Alok Kumar Gupta, Abha Singh, Akath Singh, Swosti S Das and Ravi S C

Dried and dehydrated fruit products for commercial markets

Subtropical fruits such as mango, guava, *aonla*, *bael*, and *jamun* encounter considerable post-harvest losses ranging from 20% to 30% due to high perishability. ICAR-CISH Lucknow has innovated novel products by using drying and dehydration methodologies, such as osmotic dehydration, freeze-drying, infrared drying, and microwave-assisted drying, to mitigate these losses. The application of these methods enhances shelf life, minimizes transportation expenses, and maintains both nutritional and sensory attributes. Products like freeze-dried fruit powders and cubes, leathers, candies, and pulp blocks/ cubes address the increasing domestic and international demand for nutritious and convenient snack options. The technologies developed by the institute, in conjunction with its Agri-Business Incubation program, facilitate the advancement of commercialization and promote rural entrepreneurship.

Keywords: Freeze-drying, Rural entrepreneurship, Osmotic dehydration, Subtropical fruits,Value-added products

DRYING and dehydration technologies offer effective methods to address post-harvest losses by prolonging shelf life, minimizing transportation expenses through weight reduction, and maintaining bioactive compounds essential for nutritional and functional benefits. The global dried fruit market is undergoing significant expansion, with projections indicating a CAGR of 5–7% until 2030. This growth is primarily attributed to the rising consumer preference for convenient, nutrient-rich, and minimally processed food options. The dehydrated fruit sector in India is set for considerable growth, with an anticipated CAGR of 7–8%. This growth is driven by increasing domestic consumption, potential export opportunities, and a heightened awareness of healthy snacking alternatives among the burgeoning middle-class demographic. ICAR-CISH has developed advanced, energy-efficient methods for drying and dehydration, including freeze-drying, infrared drying, and microwave-assisted drying, as well as osmotic dehydration (OD) in conjunction with hot air drying (HAD). These techniques maximize nutrient preservation, improve sensory qualities, and increase the marketability of products. This article assesses the advancements made by ICAR-CISH in the realm of dried and dehydrated fruit products, emphasizing processing methodologies, product diversification, nutritional and functional characteristics, and the potential for commercialization.

Process optimized for drying and dehydration of fruits

ICAR-CISH has developed various drying and dehydration technologies specifically designed for subtropical fruits, emphasizing the preservation of nutritional value and scalability for commercial applications. The techniques employed target the elevated moisture levels (70–90%) present in fruits, which facilitate microbial proliferation and subsequent deterioration.

Osmotic dehydration

Osmotic dehydration is a preliminary treatment method that consists of submerging fruit segments in a hypertonic solution, usually composed of sucrose or glucose syrup with a concentration ranging from 55 to 70° Brix, to promote the extraction of water via osmosis. This method decreases moisture content by 30–50% (w/w) before the final drying process, maintaining the structural integrity of the fruit. ICAR-CISH has established refined OD protocols for mango, guava, bael, and *aonla*, resulting in considerable weight reduction while incorporating natural sweeteners. This procedure produces "semi-candied" items that exhibit enhanced sensory characteristics and prolonged shelf stability. ICAR-CISH has advanced the integration of OD with infrared-drying techniques to yield dehydrated fruits characterized by a puffy, crisp texture, presenting a cost-efficient method.

Freeze-drying (Lyophilization)

Freeze-drying, also known as lyophilization, is acknowledged as the most effective technique for maintaining the nutritional quality, sensory characteristics, and structural integrity of dried fruits. The procedure entails freezing the fruit at temperatures generally below -40 to -60°C, followed by sublimation under high vacuum conditions (around 0.01–0.1 mbar). ICAR-CISH has

developed advanced FD technologies specifically designed for high-quality fruit products aimed at lucrative domestic and international markets. ICAR-CISH has refined lyophilization protocols to generate high-quality powders, segments, and cubes from guava, mango, and *aonla*.

Infrared drying

Infrared drying is an effective method for fruit dehydration because infrared radiation directly heats the fruit surface and penetrates inside, causing rapid vibration of water molecules and moisture removal. Unlike traditional hot air drying, it shortens drying time, saves energy, and helps fruits preserve their natural colour, flavour, vitamins, and antioxidant levels. This makes it ideal for heat-sensitive fruits such as mango, *aonla*, guava, and berries, where preserving nutritional content and sensory qualities is critical. Infrared drying increases the shelf life and market value of fruit goods by generating a consistent drying effect while minimizing microbial development. ICAR-CISH has developed low-sugar aonla candy, iron-fortified aonla candy, fruit bars, and powders using infrared drying.

Specific dried and dehydrated fruit products

ICAR-CISH has developed a variety of dried and dehydrated fruit products that are scientifically validated and commercially viable, aimed at fulfilling the requirements of both domestic and international markets. The products are formulated through sophisticated dehydration methods aimed at maintaining nutritional quality, prolonging shelf stability, and improving sensory characteristics. Technologies such as optimized OD, VD, and FD processes are specifically designed to align with the physicochemical properties of individual fruits. This approach guarantees high-quality results while minimizing nutrient degradation and enhancing sensory qualities. Mango-derived products utilize cultivars characterized by elevated total soluble solids (TSS) and reduced fiber content, whereas aonla products take advantage of their abundant ascorbic acid content to enhance value-added functional foods.

MANGO PRODUCTS

Ripe mango powders: Processes for freeze-drying are optimized to develop mango powders intended for use in beverages, confectionery, and bakery products. Freeze-drying, performed at -40°C under vacuum, retains over 90% of aroma compounds and bioactive constituents, including β-carotene (12–18 mg/100 g) and mangiferin (50–70 mg/100 g), but is resource-intensive. These approaches guarantee microbial safety and adherence to international food standards, rendering the powders appropriate for worldwide markets.

Dehydrated mango slices: Dehydrated semi-ripe mango slices of *Amrapali* and *Mallika*, with a moisture content reduced to 3–5%, provide a chewy consistency and contain minimal added sugar, specifically less than 5% w/w. Pretreatments utilizing 0.5% ascorbic acid or citric acid solutions effectively mitigate oxidative degradation and enzymatic browning, thereby maintaining colour and flavour integrity. Drying with an infrared dryer at temperatures ranging from 55 to 60°C facilitates the preservation of 80% of antioxidants, such as mangiferin and quercetin derivatives. The slices are promoted as nutritious snacks, containing β-carotene concentrations ranging from 10 to 15 mg/100 grams, targeting consumers who prioritize health.

Instant panna mix: Mango panna is a refreshing Indian summer drink made from raw mangoes, known for its tangy-sweet taste and cooling properties. It is particularly popular in regions with hot climates, as it helps to beat the heat. Raw mangoes are an excellent source of vitamin C, which boosts immunity, aids in collagen production, and promotes healthy skin. The instant panna mix is prepared from freeze-dried mango pulp and infrared-dehydrated mint leaves along with other ingredients. Freeze-drying preserves most of the vitamins, minerals, and antioxidants present in raw mangoes, such as vitamin C, vitamin A, and potassium.

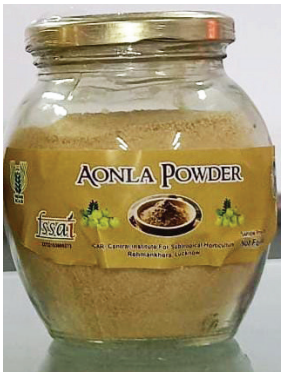
AONLA PRODUCTS

ICAR-CISH has innovated and advanced various value-added products derived from aonla, such as candy, powder, and dehydrated segments, aimed at meeting the demands of health-conscious consumers and the functional food sector.

Low sugar *aonla* candy: CISH has refined an infrared-dehydration technique for low-sugar and iron-fortified aonla candy, minimizing bitterness while retaining approximately 85% of ascorbic acid in contrast to conventional drying methods. The procedure entails OD followed by VD at regulated temperatures (50–60°C) to reduce thermal degradation of heat-sensitive compounds. The final product demonstrates enhanced sensory characteristics, featuring diminished astringency and increased sweetness, thereby increasing its attractiveness to consumers. This confectionery product has been effectively brought to market through collaborations with regional business owners, achieving popularity in health food sectors owing to its elevated antioxidant levels and a prolonged shelf life of up to 6 months when stored under standard environmental conditions.

***Aonla* powder:** *Aonla* powder functions as a multifaceted component in nutraceuticals, herbal formulations, and Ayurvedic preparations. FD technology

is utilized to generate a fine powder that preserves around 90% of ascorbic acid and 85% of ellagic acid, which are essential antioxidants contributing to the therapeutic properties of the fruit. The procedure entails lyophilization at -40°C within a vacuum of 0.1 mbar, thereby minimizing the degradation of thermolabile substances. The fine particle size of the powder, generally ranging from 100 to 200 µm, along with its low moisture content of less than 5%, contributes to its stability and solubility. This makes it an appropriate candidate for use in dietary supplements, functional beverages, and pharmaceutical formulations.



Dehydrated *aonla* segments: Freeze-dried *aonla* segments represent a valuable product, preserving approximately 90% of ascorbic acid while maintaining their structural integrity, making them suitable for incorporation into snacks, trail mixes, and various culinary applications. The FD technique maintains the cellular architecture of the fruit, yielding a crunchy texture and extending its shelf life to as much as 18 months when kept in moisture-resistant packaging. The segments exhibit a high concentration of polyphenols, with total phenolic content varying between 20 to 30 g GAE (gallic acid equivalent) per 100 g of dry weight, which plays a significant role in their antioxidant and anti-inflammatory characteristics.

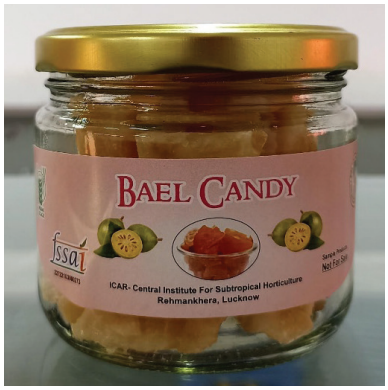
***Aonla* pomace cookies:** A value-added product is made by employing the dehydrated byproduct from aonla pomace, a waste of the juice industry, providing a nutritious and sustainable alternative for the fruit sector. The infrared-dried pomace, abundant in dietary fiber, natural antioxidants, vitamin C, and polyphenols, was integrated into the cookie formulation to augment its functional and health-enhancing attributes. This method enhances the nutritional quality and texture of the cookies while minimizing post-processing waste, hence promoting circular food economy initiatives. The creation of aonla pomace cookies offers a feasible possibility for small processing facilities to transform by-products into lucrative, health-focused treats while fostering environmental sustainability.

BAEL PRODUCTS

The fibrous, aromatic pulp of bael fruit contains a high concentration of bioactive compounds, such as marmelosin, psoralen, and phenolic antioxidants, which play a significant role in its medicinal properties. CISH has innovated processing methodologies to produce value-added bael products, such as bael powder, dehydrated pulp blocks, and ready-to-serve (RTS) beverage mixes, tailored for commercial applications.

***Bael* powder:** Bael powder is generated through the dehydration of mature bael pulp, followed by milling into a fine, stable powder that can be reconstituted into health-enhancing beverages or integrated into functional food products. The dehydration protocol developed by CISH utilizes a regulated low-temperature drying process (55–60°C for 7–10 hours) to maintain essential flavor volatiles, pectin, and bioactive compounds. The procedure effectively reduces thermal degradation, preserving around 85% of marmelosin and 90% of phenolic compounds, thereby ensuring that the powder retains its digestive and antioxidant characteristics. The final product comprises 31–33% carbohydrates, 8–10% dietary fiber, and exhibits a TSS content ranging from 30 to 38° Brix, which varies according to the cultivar.

Dehydrated pulp blocks and candy: Dehydrated bael pulp blocks and candies are produced using high-TSS cultivars, specifically CISH-B-1 with a TSS of 38° Brix and CISH-B-2 with a TSS of 31.9° Brix. The procedure consists of pulping mature bael fruit, treating the pulp with 0.1–0.2% citric acid to improve flavor and inhibit oxidative browning, and finally dehydrating at 60°C for 7–10 hours using a forced-air dryer. This approach guarantees the preservation of marmelosin (0.3–0.5% dry weight) and psoralen, which are compounds associated with gastrointestinal benefits. The dehydrated pulp blocks exhibit shelf stability, maintaining a moisture content of 6–8%. These blocks can be subjected to additional processing to produce churan, a traditional powdered digestive aid, or can be shaped into candies utilizing natural sweeteners. The nutrient composition of these products includes approximately 31.8% carbohydrates, 8% dietary fiber, and minimal levels of vitamins C and A, rendering them appropriate for health-oriented consumer segments. The advancements in processing techniques improve the commercial feasibility of bael products, utilizing the fruit's nutritional and medicinal properties while guaranteeing scalability and shelf stability for international markets.



JAMUN PRODUCTS

The institute has undertaken research that resulted in the establishment of standardized protocols for the production of dehydrated jamun pulp powder and seed flour, enhancing their nutritional and functional properties for use in commercial applications.

***Jamun* pulp powder:** The dehydration process entails the regulated drying of jamun pulp to maintain its elevated levels of anthocyanins and ellagitannins, which contribute to its distinctive purple hue and bioactive characteristics. The resultant powder functions as a natural colouring agent in food and beverage applications and as a dietary supplement, especially noted for its potential role in glycemic regulation and diabetes management. Analytical investigations reveal that jamun pulp powder maintains considerable concentrations of anthocyanins (such as delphinidin-3-glucoside) and polyphenolic compounds, which enhance its antioxidant potential and therapeutic effectiveness.

***Jamun* seed flour:** *Jamun* seeds, a byproduct of pulp processing, undergo dehydration and milling to produce a fine flour that is abundant in bioactive compounds, particularly jamboline and various alkaloids known for their hypoglycemic properties. The incorporation of seed flour into functional foods and nutraceuticals is aimed at applications in metabolic health, specifically for the management of blood glucose levels. The proximate analysis of the flour indicates a significant dietary fiber content alongside a low glycemic index, rendering it appropriate for incorporation into food formulations designed for individuals with diabetes.

CONCLUSION

The innovations developed by the institute in drying and dehydration methods for subtropical fruits such as mango, guava, aonla, bael, and jamun tackle significant post-harvest losses, improving shelf life, preserving nutritional value, and increasing market appeal. ICAR-CISH facilitates the development of rural entrepreneurs via its ABI program, which offers training, specialized knowledge, and incubation resources to promote the creation of micro, small, and medium enterprises (MSMEs). The institute has effectively enabled the formation of multiple startups that manufacture value-added products, which have achieved recognition in both local and regional markets.

For further information, contact:
ICAR-Central Institute for Subtropical Horticulture, Lucknow, Uttar Pradesh; Corresponding email: alokguptabhu@gmail.com