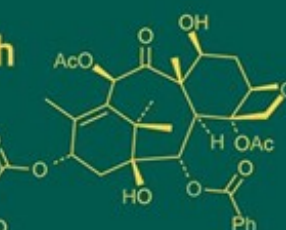
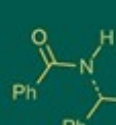


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Development, optimization and quality evaluation of an instant beverage powder mix from Aonla (*Embolica officinalis*) and unripe mango (*Mangifera indica*)

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ABSTRACT

Aonla (*Embolica officinalis* Gaertn.) and unripe mango (*Mangifera indica* L.) are endemic fruits highly nutritious and functional, the former rich in ascorbic acid and polyphenols and the latter in starch, pectin and organic acids. However, significant seasonality, high perishability and high astringency/sourness limit the direct consumption of both fruits and their availability throughout the year. Their conversion into a blended instant beverage powder mix is a viable route to value-add, long-term stability and enhanced convenience while retaining the nutraceutical benefits of the individual fruits. The objective of this paper is to present a research outline for the development, optimization and assessment of an instant beverage powder made from aonla and unripe mango pulp. The proposed approach includes pulp extraction, blending with a carrier agent (maltodextrin) and permitted additives, dehydration by cabinet or spray drying and standardization of the blend ratio using response surface methodology (RSM). Parameters to be determined include physicochemical properties (moisture content, bulk density, solubility, hygroscopicity, titratable acidity, total soluble solids and colour), nutritional and bioactive content (ascorbic acid, total phenolic content and antioxidant activity), microbiological safety, sensory acceptability and storage stability. Building on the literature on aonla- and mango-based powders and blended beverages, the paper discusses expected performance trends, the technological challenges of blending an acidic, tannin-rich fruit with a starch-rich unripe fruit and the potential of the resulting product as a low-cost, nutrient-dense, ready-to-reconstitute beverage. Implications for small-scale food processing and further experimental validation are presented.

Keywords: Aonla, *Embolica officinalis*, Unripe mango, Instant beverage powder, Spray drying, Response surface methodology, Functional food, Quality evaluation

Introduction

The beverage industry has seen a steady transition in consumer preferences to more convenient, ready-to-reconstitute and nutritious products that require minimal culinary preparation. Instant beverage powders, produced by dehydration of fruit pulp or juice with a suitable carrier agent, meet this need and have the added benefits of reduced packaging volume and transportation cost, prolonged shelf life and microbiological stability compared to fresh juices or ready-to-serve (RTS) beverages. Within this category, powders produced from underutilized indigenous fruits are garnering increased research interest due to their combined functional and nutraceutical potential as well as their capacity to reduce postharvest losses among smallholder producers.

Aonla alternatively known as Indian gooseberry, is one of the nutritionally prominent fruits grown in South Asia. It is widely recognized as having an exceptionally high ascorbic acid content in addition to hydrolysable tannins, gallic acid and ellagic acid, which together impart potent antioxidant activity (Majeed *et al.*, 2009; Khan, 2009; Scartezzini *et al.*, 2006) [2, 1, 3]. Exact quantification of the vitamin C content of aonla has been the subject of contention in the analytical literature with some enzymatic assays reporting significant levels of ascorbic acid but cautioning that conventional colorimetric methods might overestimate the true value due to co-eluting compounds such as mucic acid gallates (Khan, 2009) [1]. Independent of the precise quantification method, aonla fruit is consistently attributed high antioxidant and health-promoting properties and its polyphenolic fraction appears to play a significant role, alongside ascorbic acid, in its overall bioactivity (Scartezzini *et al.*, 2006) [3]. The fresh fruit is distinctly astringent and sour, however, which limits its direct consumption and requires processing into other forms such as candy, pickle, juice, or powder in order to improve palatability (Muzaffar *et al.*, 2022) [4].

Mango (*Mangifera indica* L.), by contrast is an extensively cultivated tropical and subtropical fruit valued primarily in its ripe state for its sugars, carotenoids and characteristic aroma. The unripe or raw fruit, how

ever, contains a unique set of nutrients and functional ingredients: starch is the major storage carbohydrate in green mango and the pulp additionally contains pectin and organic acids such as citric, malic and oxalic acid that contribute to the characteristic sourness of the unripe fruit (Lebaka *et al.*, 2021; Maldonado-Celis *et al.*, 2019) [5, 6].

During ripening, starch is progressively hydrolysed to glucose, fructose and sucrose and pectin content decreases, thereby representing a distinct raw material from the ripe fruit (Lebaka *et al.*, 2021) [5].

Raw mango has traditionally been consumed in South Asia in the form of chutneys, pickles and sour beverages and its high pectin and acid content makes it a technologically interesting complement to other fruit pulps in blended product development.

The combination of aonla and mango pulp in beverage formulation is not without precedent. Blended nectars, squashes and ready-to-serve drinks incorporating aonla and mango have been shown to achieve favourable sensory and nutritional outcomes, with blend ratios in the region of one-part aonla pulp to three parts mango pulp regularly cited as producing acceptable overall quality (Muzaffar *et al.*, 2022) [4]. Similar work has also shown that aonla pulp can be successfully combined with other bases, such as aloe vera, to produce low-calorie or functional RTS beverages (Deen, 2024) [7]. However, the specific combination of aonla with unripe, as opposed to ripe, mango, processed into a dry, instant, reconstitutable powder rather than a liquid RTS beverage, has been the subject of comparatively less systematic study. This is an important area of investigation because unripe mango contains starch and pectin that have an impact on the flow, solubility and reconstitution behaviour of the resulting powder that differs from ripe-mango-based formulations, while aonla provides a strong nutraceutical profile that must be balanced out by appropriate blend optimization in conjunction with its marked acidity and astringency.

Powder-form fruit beverages are typically produced by combining fruit pulp with maltodextrin or a similar carrier agent to raise the glass transition temperature of the feed material to prevent stickiness and facilitate efficient drying (Akhavan Mahdavi *et al.*, 2016). Maltodextrin, Gum Arabic and their combinations are the most widely used carrier agents in the spray drying of fruit juices and pulps due to their high solubility, film-forming capacity and comparatively low cost (Akhavan Mahdavi *et al.*, 2016). Processing parameters such as drying temperature, carrier agent concentration and feed flow rate have a marked influence on the moisture content, hygroscopicity, solubility and retention of bioactive compounds in the final powder and are therefore crucial to any optimization exercise (Tontul *et al.*, 2017) [8].

Against this background, the present paper addresses a comprehensive research framework for the development of an instant beverage powder mix from aonla and unripe mango, optimized for the blend ratio and processing conditions using response surface methodology and systematic assessment of the physicochemical, nutritional, microbiological, sensory and storage-related quality of the resulting product.

The specific objectives of the proposed study are as follows:

- To standardize the ratio of aonla pulp, unripe mango pulp, carrier agent and sweetener required to obtain an instant powder of acceptable physicochemical and sensory quality;
- To optimize the drying parameters using rsm to maximize the retention of ascorbic acid and antioxidant activity while minimizing the moisture content and hygroscopicity;
- To evaluate the nutritional, physicochemical and microbiological quality of the optimized powder.
- To assess the sensory acceptability and storage stability of the product over an ambient storage period.

Literature Review

Nutritional and functional composition of aonla

Aonla fruit has long been a popular ingredient in Ayurvedic medicine and is now being subjected to increased scientific study under the guise of functional food research. The fruit is reported to be rich in ascorbic acid as well as hydrolysable tannins, and also in gallic acid and ellagic acid (Khan, 2009) [1]. Comparative analytical studies using enzymatic, chromatographic and colorimetric assays have yielded variable results for ascorbic acid content, with enzymatic assays reporting vitamin C contents of the order of 200 mg per 100 g of fresh fruit, but with warnings that some conventional spectrophotometric techniques can overestimate true concentrations (Khan, 2009) [1]. Whatever the actual figure, the antioxidant capacity of aonla extracts has been consistently attributed to a combination of ascorbic acid and phenolic components, with vitamin C alone accounting for a significant proportion, though not all, of total antioxidant activity (Scartezzini *et al.*, 2006) [3]. Processing studies indicate that ascorbic acid is susceptible to loss during drying and to prolonged storage, with gradual degradation observed in dehydrated aonla products such as candy, powder and mouth fresheners following extended ambient storage (Barwal *et al.*, 2010) [9].

Nutritional and functional composition of unripe mango

The composition of the mango fruit changes during its ripening stage. In green or unripe mangoes, starch is the major component of the carbohydrates alongside a high amount of pectin and organic acids whereas, in ripe mangoes, starch is broken down into glucose, fructose, and sucrose and the amount of pectin reduces due to the fruit softening (Lebaka *et al.*, 2021; Maldonado-Celis *et al.*, 2019) [5, 6]. The sourness in raw mangoes is mainly due to the presence of citric and malic acid besides small amounts of oxalic and succinic acid as opposed to the sweet taste of ripe mangoes which is due to their sugar content (Lebaka *et al.*, 2021) [5]. The observed differences in the composition of unripe and ripe mangoes could have technological implications. For example, the higher content of pectin and starch in unripe mango pulp may have different effects on viscosity, drying characteristics, and reconstitution properties as opposed to ripe mango pulp which is higher in simple sugars and carotenoids and has been used more in previous studies on instant beverage powders (Akther *et al.*, 2020) [10].

Existing work on aonla- and mango-based beverages and powders

A body of applied research has investigated the processing of aonla and mango as single- and combination-sourced ingredients for shelf-stable products. Blended ready-to-serve beverages incorporating both aonla and mango pulp have been described, with a proportion of around 25% aonla pulp blended into 75% mango pulp frequently cited as yielding desirable sensory and chemical quality in nectar, squash and RTS products, including low-calorie variants sweetened with stevia (Deen, 2024; Muzaffar *et al.*, 2022) [7, 4]. Dehydrated aonla products such as mouth fresheners and candies have also been investigated for their storage stability, with moisture content, ascorbic acid retention and overall sensory acceptance identified as key quality parameters varying across prolonged storage (Barwal *et al.*, 2010) [9]. In the case of mango, instant mango drink powders produced by blending mango pulp with maltodextrin, sugar and acidulants have been shown to offer nutritional and sensory equivalency with commercial counterparts, with positive proximate composition and antioxidant capacity reported relative to market products (Akther *et al.*, 2020) [10].

More recently, freeze-dried instant juice powders produced from a combination of guava, amla and jamun have demonstrated the capacity for fruit-based instant powders to maintain significant levels of vitamin C, carotenoids, phenolics, flavonoids and antioxidant activity alongside physically viable properties for packaging and storage (Rafiquzzaman *et al.*, 2025) [11]. Taken together, this literature base establishes the technical viability of the proposed aonla-unripe

mango powder while highlighting the potential challenges posed by differing acid and pectin content relative to the sugar-based nature of ripe mango and guava matrices used in prior instant powder studies.

Carrier agents and drying technology for fruit powders

The dehydration of fruit pulps into powder form is hindered by the low glass transition temperature and high hygroscopicity of the sugar and acid-rich matrix, which causes stickiness, caking and poor flowability in the product during and after drying (Tontul *et al.*, 2017) [8]. Carrier agents, most commonly maltodextrin and either alone or in blends with gum arabic, are used in such cases to increase the glass transition temperature of the feed, enhance powder yield, and protect heat-sensitive bioactive compounds during processing (Akhavan Mahdavi *et al.*, 2016). Maltodextrin is preferred over other materials in food-grade applications due to its superior water solubility, neutral flavor, film-forming ability, and low cost, albeit with its relatively low glass transition temperature making the resulting spray-dried powders prone to stickiness when the inlet air temperature and carrier concentration are not optimized (Tontul *et al.*, 2017) [8]. Research into the effects of carrier agent concentration and drying temperature in other fruit powders has already demonstrated the presence of a multivariable interaction between the two, which influences the final moisture content, solubility, hygroscopicity and bioactive compound retention in the product (Tontul *et al.*, 2017) [8].

Quality evaluation parameters for instant fruit powders

Reported evaluation frameworks for instant fruit beverage powders tend to converge on a fairly consistent set of parameters. Physicochemical evaluation typically includes moisture content, water activity, bulk and tapped density, Carr index and Hausner ratio as measures of flowability, solubility or wettability, hygroscopicity, colour using CIE L, a, b values, pH, titratable acidity and total soluble solids (Akther *et al.*, 2020; Rafiquzzaman *et al.*, 2025) [10, 11]. Nutritional and functional evaluation often covers proximate composition, ascorbic acid content, total phenolic and flavonoid content and antioxidant activity assessed using assays such as DPPH or ABTS radical scavenging (Rafiquzzaman *et al.*, 2025) [11]. Microbiological analysis including total plate count and yeast and mould counts are used to confirm the hygienic quality and shelf stability of the dried product. Sensory evaluation is generally performed using hedonic scales, most commonly a 9-point scale, applied to attributes such as colour, flavour, taste, mouthfeel and overall acceptability by a trained or semi-trained panel. Storage studies typically follow changes in moisture content, ascorbic acid retention, colour and sensory scores over a period of weeks to months under ambient or accelerated storage conditions, providing the basis for shelf-life estimation (Barwal *et al.*, 2010) [9].

Materials and methods raw Materials

Fresh, disease-free aonla (*Emblia officinalis* Gaertn.) fruits of a suitable processing cultivar and mature but unripe, green-stage, mango (*Mangifera indica* L.) fruits would be procured from a local market or research orchard. Food-grade maltodextrin (dextrose equivalent 10–20), citric acid and a permitted sweetener or sugar would serve as formulation adjuncts. All chemicals required for analytical procedures would be of analytical or laboratory grade.

Preparation of pulp

Aonla fruits would be washed, blanched briefly to inactivate oxidative enzymes and facilitate deseeding and then pulped using a mechanical pulper, followed by sieving to remove fibrous residue. Unripe mango fruits would be washed, peeled and the pulp separated from the stone before being homogenized. Blanching parameters and pulp extraction methods would be standardized in preliminary trials to maximize yield and ascorbic acid retention while minimizing browning.

Formulation of the blend

Aonla pulp and unripe mango pulp would be blended in a number of trial ratios, for instance 10:90, 20:80, 30:70 and 40:60 aonla-to-mango pulp by weight, informed by ratios previously reported as favoured in aonla–mango blended beverage research (Deen, 2024; Muzaffar *et al.*, 2022) [7, 4]. Maltodextrin would be included at varying concentrations, for instance 10–30% of total solids, as the principal carrier agent, along with a fixed proportion of sweetener and, if needed, a small amount of citric acid or sodium bicarbonate to adjust the final titratable acidity to a palatable level given the intrinsic sourness of both raw materials.

Drying and powder formation

The blended slurry would be dried either in a laboratory-scale spray dryer (with inlet air temperature, feed flow rate and atomizer speed as controllable process variables) or, as an accessible alternative for smaller-scale trials, in a cabinet or tray drier operated at a moderate temperature of 55–65 °C until a friable, low-moisture mass is obtained, which would then be ground and sieved to a uniform particle size. The choice between spray drying and cabinet or tray drying would be based on available infrastructure, with spray drying generally preferred for its shorter processing time and superior powder flow properties while cabinet drying would offer a lower-cost alternative suitable for small-scale or rural processing settings.

Experimental Design and Optimization

Response surface methodology using a Box–Behnken or central composite design would be used to model the combined effects of the independent variables, namely aonla-to-mango pulp ratio, carrier agent concentration and drying temperature, on the key response variables, namely ascorbic acid retention, antioxidant activity, moisture content and overall sensory acceptability score. Second-order polynomial models would be fitted to the experimental data and analysis of variance used to assess model adequacy with the optimal formulation and processing condition identified via desirability function analysis or graphical overlay of response surfaces

Physicochemical analysis

The optimized powder would be analyzed for moisture content by the oven drying method, water activity, bulk and tapped densities, Carr index and Hausner ratio, solubility and wettability in water, hygroscopicity, colour using a colourimeter, pH, titratable acidity expressed as citric acid equivalent and total soluble solids of the reconstituted beverage. **Nutritional and Bioactive Analysis**

Proximate composition, including moisture, ash, crude fibre, crude protein and carbohydrate by difference, would be determined using standard AOAC procedures. Ascorbic acid content would be estimated by 2,6-dichlorophenolindophenol titration or high-performance liquid chromatography, total phenolic content by the Folin-Ciocalteu method, total flavonoid content by the aluminium chloride colourimetric method and antioxidant activity by DPPH and/or ABTS radical scavenging assays.

Microbiological analysis

The dried powder would be tested for total plate and yeast and mould counts using standard pour-plate techniques to confirm that it is within microbiological safety limits applicable to dry food powders.

Sensory evaluation

Sensory acceptability of the reconstituted beverage will be determined by a semi-trained panel using a 9-point hedonic scale for attributes, including colour, aroma, taste, mouthfeel and overall acceptability, with the resulting data subjected to analysis of variance in order to determine statistically significant differences among formulations.

Storage studies

The optimized powder, packed in a suitable moisture-barrier material such as a metallized or laminated pouch, would be stored under ambient conditions and subjected to periodic analysis over a period of

three to six months for changes in moisture content, ascorbic acid retention, colour, microbiological load and sensory scores to estimate shelf life. **Statistical Analysis**

All analyses would be performed in triplicate and data would be expressed as mean values with standard deviation. Analysis of variance and response surface regression would be conducted using statistical software such as Design-Expert or Minitab, with differences considered significant at $p < .05$.

Results and Discussion

As the present study employs a research and optimization framework rather than laboratory-scale experimental trials, the anticipated results are interpreted in relation to

performance trends reported in comparable studies. These trends provide a basis for predicting the behaviour of the optimized aonla–unripe mango powder formulation and may be confirmed or refined through the experimental work proposed in the study.

The optimized formulation is expected to retain a substantial proportion of the ascorbic acid originally present in fresh aonla pulp, although some degradation is anticipated as a consequence of thermal processing, drying, and exposure to oxygen. Such losses would be consistent with the reduction in ascorbic acid reported during the processing and storage of dehydrated aonla products (Barwal *et al.*, 2010) [9]. The incorporation of unripe mango pulp may further influence the drying characteristics of the formulation because of its relatively higher pectin and starch content. In contrast to ripe mango pulp, which contains a greater proportion of soluble sugars, unripe mango may produce a feed slurry with different viscosity, drying behaviour, and reconstitution characteristics. Consequently, the concentration of carrier agent may need to be optimized carefully, as higher levels of pectin and organic acids can increase feed stickiness and create challenges during spray drying (Tontul *et al.*, 2017) [8].

Among the formulation variables, the aonla-to-mango blend ratio is expected to have a major influence on both nutritional and sensory characteristics. Aonla contributes substantial amounts of ascorbic acid and phenolic compounds but is also characterized by pronounced acidity and astringency. Therefore, excessive incorporation of aonla pulp may negatively influence flavour and overall sensory acceptability. Previous studies on aonla–mango blended beverages have reported favourable quality at an aonla-to-mango ratio of approximately 1:3, suggesting that a comparable or slightly lower proportion of aonla may provide a suitable balance between nutritional value and palatability in the present powder formulation (Deen, 2024; Muzaffar *et al.*, 2022) [7, 4]. However, the optimum ratio for a spray-dried product may differ because drying and the addition of carrier agents can modify the perceived acidity, sweetness, mouthfeel, and reconstitution characteristics.

Drying temperature is also expected to play a critical role in determining powder quality. Excessively high inlet temperatures may promote thermal degradation of ascorbic acid and other heat-sensitive bioactive compounds, in addition to increasing browning reactions. Conversely, insufficient drying temperatures may result in excessive residual moisture, poor powder stability, caking, and an increased risk of microbial deterioration. Therefore, an intermediate drying temperature is expected to provide a suitable compromise between moisture removal and retention of nutritional and sensory quality.

The optimized powder is anticipated to exhibit a moisture content below 5%, together with satisfactory flow properties and reconstitution characteristics. A favourable Carr index would indicate improved flowability, while water solubility is expected to fall approximately within the range of 80–90%. These values would be broadly comparable with those reported for instant mango drink powders and freeze-dried tropical fruit juice powders (Akther *et al.*, 2020; Rafiquzzaman *et al.*, 2025) [10, 11]. The relatively low moisture content would also be beneficial for minimizing caking and improving storage stability.

Sensory evaluation is expected to favour an intermediate aonla-to-mango ratio combined with a moderate carrier-agent concentration.

Such a formulation would be expected to provide an acceptable balance between the characteristic tartness and astringency of aonla and the comparatively milder flavour and starch-associated mouthfeel contributed by unripe mango. Excessive carrier-agent concentration, although potentially beneficial for drying performance, may dilute the characteristic fruit flavour and reduce the nutritional density of the powder. Hence, optimization should consider both processing performance and sensory acceptability rather than maximizing any single response.

During storage, a gradual reduction in ascorbic acid content and sensory quality is anticipated. Such changes would be consistent with the oxidative and physicochemical degradation observed in other dehydrated aonla-based products during storage (Barwal *et al.*, 2010) [9]. Moisture migration, oxygen exposure, and temperature are likely to contribute to these changes, with higher moisture and temperature conditions expected to accelerate quality deterioration. Accordingly, the use of moisture- and oxygen-barrier packaging, together with cool and dry storage conditions, would be important for preserving the nutritional, physical, and sensory quality of the optimized powder.

Overall, the expected results indicate that successful optimization of aonla–unripe mango instant powder will require a balance among blend ratio, carrier-agent concentration, and drying temperature. The most desirable formulation is expected to combine adequate retention of ascorbic acid and other bioactive compounds with low moisture content, satisfactory flowability, good water solubility, and high sensory acceptability. Since these outcomes are predicted from trends reported in related literature rather than from completed experimental trials, the proposed values should be regarded as anticipated performance ranges rather than experimentally established results.

Conclusion

The proposed development of an instant beverage powder mix from aonla and unripe mango addresses a gap in the current state of fruit processing and utilization research, combining two nutritionally unique but underutilized indigenous fruits into a convenient, shelf-stable functional beverage. The literature reviewed demonstrates that both fruits offer valuable, albeit compositionally distinct, functional properties, aonla providing significant antioxidant and vitamin C activity and unripe mango contributing starch, pectin and organic acids and that similar blended and powdered fruit products have demonstrated favourable nutritional, physicochemical and sensory results when formulation and drying parameters are carefully optimized. The research framework presented, encompassing pulp preparation, RSM-based optimization of blend ratio and drying parameters and comprehensive physicochemical, nutritional, microbiological, sensory and storage evaluation, provides a foundation for future experimental work. Successful development of this product could provide a low-cost, nutrient-dense beverage option with potential applications in small-scale food processing enterprises and rural value-addition initiatives, as well as contributing to the reduction of postharvest losses of two seasonal indigenous fruits. Future experimental verification of the framework proposed in this paper, including full RSM trials and extended storage studies, is recommended to confirm the anticipated performance trends discussed above and to establish a final, validated formulation.

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