Findings were synthesised qualitatively; no meta-analysis was undertaken.

No experiments involving animals or human participants were conducted for this article, and ethics committee approval was therefore not required. No statistical analysis was performed and no level of significance was applicable; where significance levels are mentioned, they are those reported in the cited studies. No specialised software was used. All tables were compiled by the authors from the cited sources [8, 16-25].

RESULTS AND DISCUSSION

Nutritional and phytochemical basis for incorporation

Moringa leaves combine macronutrients and micronutrients with a diverse set of secondary metabolites (Table 1). Nutrient content varies with cultivar, agro-climatic conditions, leaf maturity and post-harvest processing, so reported values are not interchangeable between studies [1]. Leaf extracts show the greatest antioxidant activity among the plant parts [8], and the bioactive fraction—polyphenols, flavonoids and isothiocyanates—is considered the main driver of the observed biological effects [9, 26-35]. The leaves also contain small amounts of anti-nutritional factors, and the bioaccessibility of many leaf components has not been adequately studied [1]. For gummy development this means that “moringa content” expressed only as grams of leaf powder is a weak specification; a defined marker such as total phenolics or a named flavonoid is needed.

Table 1 is compiled from references [1-3, 8, 9].

The gummy matrix and its components

A gummy is a gel network in which the gelling agent determines structure, the sugar or polyol supplies bulk and sweetness and influences gel strength, and the plasticiser controls moisture retention and elasticity. Gelatin remains the most widely used gelling agent because it maintains gel structure during storage [7]; pectin and sodium alginate are plant-derived alternatives suited to vegetarian and halal-sensitive products [5, 6]. The desired product is soft, elastic,

springy and flexible [7,36-41]. Moringa is a particularly demanding active because leaf powder adds insoluble particulate matter and a strong flavour, whereas extracts add soluble polyphenols that may interact with proteins such as gelatin. Both effects should be assessed explicitly rather than assumed to be negligible.

Reported moringa gummy formulations

Three formulation studies on moringa chewable gummy tablets are summarised in Table 2. All were prepared by heating and congealing or pouring, and all focused on physical quality attributes; none reported clinical or in vivo outcomes. Using leaf powder, gelatin (5.0, 7.5, 10.0%) and pectin (1.0, 1.5, 2.0%) were compared in a completely randomised design at $\alpha = 0.05$, and 10% gelatin and 1.5% pectin were judged optimal because they met all physical requirements, showed no syneresis and gave the best texture [5]. Pectin-based gummies swelled more than gelatin-based ones and did not exhibit syneresis, whereas gummies with 5% gelatin did [5]. In an extract-based system, swelling ratio, dissolution time, gumminess and chewiness all increased with sodium alginate (6-8%) or pectin (6-10%) concentration, and pectin was identified as a promising carrier across that range [6]. A third study applied a 2² factorial design to sucrose (filler) and propylene glycol (plasticiser) in a gelatin-based extract gummy, noting that the earlier gelatin texture needed further optimisation toward a firmer product [7].

Table 2 is compiled from references [5-7].

Several observations follow. First, the evidence base comes essentially from one research group, so independent replication is lacking. Second, the studies optimise one or two factors at a time, which cannot reveal interactions such as gelling agent $\times$ pH or sweetener $\times$ water activity. Third, bioactive content of the finished gummy, sensory acceptance by target consumers, and storage stability were not primary outcomes. A formulation judged optimal on texture alone may still have lost much of its phenolic content during cooking or may be microbiologically unstable.

Optimisation strategies

Response surface methodology (RSM) and related designed experiments allow several factors to be varied simultaneously, model their interactions and locate an optimum with fewer runs than one-factor-at-a-time work [10, 41-50]. For gummies, Box-Behnken or central composite designs are well suited to three to five continuous factors, with desirability functions used to balance competing responses such as hardness versus dissolution time. The factorial

Table 1: Major constituents of *Moringa oleifera* leaves and reported biological activities

Constituent class	Representative constituents	Reported activities
Macronutrients	Protein with essential amino acids; dietary fibre [1, 2]	Nutritional support, relevant to malnutrition [1, 3]
Vitamins and minerals	Provitamin A (β -carotene), vitamin C, calcium, iron, potassium [1, 2]	Micronutrient supply; iron and vitamin C content of interest for anaemia-oriented products [1, 3]
Phenolics and flavonoids	Quercetin and kaempferol glycosides, chlorogenic acid [2, 9]	Antioxidant, anti-inflammatory, glucose-modulating [8, 9]
Glucosinolates / isothiocyanates	Glucomoringin and its isothiocyanate [2, 9]	Anti-inflammatory, antidiabetic and chemoprotective effects in experimental systems [8, 9]
Anti-nutritional factors	Tannins, phytates, oxalates (low levels) [1]	May reduce mineral bioavailability; relevant to iron-fortification claims [1]

Table 2: Summary of reported moringa chewable gummy formulation studies

Study	Moringa material	Variables studied	Principal findings
Rani et al. 2021 [5]	Leaf powder	Gelatin 5.0, 7.5, 10.0%; pectin 1.0, 1.5, 2.0%; completely randomised design, $\alpha = 0.05$	10% gelatin and 1.5% pectin optimal; pectin gave higher swelling and no syneresis; 5% gelatin showed syneresis; hardness rose with gelatin
Rani et al. 2022 [6]	Ethanollic leaf extract	Na-alginate 6, 7, 8%; pectin 6, 8, 10%	Swelling ratio, dissolution time, gumminess and chewiness increased with concentration; swelling ~20-22% (alginate) vs ~1.9-2.1% (pectin); pectin promising carrier
Rani et al. 2023 [7]	Leaf extract	Sucrose $\times$ propylene glycol, 2 ² factorial design; gelatin base; pour method	Filler and plasticiser levels shown to govern gummy structure and elasticity; further texture optimisation toward firmness indicated

Table 3: Suggested quality-by-design framework for moringa gummy development

Element	Parameter	Rationale / measurement
Critical material attributes	Leaf powder particle size and moisture; marker content (total phenolics or flavonoid); gelling-agent grade (gelatin bloom, pectin methoxyl degree)	Control batch-to-batch variability in the raw material; define dose by marker, not mass alone
Critical process parameters	Cooking temperature and time; pH; stage and temperature of moringa addition; depositing temperature; setting and drying time	Govern gel formation, bioactive retention and final moisture
Critical quality attributes	Hardness, gumminess, chewiness; syneresis; swelling ratio; dissolution time; weight variation; water activity; bioactive content; sensory acceptance; microbial limits; stability	Link physical performance, product safety and the intended health claim
Design and analysis	Screening factorial design followed by Box-Behnken or central composite design; desirability function; validation runs [10]	Model interactions and identify a design space

designs used so far [5, 7] are an appropriate first screening step, but should be followed by response-surface modelling with validation runs and confirmation of predicted optima.

Table 3 proposes a quality-by-design (QbD) structure for moringa gummies. Because moringa bioactives are likely to be heat- and pH-sensitive, addition of leaf powder or extract late in the process, after the gel base has cooled toward its depositing temperature, deserves systematic testing as a process parameter. Reduced-sugar or polyol-based matrices should also be examined, since a high-sucrose gummy is difficult to reconcile with glycaemic-control claims.

Table 3 is the authors' proposal, informed by references [5-7, 10].

Health impact of moringa leaf and relevance to the gummy format

The health rationale for moringa gummies rests on the activities of the leaf rather than on studies of the gummy itself. Leaf extracts show antioxidant activity and tissue-protective effects in animal models, and five human studies using powdered whole leaf have reported antihyperglycaemic and antidiyslipidaemic activity [8]. The effect of moringa leaf on chronic hyperglycaemia and dyslipidaemia has been reviewed in detail, with a plausible contribution from isothiocyanates and polyphenols [9, 11]. Bioactive components of the leaf are also credited with protection against chronic disease through antioxidant and anti-inflammatory mechanisms [9]. On the nutritional side, moringa leaf is of interest for micronutrient deficiency, although human trials of efficacy against undernutrition were lacking at the time of the major safety review [8].

Three caveats limit translation to gummies. (a) Doses and preparations in human studies differ from those achievable in a gummy: a chewable unit typically holds a small mass of active, so the number of gummies per day needed to match a studied dose

must be calculated and justified. (b) Processing may alter bioactive content, and bioaccessibility from a gel matrix is unknown [1]. (c) Sugar load and any glucose-lowering action raise practical questions for people with diabetes, including possible additive effects with antidiabetic medicines, which should be considered in labelling and clinical protocol design.

Regarding safety, animal studies with aqueous leaf extracts indicate a high degree of safety, and no adverse effects were reported in the human studies reviewed [8]. Standardisation of products remains an acknowledged problem [8]. For a gummy intended for children or long-term use, contaminant limits (heavy metals, microbial load), allergen statements and post-marketing surveillance should be built into development.

Research gaps

The principal gaps are: absence of clinical trials of moringa gummies; reliance on physical endpoints in formulation work; limited use of response-surface optimisation; lack of data on retention and bioaccessibility of leaf bioactives in gel matrices; and no stability or shelf-life data under defined storage conditions. Comparative studies of gelling agents (gelatin, pectin, alginate, carrageenan, starch) with a standardised leaf material, and sensory testing in the intended consumer group, would substantially strengthen the field.

CONCLUSION

Moringa leaf is a nutritionally and phytochemically rich ingredient whose palatability problems may be addressed through a gummy dosage form. The reported formulations show that gelling-agent type and concentration chiefly determine texture and dissolution, with 10% gelatin and 1.5% pectin performing best for leaf powder, and that sweetener and plasticiser levels refine elasticity. However,

optimisation has so far been limited to simple designs and physical endpoints, and the health benefits invoked are extrapolated from leaf-level evidence rather than demonstrated for the gummy. Future work should use response-surface designs within a quality-by-design framework, define dose by a standardised marker, evaluate bioactive retention, stability and sensory acceptance, explore reduced-sugar matrices, and ultimately test the finished product in well-designed, adequately powered randomised trials.

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HOW TO CITE THIS ARTICLE: Ghatage AD, Bandgar VA, Sawant DV, More AA, Patil PP, Patil PD, Patil AR, Jangme C. *Moringa oleifera* Leaf-Based Gummies: Formulation Optimisation and Impact on Health – A Review. *J Adv Sci Res*. 2026;17(10): 1-5 **DOI:** 10.55218/JASR.2026171001