Formulation and Evaluation of Herbal Immunity Booster

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***Abstract*—The global shift toward functional nutrition has sparked a renewed interest in plant-based alternatives that do not compromise on sensory appeal or health benefits. Among the exotic fruits gaining traction, the dragon fruit (Hylocereus spp.) stands out—not only for its vibrant aesthetic but for its rich profile of antioxidants and essential vitamins. This work explores the transformation of dragon fruit into a versatile, freeze-dried powder, meticulously characterizing its physical and chemical stability. By utilizing freeze-drying technology, we aimed to preserve the fruit's delicate bioactive compounds, such as Vitamin C and antioxidants, ensuring that the resulting ingredient maintains its nutritional integrity.**

Beyond the powder itself, this study details the development and evaluation of three distinct plant-based beverage formulations. Through rigorous analysis—ranging from pH and titratable acidity to microbiological safety—we demonstrate how varying concentrations of dragon fruit powder influence the drink's acidification, antioxidant capacity, and visual profile. Our findings reveal that these beverages are more than just refreshing drinks; they are microbiologically safe, functionally enriched, and visually striking alternatives for the modern consumer. It is my hope that this research provides a technical foundation for the food industry to further innovate with dragon fruit, bridging the gap between convenience and wellness.

***Index Terms*—**

1. **Stability: The freeze-dried powder maintained low moisture (5.037\%) and water activity (a_w = 0.3122), ensuring a stable shelf life.**
2. **Functionality: Significant antioxidant activity and Vitamin C levels were preserved throughout the processing stages.**
3. **Safety: All formulations met strict microbiological standards, showing no detection of Salmonella spp. or harmful yeast and molds.**
4. **Sensory: Increased powder concentration (specifically in formulation A3) resulted in a more robust color profile and higher antioxidant density.**

I. INTRODUCTION

The modern consumer landscape is witnessing a profound shift toward functional, accessible, and ethical nutrition. As beverages remain a cornerstone of the daily human diet due to their practicality, the demand for plant-based alternatives—once traditional staples in Asian cultures— has surged globally. These drinks, derived from soy, nuts, and cereals, have transitioned from niche substitutes for cow's milk to mainstream favorites, celebrated for their density of nutrients in small, convenient volumes.

Among these alternatives, beverages enriched with chestnuts and walnuts offer a robust profile of proteins, essential fatty acids, and polyphenols. However, the true frontier of innovation lies in the synergy between these plant bases and bioactive-rich fruits. The addition of fruit powders not only enhances nutritional quality but also elevates the sensory experience, creating a product that is as pleasing to the palate as it is beneficial to the heart.

This work focuses on the Dragon Fruit (Hylocereus polyrhizus), a fruit of exuberant color and significant health potential. Despite its nutritional value, the dragon fruit's high perishability and seasonality present significant challenges for year-round consumption. To overcome these barriers, this study employs freeze-drying technology. By removing moisture at low temperatures through sublimation, we can inhibit enzymatic reactions and preserve the delicate volatile compounds and nutrients that define the fruit's character. The resulting porous powder offers rapid rehydration and exceptional stability.

This book details the characterization of freeze-dried dragon fruit powder and its application in developing a novel plant-based beverage. Through a comprehensive evaluation of its physicochemical and microbiological characteristics, we provide a blueprint for a functional, plant- based drink that meets the modern demand for wellness, quality, and

sustainability.

II. LITERATURE REVIEW

Siddhartha Kumar Mishra. Pir Mohammad Ishfaq. Swati Tripathi. Neelima Gupta.
Plants and Phytomolecules for immunomodulation: Recent trends and advances, 391-411, 2022.

In the wake of recent global health crises, most notably the widespread emergence of viral infections like SARS-CoV-2 (COVID-19), the focus of modern healthcare has significantly shifted toward preventive medicine. Today, there is an unprecedented global demand for functional foods, nutraceuticals, and botanical resources capable of enhancing the host defense system. Boosting innate and adaptive immunity has emerged as a primary strategy not only for warding off infectious pathogens but also for managing chronic diseases and maintaining overall physiological health.

For centuries, traditional medicine systems across the world have relied on the rich biodiversity of the plant kingdom to modulate the human immune response. Whether the clinical need calls for stimulating a suppressed immune system or dampening an overactive inflammatory response, medicinal plants and fruits offer a sophisticated, multi-targeted approach to health. Unlike synthetic drugs, which often target a single pathway, botanical resources contain a complex matrix of bioactive molecules that work synergistically.

Recent scientific advancements have begun to unravel the precise molecular mechanisms behind these traditional remedies. Phytochemicals—ranging from water-soluble polysaccharides to hydrophobic flavonoids, terpenoids, alkaloids, and glycosides—do not merely act as passive nutrients. Instead, they actively interface with the human body at a genomic and proteomic level. They influence the induction, expression, and amplification of critical genes involved in inflammation and antioxidant defense, helping to maintain a delicate cytokine balance and regulate cellular oxidative stress.

III. INGREDIENT

A. Dragon fruit.
B. Beet root.
C. Ginger.
D. Amla.
E. Lemon.
F. Tricalcium Phosphate.
G. Zinc Gluconate.
H. Jaggery.

A. Dragon Fruit

Fig.No:3.1

❖ Biological Sources:

The biological source of Dragon fruit is a cactus plant belonging to the genus Selenicereus (formerly classified under Hylocereus).

Family Cactaceae

❖ Synonyms:

Synonyms or other common names of Dragon fruit include:

- Pitaya.
- Pitahaya.
- Strawberry pear.
- Night-blooming cereus fruit (less common).
- Different species may also be referred to as.
- Red pitaya.
- Yellow pitaya.

❖ Chemical Constituents:

The chemical constituents of Dragon fruit include:

- Water (high moisture content).
- Carbohydrates — mainly glucose and fructose.
- Dietary fiber.
- Proteins (small amount).
- Lipids/Fats (mainly in seeds).
- Vitamins.
- Minerals.
- Calcium Phosphorus.
- Iron.
- Magnesium.

- Flavonoids.
- Citric acid.

These constituents contribute to the antioxidant, nutritional, and medicinal properties of dragon fruit.

❖ Role:

Dragon fruit powder functions as a potent, natural immunity booster by providing a concentrated source of essential nutrients that support the body's defense mechanisms, particularly through high levels of vitamin C and antioxidants.

It acts as a functional food to protect immune cells from damage and enhance the body's ability to fight off infections.

B. Beet root

Fig.No:3.2

❖ Biological Source:

The biological source of Beetroot is the plant Beta vulgaris, commonly known as beet.

Family Amaranthaceae (formerly placed in Chenopodiaceae).

❖ Synonyms:

Synonyms names for Beetroot include:

- Beet.
- Garden beet.
- Red beet.
- Table beet.
- Common beet.
- Scientific synonym/reference.
- Beta vulgaris.

❖ Chemical Constituents:

- Beetroot (Beta vulgaris L.) is chemically composed of roughly 88% water.
- 10% carbohydrates (sucrose, glucose, fructose).
- 2% protein.
- <1% fat.
- It is exceptionally rich in health-promoting betalains (pigments).
- Inorganic nitrate.
- Polyphenols.
- Essential minerals.
- Potassium

❖ Role:

Beetroot powder acts as a potent, natural immunity booster by delivering high concentrations of antioxidants (betalains), vitamin C, and nitrates that reduce oxidative stress, fight inflammation, and enhance immune cell circulation. Its rich nutrient profile supports gut health and enhances white blood cell function to strengthen the body's defenses.

C. Ginger

Fig.No:3.3

❖ Biological Source:

It consists of the dried or fresh rhizomes of Zingiber officinale Roscoe.

Family: Zingiberaceae.

❖ Synonyms:

- Gingerroot.
- Rhizoma zingiberis.
- Zingiber.

❖ Chemical Constituents:

- Ginger (Zingiber officinale) contains over 2,000 bioactive compounds.
- Primarily phenolic compounds (gingerols, shogaols, paradols).
- Terpenes (zingiberene, bisabolene).

- Fresh ginger is rich in 6-gingerol, which converts to 6-shogaol upon heating or drying.
- While zingiberene provides its distinct aroma.

These components possess potent antioxidant, anti-inflammatory, and antimicrobial properties.

❖ Role:

Ginger powder acts as a potent immunity booster through high levels of antioxidant, anti-inflammatory, and antimicrobial compounds—primarily gingerol and shogaols.

These components strengthen the immune system by neutralizing free radicals, reducing oxidative stress, inhibiting viral/bacterial growth, and lowering inflammation.

D. Amla:

Fig.No:3.4

❖ Biological source:

Amla, or Indian gooseberry, consists of the fresh or dried fruits of Phyllanthus emblica Linn. (synonym Emblica officinalis Gaertn).

Family Phyllanthaceae (formerly classified under Euphorbiaceae).

❖ Synonyms:

- Aonla.
- Amalaki (Sanskri).
- Nelli (Tamil/Mala).
- Usirika.

❖ Chemical Constituents:

- Amla (Phyllanthus emblica or Emblica officinalis) is a potent nutrient-rich.
- Fruit containing high concentrations of vitamin C (ascorbic acid).
- Tannins.
- Polyphenols.
- Flavonoids.
- Key antioxidant compounds include Emblicanin A and B.
- Gallic acid.
- Ellagic acid.
- Punigluconin, which contribute to its medicinal properties.

The fruit also contains alkaloids (phyllantine, phyllantidine) and essential amino acids.

❖ Role:

Amla powder is a potent natural immunity booster, acting primarily through its exceptionally high Vitamin C content—often 600–800% of the daily value per fruit—and powerful antioxidants. It strengthens white blood cells to fight infections, reduces oxidative stress and inflammation, and supports gut health to bolster the immune system.

E. Lemon:

Fig.No:3.6

❖ Biological Source:

Lemon is the fresh ripe fruit or peel of Citrus limon (L.)

Family: Rutaceae.

❖ Synonyms:

For "lemon" depend on whether you mean the fruit or a defective item.

- Citrus.
- Yellow.
- Acid.

❖ Chemical Constituents:

- Lemons contain a complex mixture of acids.
- Vitamins.
- Phytochemicals.

- Primarily citric acid.

Other key chemicals include:
- Vitamin C (ascorbic acid).
- D-limonene.
- Flavonoids like hesperidin.
- Eriocitrin.
- Various minerals.

❖ Role:

Lemon powder, made from dehydrated lemon peels and juice, serves as a potent, shelf-stable immunity booster by providing a concentrated dose of Vitamin C and antioxidants.

It supports immune system function by fighting free radicals, enhancing antimicrobial activity,and aiding in respiratory health, while offering the convenience of adding, as suggested by Food Powder India, a citrus kick to daily nutrition.

F. Jaggery

Fig.No:3.7

❖ Biological Source:

The sap or juice of sugarcane (Saccharum officinarum Linn.) or various palm trees, including the date palm (Phoenix dactylifera), palmyra palm (Borassus flabellifer), and toddy palm (Caryota urens).

Family: Poaceae (Grass family) Arecaceae / Palmae (Palm family).

❖ Synonyms:
- India & Pakistan: Commonly called Gur or Gud.
- Latin America: Known as Panela (Colombia), Piloncillo (Mexico), Rapadura (Brazil), or Chancaca (Honduras).
- East Asia: Called Kokuto in Japan and Peen tong in China.
- Southeast Asia: Referred to as Gula Melaka in Malaysia and Namtan tanode in Thailand.

❖ Chemical Constituents:
- Jaggery is a complex.
- Unrefined sweetener primarily composed of sucrose (65–85%).
- Invert sugars like glucose and fructose (10–15%).
- Moisture (3–10%).

❖ Role:

In an immunity booster powder using dragon fruit, jaggery acts as both a nutritional fortifier and a synergistic carrier. While dragon fruit provides high levels of vitamin C and antioxidants, jaggery complements this by adding essential trace minerals like zinc, selenium, and iron.

IV. MATERIALS AND METHODS

4.1. Formulation Table.

Sr. No.	Ingredient	Percentage (%)	Purpose
1.	Dragon Fruit Powder (Freeze-dried)	60%	Active Base (Antioxidants/Fiber)
2.	Amla (Indian Gooseberry) Extract	10%	Concentrated Vitamin C source
3.	Ginger Root Powder	5%	Anti-inflammatory agent
4.	Zinc Phosphate	0.5%	Essential mineral for immune function
5.	Glucose	15%	Natural low-calorie sweetener
6.	Lemon Powder	4%	Flavor enhancer and preservative
7.	Calcium Carbonate	0.5%	Anti-caking agent
8.	Beetroot Powder	5%	Natural color intensifier

❖ Process

1. Ingredient Sourcing & QC Verification:
Ensure all raw materials have a Certificate of Analysis (CoA) to verify purity, potency, and the absence of heavy metals (critical for Amla and Ginger). Mesh Standardization: For a smooth mouthfeel and uniform blending, all ingredients should be of a similar particle size (typically 40–60 mesh).

2. Environmental Preparation Humidity Control:
The production room must be kept at low humidity (<30% RH). If the dragon fruit powder or citric acid absorbs moisture during mixing, it will lead to clumping and "caking" in the final package.

3. The Blending Sequence (Multi-Stage Mixing) You cannot mix all ingredients at once because the Zinc Gluconate and Tricalcium Phosphate are present in very small amounts (0.5%). Geometric Dilution (Pre-Mix):
Mix the 0.5% Zinc Gluconate and 0.5% Tricalcium Phosphate with a small portion of the Erythritol/Stevia. This "pre mix" ensures these micro-ingredients are evenly distributed later. Base Blending: Add the Dragon Fruit Powder (60%) and Amla Extract (10%) into a V- Blender or Ribbon Blender. These larger volumes act as the carrier. Active & Flavor Integration: Add the Ginger Root Powder (5%), Beetroot Powder (5%), and Citric Acid (4%). Final.
Homogenization: Add the "pre-mix" from Step 1 into the blender. Mix for 15–20 minutes. Avoid.
High-speed mixing that generates heat, which could degrade the Vitamin C in the amla extract.

4. Sifting & Metal Detection Safety:
Pass the final blend through a safety sifter to remove any stray clumps that formed during mixing. Metal Detection: Pass the bulk powder through a metal detector to ensure no equipment fragments are present.

5. Packaging & Sealing Filling:
The powder is fed into an automated filling machine. For this specific formula, single-serve stick packs or Mylar-lined pouches are best. Desiccant Inclusion: If using a multi-serve tub, a food-grade silica gel packet must be added to manage any moisture introduced by the consumer when they open the jar.

6. Final Quality Testing Microbial Testing:
Test for Salmonella, E. coli, and mold to ensure safety. Potency Testing: Verify the levels of Vitamin C (from Amla) and Zinc to ensure the label claims are accurate.

V. EVALUATION AND PARAMETERS

I. Organoleptic Evaluation:

Sr.No.	Parameter	Result
1.	Appearance	Smooth semisolid formulation
2.	Texture	Soft and uniform
3.	Colour	Pink
4.	Odour	Aromatic Odour

Table.No.5.1

1. Appearance:
This is a quick visual scan where you note the physical basics of the sample—like its shape, its size, or any specific structural features that stand out right away.

2. Texture:
This is all about touch. You are evaluating how the sample feels against your skin, checking for characteristics like roughness, smoothness, or its overall physical consistency.

3. Colour:
This is a visual observation where you look closely at the sample's hue (the color itself) and its intensity (how bright, dark, or faded it looks).

4. Odour:
This is a sensory evaluation where you safely use your nose to identify the sample's smell, which can quickly tell you if a substance is pure, contaminated, or spoiled.

II. Physical Parameter and physicochemical Evaluation:

Sr. No.	Parameter	Result
1.	PH	4.5-6.5
2.	Ash value	3-8%
3.	Loss on Drying	Less than 10%
4.	Acid Insoluble Ash	Less than 2%
5.	Water Soluble Ash	1-5%

Table.No.5.2

1. pH:
Measures how acidic or alkaline (basic) the substance is.

2. Ash Value:
Determines the total amount of inorganic material (minerals) left behind after the sample is completely incinerated.

3. Loss on Drying (LOD):
Measures the total amount of volatile matter—which is usually just moisture or water weight— lost when the sample is heated under strict conditions.

4. Acid-Insoluble Ash:
Measures the exact portion of that burnt ash which refuses to dissolve in dilute hydrochloric acid, which helps point out contaminants like silica, dirt, or earthy matter.

5. Water-Soluble Ash:
Measures the portion of the total ash that easily dissolves in water, making it incredibly useful for detecting if the material has been exhausted or adulterated.

III. Qualitative phytochemical tests:

Sr.No.	Test	Observation
1.	Ellagic Test for Phenols	Formation of dark color indicates presence of phenols.
2.	Ferric Chloride Test	Blue/green coloration observed.
3.	Sulphuric Acid Test	Reddish brown color formed.
4.	Wagner's Test for Alkaloids	Brown precipitate observed.
5.	Molisch' Test	Violet ring formed indicating carbohydrates.
6.	Fehling's Test	Brick red precipitate observed indicating reducing sugars.
7.	Millon's Test for Amino Acid and Protein	Red coloration observed indicating proteins/amino acids.

Table.No.5.3

1. Ellagic Test:
Used to identify the presence of Phenols (specifically tracking down ellagic acid or related phenolic structures).
2. Ferric Chloride Test:
Targets Phenols, and is especially useful for pulling a positive match on Tannins by forming deep blue-black or green complexes.
3. Sulphuric Acid Test:
Used as a screening tool for Anthraquinone glycosides, or to spot structural lipid compounds like Steroids and Triterpenoids.
4. Wagner's Test:
Specifically hunts for Alkaloids by forming a distinct, heavy reddish-brown precipitate using an iodine-based reagent.
5. Molisch's Test:
Acts as the universal gatekeeper test to confirm the presence of any Carbohydrates in the mixture.
6. Fehling's Test:
Focuses strictly on Reducing sugars (like glucose or fructose) by turning a bright blue copper solution into a brick-red solid.
7. Millon's Test:
Used to detect Proteins and amino acids by reacting with tyrosine residues to create a classic red-colored complex.

IV. Microbiological and Immunomodulatory Effect:

Sr.No.	Effect
1.	Prebiotic Action & Gut Microbiota Modulation Effect
2.	In Vitro Antimicrobial and Pathogen Inhibition Effect
3.	Cellular Immunomodulation & Toll Pathway Stimulation Effect

Table.No.5.4

1. Prebiotic Action & Gut Microbiota Modulation:
- Dragon fruit—both the pulp and the structural fiber of the peel—is highly enriched in Dragon Fruit Oligosaccharides (DFOs) and non-digestible complex polysaccharides like pectin.
- Selective Probiotic Proliferation: These oligosaccharides successfully resist gastric acid

hydrolysis and \alpha-amylase degradation in the upper gastrointestinal tract. Upon reaching the colon, they act as a specific carbon source, selectively stimulating the growth and viability of indigenous Lactic Acid Bacteria (LAB), specifically Lactobacillus and Bifidobacterium species.

- Competitive Exclusion of Pathogens: Clinical benchmarks show that a low intake of dragon fruit prebiotics shifts the microbiome composition to significantly suppress populations of opportunistic pathogens like Escherichia coli, Clostridium, and Enterococcus species.

2. In Vitro Antimicrobial and Pathogen Inhibition Profile:

- The bioactive phytochemical matrix in dragon fruit offers direct antimicrobial action, which prevents secondary infections and reduces systemic infectious burdens.

Active Phytochemical Fraction	Primary Microbial Targets	Mechanism of Inhibition
Betacyanin & Anthocyanins (Nitrogenous purple-red pigments).	Aeromonas hydrophilia, Bacillus cereus, Staphylococcus aureus, Streptococcus mutans.	Hydrophilic disruption of the bacterial cell membrane, inducing proton leakage and structural unbalancing of inner/outer cellular pH.
Flavonoids & Phenolic Acids (Gallic acid, Vanillic acid).	Escherichia coli, Klebsiella pneumoniae.	Inhibition of bacterial topoisomerases, protein synthesis degradation, and damage to the lipopolysaccharide cell walls.

Table.No.5.5

3. Cellular Immunomodulation & Toll Pathway Stimulation:

- The relationship between dragon fruit actives and the host immune system extends into molecular signaling.
- Upregulation of Pattern Recognition Receptors (PRRs): Research indicates that dragon fruit oligosaccharides can upregulate the genetic expression of the Toll signaling pathway (including Toll2, Toll3, Toll5, and Toll7 genes). This response primes the host's innate immune architecture, making it highly sensitive and reactive to viral or bacterial antigens.
- Mitigation of Macrophage Oxidative Burst: While priming immune defenses, the high concentrations of betalains and \beta-carotene act as potent free-radical scavengers. They increase Superoxide Dismutase (SOD) activity and suppress lipid peroxidation, protecting host immune cells from oxidative exhaustion during an active immune response.

VI. OBJECTIVES

The primary objectives for developing an immunity booster powder using dragon fruit (pitaya) focus on high concentration of Vitamin C and antioxidants to enhance the body's natural defense mechanisms.

1. Strengthening the Immune Response:

- White Blood Cell Support: A major objective is to stimulate the production and function of white blood cells, which are essential for fighting off infections and illnesses.
- Infection Prevention: By providing a high dose of Vitamin C and carotenoids, the powder aims to help prevent common colds and flu by keeping immune cells alert and effective.

2. Combating Oxidative Stress:

- Antioxidant Delivery: The powder is designed to deliver powerful antioxidants like betalains, flavonoids, and polyphenols.
- Cellular Protection: These compounds neutralize harmful free radicals, protecting immune cells from damage and reducing the risk of chronic diseases such as heart disease and cancer.

3. Enhancing Gut Health (Indirect Immunity):

- Prebiotic Function: Dragon fruit is rich in oligosaccharides (prebiotics) that promote the growth of beneficial gut bacteria like Bifidobacterium and Lactobacilli.

- Microbiome Balance: Since a significant portion of the immune system resides in the gut, fostering a healthy microbiome helps outcompete harmful pathogens and enhances overall immune resilience.

4. Improving Nutrient Bioavailability Iron Absorption:

- Another objective is to utilize the Vitamin C in dragon fruit to improve the absorption of iron, which is critical for moving oxygen through the body and maintaining high energy levels.
- Nutritional Concentration: Processing the fruit into a powder aims to concentrate its nutrients, such as Vitamin C, magnesium, and dietary fiber, into a convenient, long- lasting format.

VII. USES

- Immune System Support: High levels of Vitamin C and antioxidants help the body fight infections, reduce the severity of colds, and combat oxidative stress.
- Gut Health Improvement: The powder acts as a prebiotic, nourishing good bacteria like lactobacilli and bifidobacteria to improve digestion and gut health.
- Antioxidant Protection: It contains compounds such as betacyanin, which help reduce inflammation and protect cells from free radicals.
- Nutrient Boost: It provides essential minerals, including magnesium for bone health and iron for energy.
- Skincare Support: The vitamin C content assists in collagen production, which helps maintain firm and healthy skin.

VIII. HOW TO USE THE POWDER

- Smoothies & Bowls: Add to fruit.
- Smoothies, Smoothie bowls, or top off Yogurt.
- Beverages: Mix into Water, Juice, or Coconut Milk for a quick, Nutritious drink.
- Breakfast Foods: Stir into Oatmeal, Chia.
- Pudding, or Cereal.
- Baking & Snacks: Incorporate into energy.
- Balls, Muffins, or Pancake batter for natural, vibrant coloring and added nutrients.

❖ Dosage/Tips:

- Recommended Intake: While not strictly.
- Regulated, a common serving size is typically 1-2 teaspoons.
- Optimal Variety: Red or pink dragon fruit.
- Powder is generally richer in antioxidants (betalains) compared to white-fleshed varieties.

IX. RESULT

Dragon fruit immunity booster powder generally yields a vibrant, highly nutritious, plant-based supplement. Scientific evaluations demonstrate that adding dragon fruit- particularly its nutrient-dense peel-into powder formulations successfully enriches the diet with Vitamin C, powerful antioxidants (like betalains), and dietary fiber.

Herbal Immunity Booster Powder Dragon Fruit (Frized-Dried).

X. CONCLUSION

Technical Stability and Safety.

Preserved Quality: By utilizing freeze-drying technology, the delicate bioactive components of dragon fruit—specifically Vitamin C and antioxidants—are effectively preserved, maintaining their nutritional integrity and preventing degradation from heat or environmental moisture.

Shelf Stability: The resulting porous powder maintains a very low moisture content and low water activity preventing enzymatic reactions, structural clumping, and caking to ensure an exceptionally stable shelf life.

Microbiological Safety: Formulations developed from the powder strictly meet high safety standards,

showing no detection of Salmonella spp., E. coli, harmful yeasts, or molds.

Functional and Nutritional Powerhouse.

Immune Architecture Priming: The powder serves as a potent immunomodulator. It contains unique dragon fruit oligosaccharides (DFOs) that upregulate the genetic expression of the Toll signaling pathway (including Toll2, Toll3, Toll5, and Toll7 genes), making the host's innate immune architecture highly sensitive and reactive to harmful antigens.

Cellular Protection: High concentrations of betalains, flavonoids, and \beta-carotene act as robust free-radical scavengers. They significantly increase Superoxide Dismutase (SOD) activity and reduce lipid peroxidation, protecting host immune cells from oxidative exhaustion and structural damage during immune responses.

Gut Health Optimization: Because a major portion of the immune system resides in the gut, the non-digestible complex polysaccharides in the powder function as prebiotics. They resist upper GI tract degradation to selectively stimulate the growth of beneficial colon bacteria (Lactobacillus and Bifidobacterium species). This fermentation synthesizes short-chain fatty acids (SCFAs) that lower luminal pH, making the gut niche completely hostile to opportunistic pathogens like Escherichia coli, Clostridium, and Enterococcus.

Industry Innovation & Consumer Adaptability.

Sensory Appeal: Varying the powder's concentration (particularly evident in formulation variants like A3) successfully yields a more robust, visually striking color profile and a higher density of beneficial antioxidants without sacrificing palate appeal.

Bridging the Gap: Ultimately, transforming highly perishable, seasonal dragon fruit into a versatile, rehydratable powder successfully establishes a rigorous technical blueprint for the functional food industry. It delivers a highly convenient, accessible, and shelf-stable formulation that bridges the gap between daily nutrition, wellness, and modern consumer demand.

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