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Innovative Nutraceutical: *Gracilaria corticata* Gummies for Pediatric Malnutrition

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Abstract
Pediatric malnutrition is one of the significant issues in the global health as, in low-resource environments, a lack of the necessary nutrients negatively affects the growth, immunity, and cognitive abilities. Traditional nutritional supplements like syrups and tablets tend to be poorly palatable, non-adherent and lack stability, which decreases their efficacy among pediatric populations. This research paper presents a plant-based nutraceutical gummy with *Gracilaria corticata* as an alternative delivery method that is easy to use by children. The gummies were designed based on g. corticata extract as a natural source of agar polysaccharides, dietary fiber and mineral and mixed with honey and fruit puree to make the gummies sensory acceptable. Proximate composition analysis showed significant nutritional improvement, and dietary fiber (6.46%), crude protein (2.60%), ash content (3.86%), and low fat were the main (0.22) macronutrients. Physicochemical analysis indicated that it had a stable pH level (4.2 + 0.1) and a high level of total soluble solids (72 + 1 o Brix), which indicated gel stability and shelf stability. Textural analysis showed that hardness had increased gradually and slowly controlled in storage whereas microbial analysis revealed that total plate counts were highly below acceptable safety levels in five weeks. The FTIR spectroscopy confirmed the maintenance of functional groups of the agar polysaccharides and proteins after the thermal process. The overall acceptability of sensory assessment based on a 9-point hedonic scale was high (8.6) as it proved the suitability of the product to consumers. The results indicate that Gracilaria corticata-derived gummies are a stable, clean label, and scalable nutraceutical preparation with possible pediatric nutritional intervention program implementation. More research on bioavailability and long-term efficacy should be done to make translational use.

Keywords: *Gracilaria corticata*, nutraceutical gummies, pediatric malnutrition, agar polysaccharides, functional foods.

I. INTRODUCTION

Malnutrition among children continues to be a major global health concern, particularly in low- and middle-income countries where access to fresh and nutrient-rich foods is often limited [1]. Deficiencies in essential micronutrients such as iron, zinc, magnesium, and dietary fiber are strongly associated with impaired physical growth, weakened immune function, and delayed cognitive development in children [2]. Although fortified foods and dietary supplements are widely used to address these deficiencies, conventional delivery formats like syrups, tablets, and powders often face challenges such as poor taste, low acceptance among children, and limited storage stability. These limitations highlight the need for more effective, palatable, and child-friendly nutritional delivery systems that can improve compliance and overall health outcomes.

In recent years, functional foods and nutraceutical-based delivery approaches have gained attention as promising alternatives for improving nutrient intake in children. Among these, marine-derived bioresources, particularly algae, have emerged as valuable candidates due to their rich composition of bioactive compounds and health-promoting properties [10]. The red seaweed Gracilaria corticata isespecially notable for its abundance of phytochemicals, antioxidants, and structurally significant polysaccharides such as sulfated galactans and agar [2]. These compounds not only contribute to its nutritional value but also enhance its functional properties in food systems. The agar derived from G. corticata exhibits excellent gel-forming ability, thermal stability, and physicochemical strength, making it highly suitable for incorporation into food formulations and biodegradable biopolymer systems [4,6]. Additionally, its structural and thermal characteristics support its use in sustainable food matrices and advanced processing applications.

The incorporation of seaweed into food products, including bakery and confectionery items,

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has shown significant improvements in both nutritional quality and functional performance [8,9]. Recent studies have also demonstrated the feasibility of developing seaweed-based jelly and gummy products with favorable sensory attributes [3]. However, despite these advancements, there remains a lack of comprehensive research focusing on the application of Gracilaria corticata in pediatric nutraceutical gummies, particularly with detailed evaluation of formulation, stability, and acceptability. Therefore, the present study aims to develop a *G. corticata*-based gummy formulation utilizing its natural agar as a plant-based gelling agent. The study further evaluates its proximate composition, physicochemical and textural properties, microbial safety, and sensory acceptability. By integrating marine biotechnology with pediatric nutrition, this work proposes a sustainable, clean-label, and nutrient-enriched delivery system to help address micronutrient deficiencies in children.

II. Materials and methods

2.1 Materials

A certified source of coastal *G. corticata* was dried and then turned into a fine extract before being formulated. G. corticata was chosen because it is a high yield agar, rich in minerals, and contains functional polysaccharides. The raw honey was used as the basic sweetener and humectant with blueberry puree added to add flavor, natural color, and antioxidants. Citric acid that was used was of food standard as a pH regulator. All analyzing chemicals and reagents were of analysis quality.

2.2 Preparation of *Gracilaria corticata* Fortified Gummies

The nutraceutical gummies were developed based on 20 g of *G. corticata* extract as the functional ingredient and intrinsic gelling agent based on its agar polysaccharide level [5]. A 80 mL volume of potable water was added to the extract and it was left to hydrate, being stirred constantly. Then, 120 g natural honey and 100 g blueberry puree were added and blended together to create a homogenous mixture. The formulation was incubated at a temperature of 90°C and let stand 10 minutes to allow maximum dissolution of agar and ideal network formation of agar gels as evidenced by a study of thermal behavior of G. corticata polysaccharides. Citric acid (1 g) was also added to neutralize the pH and bring it to acidic level which stabilizes the gel and inhibits microbes. The hot mixture was dispensed into silicone trace metals molds to allow setting at 25°C. The gummies formed demolded and stored in airtight containers at room temperature to be analyzed in future. Other related jelly type preparations made of seaweed have shown sufficient gel strength and sensory viability [6].

2.3 Proximate Composition Analysis

The AOAC standard methods were used to determine proximate composition [6]. The moisture content was determined under the method of the hot air oven until the weight remained constant at 105 °C.Crude protein was estimated using the Kjeldahl method with a conversion factor of 6.25. Crude fat was determined by Soxhlet extraction using petroleum ether. Ash content was measured by incineration at 550°C. Total dietary fiber was quantified using the enzymatic–gravimetric method, and total carbohydrate content was calculated by difference. Nutritional enhancement of seaweed-incorporated food systems has been widely validated in functional and bakery products [9,10].

2.4 Physicochemical Analysis

The pH of the samples was measured using a calibrated digital pH meter. Total soluble solids (TSS) were determined using a digital refractometer and expressed as °Brix. Physicochemical characteristics of seaweed-based food matrices are known to significantly influence product stability and consumer acceptability.

2.5 Textural Analysis

Textural properties were evaluated using a texture analyzer equipped with a cylindrical probe in compression mode. Hardness values (N) were recorded at Week 1, Week 3, and Week 5. The gel-forming ability and physio-mechanical characteristics of *G. corticata* polysaccharides contribute significantly to structural integrity and resilience [6].

2.6 Microbial Analysis

Microbial quality was assessed using serial dilution followed by spread plate techniques. Total plate count (TPC) was determined on Nutrient Agar incubated at 37 °C for 48 h. Yeast and mold counts were evaluated on Potato Dextrose Agar at 25 °C for 5 days. Results are expressed as colony forming units per gram (CFU/g). Acidic pH and thermal processing were used to enhance microbial stabilityin gummies formulation [7].

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2.7 FTIR Analysis

The FTIR spectrum showed a broad peak around 3200–3400 cm^{-1} (≈3420 cm^{-1}), which is mainly due to O–H stretching and indicates strong hydrogen bonding within the agar network, contributing to its gel-forming nature. A smaller peak near ~2930 cm^{-1} reflects C–H stretching, confirming the presence of a carbohydrate-based structure. The band between 1650–1550 cm^{-1} is likely due to bound water and traces of proteins present in the sample. Further, prominent peaks in the regions of 1000–1150 cm^{-1} (≈1012 cm^{-1}) and 800–950 cm^{-1} suggest glycosidic linkages and sulfate groups, supporting the presence of sulfated polysaccharides typical of *G. corticata*.

2.8 Sensory Evaluation

20 members did taste analysis. These individuals rated looks, smell, flavor, feel, along with general approval on a nine-level satisfaction chart. Studies lately show seaweed sweets can work well when made into jellies or chewy candies [8].

III. RESULTS AND DISCUSSION

3.1 Proximate Composition Analysis

As presented in **Table 1**, the nutritional architecture of gummies derived from *G. corticata* is predominantly defined by its carbohydrate profile, which amounts to 74.82%. This high concentration is primarily driven by the synergy between honey, natural fruit pulp, and alginate sugars, mirroring established benchmarks for seaweed-based confectionery. Interestingly, while traditional candies are often dismissed as "empty calories," the inclusion of *G. corticata* introduces a more complex nutritional matrix. The protein content, recorded at 2.60%, represents a blend of algae-specific proteins and active nitrogenous substances. While this may not classify the gummy as a "high-protein" food, it significantly outperforms standard gelatin-based sweets, offering a functional edge over conventional animal-derived products.In keeping with the natural lipid profile of red seaweed, fat levels remained nearly undetectable at a negligible 0.22%. This lack of fat is a key characteristic of the *Gracilaria* genus, making these gummies an attractive option for low-fat dietary formulations. Perhaps most notably, the sample provides 6.46% dietary fiber, a direct result of the agar and sulfated galactans inherent to the seaweed. These specific polysaccharides are not just structural components; they are prized for their prebiotic potential and health-enhancing properties. The presence of essential minerals was also verified by a 3.86% ash content, a value that aligns perfectly with previous literature on *Gracilaria* species [9]. These results confirm that the nutritional elements have been successfully optimized, achieving a delicate balance between health-conscious ingredients and the structural integrity required for a palatable gummy.Beyond the basic macro-nutritional data, the development of these *Gracilaria*-based gummies addresses a growing consumer demand for "clean label" and sustainable snacks. By replacing synthetic binders and animal-derived gelatin with seaweed polysaccharides, the formulation bridges the gap between traditional confectionery and the therapeutic benefits of marine bioactives. This transition toward seaweed-based dietary supplements is not merely a trend; it reflects a systemic shift in food science toward utilizing under-exploited marine resources to combat micronutrient deficiencies [10]. As we continue to uncover the multi-faceted roles of seaweed metabolites in metabolic health, thesegummies serve as a functional vehicle for delivering bioactive compounds in a format that is both accessible and enjoyable for the end-user.

Table 1. Proximate composition of *G. corticata* fortified gummies

Components	Percentage (%)
Moisture	18.50%
Crude Protein	2.60%
Total Dietary Fiber	6.42%
Ash	3.86%
Carbohydrates	74.82%
Crude Protein	2.60%

3.2 Moisture Content and Shelf Suitability

The quantity of water is essential for the sensory properties, microbiological resistance, and shelf life of gummies. The moisture content as shown in **Table 2** of the gummies based on *G. corticata* at 18.5% as in 0.925g coincides with the normal moisture content for chewy candies. This ensures that the sweets maintain their pleasant softness but are not overly hydrated, thereby preventing molds and bacteria from colonizing them. It is possible that thermal processing at 90 °C followed by cooling influenced the result, contributing to the development of a high-quality gel network that retains water effectively [9]. Since the components of the agar gum are highly hydrophilic, the water is held firmly within them without causing the product to become gelatinous.

Table 2. Moisture content of *G. corticata* fortified gummies

Parameter	Value(g)
Sample weight	5g
Final dry weight	4.075g
Moisture loss	0.925g
Moisture content	1.5g

3.3 Physicochemical Properties - pH and TSS

The physical and chemical properties of the enhanced gummies can be viewed in Table 3 below. The mixture pH as shown in **Table 3**is (4.2 ± 0.1), making it slightly acidic. This condition contributes significantly towards the maintenance of the agar gel structure since such jellies are more stable under slightly acidic conditions [11]. In addition, due to the fact that most pathogenic microorganisms cannot multiply at acidity levels above 4.5, this feature provides additional safety to the product. With an apparent concentration (72 ± 1 °Brix), it implies that there is high sugar and soluble solids content. Honey, fruits' pulp, and algal polysaccharides contribute primarily to this characteristic. It is common knowledge that whenconfectionery products contain a high percentage of °Brix, they tend to be harder, sweetened, and less prone to deterioration due to the crowded environment. Sugars tightly condensed in such an environment remove water from bacteria by creating a pressure difference between cells.

Table 3. Physicochemical properties of *G. corticata* fortified gummies

Parameter	Value
pH	4.2 ± 0.1
TSS(Brix)	72 ± 1

3.4 Textural Hardness

The texture is very important in determining whether or not consumers enjoy eating gummy confectionaries since the firmness determines the texture of gummies. In this case, after the fifth week, the hardness of gummies prepared from *G. corticata* increased gradually from 12.5 N to 14.2 N as shown in **Table 4**. The slow increase may be attributed to the gradual changes in the level of moisture content in the gel network. Reduced moisture in the storage conditions results in reduced molecular movements, which causes a gradual stabilization of the double helices of the agar. Moreover, hydrogen bonding among the sulfated galactans increases molecular packing in the gummies during this period. Nonetheless, all the readings remained within the optimal range for chewable confectionaries [12].

Table 4. Textural hardness of *G. corticata* fortified gummies during storage

Storage Time	Hardness (N)
Week 1	12.5
Week 3	13.1
Week 5	14.2

3.5 Microbial Stability

Results of the microbiological test are presented in **Table 5**. Despite a minor increase in the number of total plates due to storage, the levels remained significantly below the acceptable limit of 10^4 CFU/g for sweets, thus indicating the high quality concerning microbiological safety. Similar results were observed in previous works studying the microbial load in various types of gel and jelly products, manufactured from seaweed extracts. This insignificant microbial population can be attributed to the multiple protective mechanisms included in the recipe itself. First, the relatively low pH value (4.2 ± 0.1) contributes to the formation of the hostile environment because most pathogenic bacteria are unable to develop within the range of pH<4.5. At the same time, increased sugar content (72 ± 1 °Brix) helps remove water through osmosis, leaving no room for pathogenic bacteria survival. Moreover, high temperature treatment, specifically heating up to 90 °C for 10 minutes, allows eradicating bacteria before manufacturing the final product and thus contributes to the enhanced stability of complex gel, formed by polysaccharides [13]. However, the unique combination of bioactive compounds with sulfated polysaccharides of Gracilaria corticata might increase microorganism resistance, which was previously shown when analyzing other plants. It can be concluded that yeast and mold cultures were not detected in the product, and pathogenic germs did not manifest their presence.

Table 5. Microbial analysis of *G. corticata* fortified gummies

Storage Time	TPC (CFU/g)	Yeast &Mold (CFU/g)	Status
Week 1	$<10^1$	Nil	Safe
Week 3	1.1×10^2	Nil	Safe

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Week 5	2.4×10^2	1.0×10^1	Safe

3.6 FTIR Structural Characterization

The FTIR spectrum as shown in **Figure 1** and **Table 6**of gummies prepared using *Gracilaria corticata* indicates that the fundamental structural components of agar-based polysaccharides remained intact after processing. A broad absorption band observed in the range of 3200–3400 cm^{-1} is attributed to O–H stretching vibrations, characteristic of hydroxyl groups present in polysaccharides. These hydroxyl groups are essential for the formation of intermolecular hydrogen bonds, which play a critical role in establishing and stabilizing the gel network. The persistence of this broad band suggests that the hydrogen-bonding interactions necessary for gel formation were preserved, thereby supporting the structural integrity and stability of the gummy matrix.

In the fingerprint region, prominent peaks between 1000 and 1150 cm^{-1} correspond to C–O–C glycosidic linkages and C–O stretching vibrations within the polysaccharide chains [7]. These peaks confirm the presence of the carbohydrate backbone and indicate that the primary structure of agar was not significantly altered during thermal processing. The retention of these characteristic bands demonstrates that the glycosidic bonds remained stable, preventing degradation of the polymer network. This structural stability is crucial, as any disruption in these linkages could negatively impact the textural and functional properties of the final product.

Additionally, absorption bands in the region of 800–950 cm^{-1} are associated with S–O stretching vibrations, indicative of sulfated galactans[8] typically found in red algae. The presence of these sulfate groups confirms the retention of bioactive components inherent to *G. corticata*. Notably, these characteristic peaks remained evident even after heating at 90 °C, suggesting that the agar polysaccharides exhibit considerable thermal stability under controlled processing conditions. Overall, the FTIR analysis confirms that the preparation method effectively preserved the molecular structure and functional groups of the algal polysaccharides, thereby maintaining both the gel-forming capability and potential bioactivity of the gummies.

The retention of hydroxyl, glycosidic, and sulfate-associated peaks confirms that both the structural integrity and bioactive potential of the polysaccharides were maintained. From a formulation standpoint, this translates into a stable gel matrix with preserved functional performance and potential health benefits. Overall, the results validate the robustness of the processing approach and support the feasibility of incorporating algal polysaccharides into gummy formulations without compromising their physicochemical or biofunctional properties.

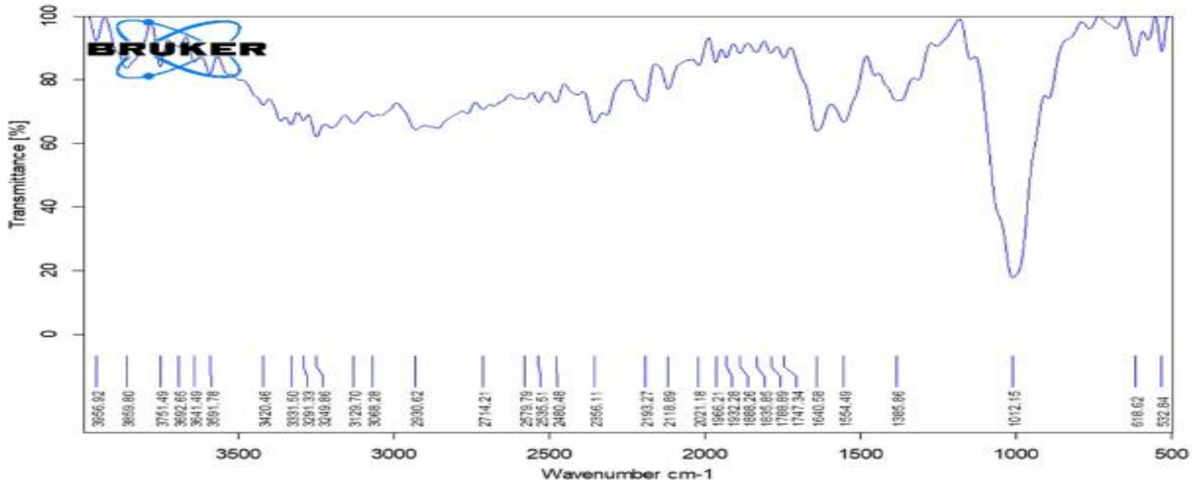

Figure1. FTIR spectrum of G. *corticata* fortified gummies showing characteristic functional groups

Table 6. FTIR peak assignments of *Gracilaria corticata* fortified gummies

Wavenumber (cm^{-1})	Functional Group / Vibration	Significance / Interpretation
3200–3400 (≈3420)	O–H stretching (broad)	Hydrogen bonding within agar polysaccharide network; responsible for gel formation and structural stability
~2930	C–H stretching	Aliphatic C–H vibrations of carbohydrate backbone confirming organic polysaccharide framework
1650–1550	Amide I / H–O–H bending	Overlapping vibrations from residual protein components and bound water associated with algal matrix
1000–1150 (≈1012)	C–O and C–O–C stretching	Glycosidic linkages of agar polysaccharides confirming structural integrity of carbohydrate backbone
800–950	S–O / C–O–S vibration	Sulfated galactans characteristic of red seaweed (*Gracilaria*) polysaccharides

3.7 Sensory Evaluation

Figure 2 shows how people rated the samples by taste and feel. A score of 8.6 out of 9 means most liked the gummies made from *G. corticata*, hinting they might do well if sold widely. Other sweets using seaweed also scored highly once their firmness and sugar levels were adjusted just right. Judges gave top marks for look and bite and thanks to even structure and clear color from stable agar gels. Chewiness and smooth sensation came down to how well the plant's natural sugars formed solid yet soft gels. With deeper color coming from algae and fruits, the look got stronger - think plant chemistry backing up what eyes see. Not quite as fragrant when set beside regular versions, true enough, though earlier work spotted similar quiet scents from sea-based parts before. Still, people didn't mind much; flavor stayed good even with G. corticata added in at that amount. From start to finish, it works: ocean-powered actives fit neatly here, sitting well on the tongue, feeling right, welcomed without hassle [18].

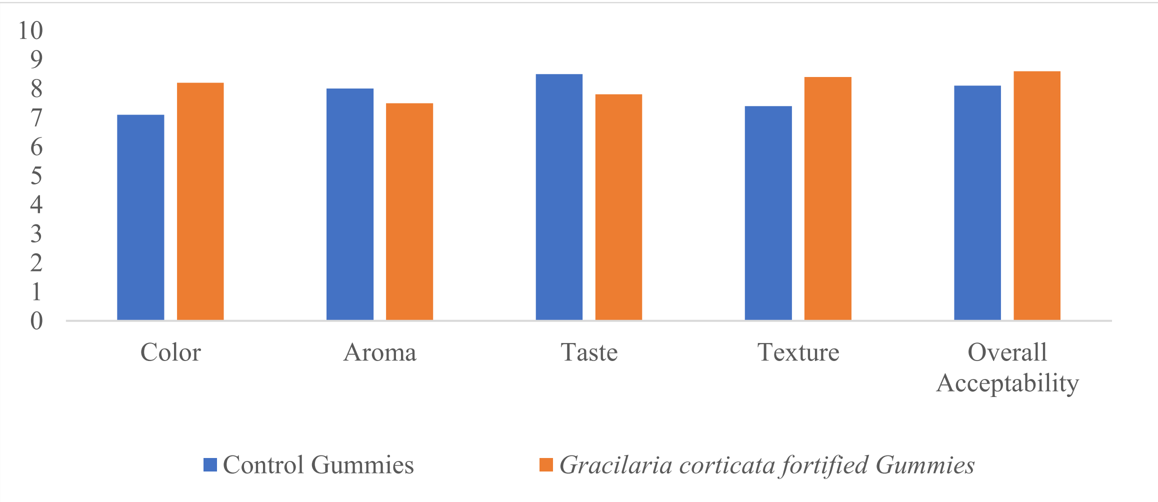

Figure 2. Sensory evaluation scores of *G. corticata* fortified gummies

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IV. CONCLUSIONS

Hence we successfully developed gummies using red algae called *G. corticata*, turning it into a plant-powered food boost that people find pleasant to eat. Because we added 20 grams of seaweed extract, the sweets carried more fiber - about 6.46 percent - and bumped up protein to 2.60 percent, yet stayed very low in fat at just 0.22 percent, matching what earlier studies showed about this algae. Water levels sat around 18.5 percent, not too wet nor too dry, while carbs took up most of the space at 74.82 percent, giving each bite a satisfying feel along with usable energy, much like other candy-like treats boosted with ocean plants. The mix leaned toward sour with a pH of 4.2, give or take 0.1 point, and packed in plenty of dissolved sugars measuring 72 °Brix, plus or minus one unit, helping form a firm jelly structure while also blocking microbes thanks to acidity paired with sugar strength. Over time on shelves, the gummies slowly grew firmer due to changes inside the natural agar web, but still held onto their springy quality so chewing stayed comfortable. No harmful germs multiplied out of control during storage, proving that layering several protection methods worked well to keep spoilage at bay. Heat treatment did not damage essential chemical features tied to sulfated galactans and agar, shown through FTIR analysis. Gummies with added nutrients held up well in texture, smell, taste, and stayed free from harmful microbes. The material kept its shape and useful qualities after processing. Children could benefit from treats made using Gracilaria corticata because it offers vital nutrients safely. This seaweed might play a role in fighting hidden hunger while supporting better eating habits. Lab results support its use in everyday food designs meant for young eaters. Structural clues remained intact even when exposed to high temperatures. Nutritionally improved versions met basic requirements without losing appeal. Natural compounds survived manufacturing steps without breaking down. A common ocean plant becomes a practical source for health-focused snacks. No major shifts were seen in composition after cooking methods applied. What started as algae ended as edible product fit for consumption test .

V. CONFLICT OF INTEREST

The authors declare that there is no conflict of interest. This research was conducted solely for academic purposes, with no financial, commercial, or personal interests influencing the outcomes.

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