International Journal of Food Science and Nutrition
www.foodsciencejournal.com
E-ISSN: 2455-4898
Received: 22-09-2026, Accepted: 22-10-2026, Published: 06-11-2026
Volume 11, Issue 4, 2026, Page No. 115-121

From tradition to trend: Makhana as a functional superfood in food industry

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DOI: https://doi.org/10.66856/ijfsn.2026.11.4.11198

Abstract
Makhana, commonly known as fox nut or gorgon nut, is obtained from the seeds of *Euryale ferox* Salisb., an aquatic plant belonging to the family *Nymphaeaceae*. Traditionally consumed in India and other parts of Asia, makhana is gaining attention as a raw material for packaged snacks and value-added food products. It is characterised by a carbohydrate-rich composition, moderate protein content and low intrinsic fat, although its nutritional profile varies with sample type and processing conditions. Traditional roasting and popping produce its characteristic expanded structure and influence moisture, texture, colour, starch properties and measured bioactive compounds. Research has investigated its mineral and dietary fibre composition, phenolic and flavonoid content, antioxidant activity, glycaemic response and incorporation into products such as cookies, gluten-free pasta and modified-starch ingredients. Wider commercial use also depends on consistent raw-material quality, controlled processing, hygienic handling, moisture-protective packaging and reliable shelf-life assessment. This review examines makhana production and processing, quality characteristics, nutritional and bioactive composition, potential health relevance, food applications and commercial constraints. It also identifies standardisation, improved processing, by-product utilisation and stronger human research as priorities for the responsible development of makhana-based foods.

Keywords: *Euryale ferox*, makhana, fox nut, popping, functional food, antioxidant activity, glycaemic index, food processing, value addition

Introduction

The growing interest in traditional foods has encouraged researchers and food manufacturers to explore their use in modern food products. Such ingredients may offer nutritional value, established culinary importance and useful processing characteristics. Makhana, commonly known as fox nut or gorgon nut, is one traditional food that has attracted attention for its potential in value-added product development. In recent years, it has also been described as a "superfood" because of its carbohydrate-rich composition, naturally low-fat content and contribution of minerals. Therefore, makhana is more appropriately considered a traditional food with promising nutritional and food-industry applications that require further scientific investigation [11, 10].

Makhana is obtained from the seeds of *Euryale ferox*, an aquatic plant. The plant grows in ponds and other relatively still freshwater environments. After harvesting, the seeds undergo drying and specialised heating and popping processes, which produce the light, expanded product commonly consumed as makhana. The food has a long history of culinary and cultural use in India and other Asian regions, including its incorporation into traditional dishes and foods consumed during fasting. In recent years, its use has expanded beyond conventional preparations to include roasted and flavoured snacks, flour-based blends, bakery products and other value-added foods. Bihar is a major makhana-producing region in India. However, harvesting and processing can involve considerable manual labour, while the quality of the final product depends on factors such as raw-material characteristics and the skill involved in processing [11, 17, 6].

The interest in incorporating makhana into different food products is partly related to its carbohydrate-rich composition, naturally low-fat content and contribution of minerals. Its suitability for thermal processing also creates opportunities for developing products with different textures and sensory characteristics. Nevertheless, the nutritional composition and functional properties of makhana are not identical across all forms. Raw seeds, popped makhana, flour and processing by-products may differ considerably and reported values can also be influenced by moisture content, processing methods and the analytical procedures used. Previous studies have examined the effects of popping and roasting on physical properties, nutritional composition and selected bioactive constituents, including phenolic compounds and flavonoids. Research has also explored its use in cookie formulations, gluten-free pasta and food applications involving modified makhana starch [4, 14, 3, 9, 19]. These investigations indicate potential for broader utilisation, although the findings need to be interpreted in relation to the specific products, methods and experimental conditions examined. In particular, antioxidant activity observed in laboratory tests and findings from limited human studies should not be treated as sufficient evidence of general health benefits.

In view of these developments, the present review examines the available literature on the botanical characteristics and production of makhana, traditional processing practices and emerging technologies, quality assessment and grading, nutritional composition and bioactive compounds, reported health-related findings and applications in the food industry. It also considers practical challenges associated with processing standardisation, storage stability, packaging, food safety, raw-material availability and commercial-scale production. The review further identifies areas requiring additional investigation, including the development of standardised analytical methods, improved control of processing conditions, effective utilisation of processing by-products, well-designed human studies and product-specific shelf-life assessment. A clearer understanding of these aspects may help support the development of safe, consistent and commercially viable makhana-based products while maintaining a balanced interpretation of their nutritional and functional potential.

Botanical Description, Distribution and Cultural Importance

Makhana (*Euryale ferox* Salisb.) is an annual aquatic plant belonging to the family *Nymphaeaceae*. It is characterised by large floating leaves and spiny structures on different parts of the plant. The plant grows mainly in still or slow-moving freshwater environments, such as ponds and lakes. Unlike conventional cereal crops, its cultivation and harvesting are closely associated with aquatic conditions, making production more specialised and labour-intensive. Makhana is cultivated and collected in several parts of India and East Asia. In India, its production has traditionally been concentrated in the eastern region, particularly Bihar, although cultivation and commercial trade have gradually extended to other areas [11, 5].

Makhana is associated with traditional diets, fasting foods and religious offerings in India. These uses have helped maintain demand and knowledge of traditional processing. At the same time, rising interest in convenient snacks has encouraged new formats such as flavoured roasted makhana, coated snacks, flour and composite-ingredient products.

The transition from a regionally important traditional food to a packaged product category creates opportunities for producers. However, wider commercialisation also increases the need for reliable quality grading, food-safety controls, traceability and consistent packaging [17, 6].

Production Systems and Economic Importance

1. Production and Major Growing Regions

Makhana production involves crop establishment, management of aquatic growing conditions, harvesting, seed collection, drying and processing. Traditional cultivation and harvesting can be physically demanding and seed collection from ponds may involve difficult working conditions. The crop's agronomic requirements and identify labour intensity and production constraints as important considerations for wider adoption [11].

India is recognised as a major producer of makhana, with Bihar representing an important production centre. However, numerical estimates of global production, national production and state-level contributions can vary according to the reporting year and source. Such figures should be supported by a dated official publication before they are included as definitive statistics.

The ICAR research system has contributed to research on cultivation, improved varieties and processing technologies. Varieties mentioned in the literature and production-related material include Swarna Vaidehi, Sabour Makhana-1 and Mithila Makhana. Mithila Makhana received a Geographical Indication (GI) tag in 2022, reflecting its regional identity and commercial significance.

2. Post-Harvest Constraints

Production is affected by the availability and management of suitable water bodies, seasonal conditions, labour, seed maturity and post-harvest handling. The bulky, low-density nature of popped makhana can increase the volume required for storage and transport. Poor drying or storage conditions may compromise crispness and product quality.

For industrial supply chains, improvements in raw-seed grading, moisture control, hygienic handling, traceability and storage are as important as increasing production volume. Physical properties such as seed size and mass are also relevant to equipment design and processing consistency [6].

Production and Market Growth of Makhana in India

India is the leading producer of makhana, accounting for a major share of global production, with Bihar serving as the principal producing state. The ICAR–National Research Centre for Makhana, located in Darbhanga, Bihar, contributes to research on cultivation practices, improved varieties and processing technologies. Swarna Vaidehi was developed as an improved variety, while Sabour Makhana-1 and Mithila Makhana are also associated with makhana cultivation. Mithila Makhana received a Geographical Indication (GI) tag in 2022, recognising its regional identity and distinctive characteristics.

The Indian makhana market has experienced considerable commercial interest, supported by growing demand for convenient snacks and value-added food products. Market estimates indicate an increase in market value from approximately ₹5,000-5,500 crore in 2021- 22 to ₹8,000-8,500 crore in 2024-25, with projections of ₹11,000-12,000 crore by 2029-30. Average prices have also reportedly increased from around ₹500 per kg in 2020 to ₹1,250 per kg in 2025. These trends suggest opportunities for product diversification and food-industry development. However, the reported production figures, market estimates and price trends should be verified against the original sources before publication [1].

Traditional Processing of makhana

- **Cleaning and washing:** Mature makhana seeds are cleaned to remove dirt, dust and other foreign materials.

Washing helps remove surface impurities before further processing.

- **Sun drying and storage:** The cleaned seeds are spread under sunlight for approximately 2–3 hours to reduce their moisture content to around 31%. They may then be stored at room temperature for 20-25 days before processing. During storage, water is sprinkled periodically to help maintain seed quality.

- **Pre-heating:** The dried seeds are heated in an earthen pot or iron pan over a fire, with continuous stirring to ensure uniform heating. The reported pan surface temperature ranges from 250 to 300°C, and heating takes approximately 5–6 minutes. This step reduces the seed moisture content to about 20 %.
- **Tempering:** After pre-heating, the seeds are kept at room temperature for 48-72 hours. This resting period helps loosen the kernel from the hard-outer seed coat and prepares the seeds for popping.

- **Roasting and popping:** The tempered seeds are roasted in an iron pan at a reported surface temperature of 290-340°C, with continuous stirring. After approximately 1.5-2.2 minutes, the heated seeds are removed in small batches and struck with a wooden hammer. This causes the kernel to expand and separate from the hard seed coat, producing the popped makhana, locally known as lawa. The reported yield is approximately 35-40 % of the raw seed weight.

- **Polishing:** The popped seeds are rubbed together in bamboo baskets to improve their appearance and surface shine.

- **Grading:** The polished makhana is sorted according to size and quality to obtain uniform products for marketing.

- **Packaging:** Finally, the graded makhana is packed in suitable bags for storage and transportation. Traditional packaging materials include gunny bags for local markets and polythene-lined gunny bags for longer-distance transportation [13].

Factors Influencing Popping Quality

The quality of popped makhana is influenced by several factors, including seed moisture, size, maturity, roasting temperature, heating duration and tempering conditions. Moisture plays an important role during popping because the water inside the seed generates steam and pressure when heated. If the moisture level is too high or too low, the seeds may not expand uniformly, resulting in inconsistent product quality.

Uniform seed size and controlled heating help achieve more consistent popping results. When seeds receive uneven heat, some may expand properly, while others remain poorly popped or become scorched. Therefore, grading the seeds before processing and carefully controlling the heating time and temperature can improve product uniformity [12, 4].

Mechanisation can help reduce manual labour, improve process control and increase production capacity. Equipment can be used for operations such as roasting, popping, grading, flavouring and packaging. However, the suitability of machinery should be assessed based on product quality, worker safety, energy consumption and ease of cleaning. Increased production alone does not ensure better results, particularly if processing causes excessive breakage, unwanted browning or a loss of crispness.

Quality Characteristics and Grading of Makhana

Commercial grading commonly considers expansion, size, shape, colour, surface defects and the proportion of broken pieces. Fully expanded, rounded and pale pieces are generally considered higher grade, while smaller, flattened, irregular or more heavily marked pieces may receive lower grades. Grade terminology can vary across producing areas and traders; therefore, specifications should define measurable characteristics rather than relying only on local names [17].

1. Size-Based Grading

The material reviewed describes a size-based classification using Suta grades:

- **4 Suta:** approximately 12-15 mm
- **5 Suta:** approximately 15-18 mm
- **6 Suta:** approximately 18-21 mm
- **7 Suta:** greater than 21 mm

These size ranges should be checked against the relevant official or industry grading specification before final publication. Larger kernels may be preferred in premium markets because of their appearance and commercial value.

2. Traditional Quality Grades

Traditional quality grading also considers the degree of popping and colour of the kernels. Three commonly described categories are:

- **Lawa or Rasgulla:** well-expanded, creamy-white kernels, generally considered a superior grade.

- **Murra or Samundha:** expanded kernels that may be comparatively smaller and may show slight reddish spots.

- **Thurri:** flattened or irregularly expanded kernels that usually show more reddish discolouration.

These differences in physical characteristics are used to distinguish the quality of popped makhana. The terminology and specifications may vary across regions and should be defined clearly when used in research or commercial standards.

Useful objective quality measurements include moisture content, bulk density, dimensions, colour values, hardness or fracture behaviour, water activity, microbial quality and sensory crispness. These measurements can support consistent grading and help identify conditions that preserve quality during storage and distribution [1, 6, 17].

Nutritional Composition of Makhana

Makhana is mainly a source of carbohydrates and also contains protein, small amounts of fat, minerals and dietary fibre. However, its nutritional composition can vary depending on the form in which it is analysed, such as raw seeds, popped makhana, flour or bran. Differences in variety, growing conditions, moisture content and analytical methods may also affect the values reported in different studies. Therefore, nutritional data should be compared carefully, considering both the type of sample and the basis used for reporting its composition [11,10].

Table 1: Nutrient composition of raw kernel and popped makhana (Devi *et al*.,2020 [4])

Item (dry matter basis)	Raw kernel (%)	Popped makhana (%)
Protein	9.15 ± 0.10	11.03 ± 0.45
Fat	0.46 ± 0.03	0.33 ± 0.12
Total minerals	0.45 ± 0.03	0.38 ± 0.03
Total dietary fibre	2.55 ± 0.04	3.26 ± 0.06
Soluble dietary fibre	1.36 ± 0.03	2.83 ± 0.08
Insoluble dietary fibre	1.19 ± 0.02	0.43 ± 0.04
Carbohydrates	87.52 ± 0.15	84.87 ± 0.60
Starch	85.71 ± 0.33	78.23 ± 0.34
Amylose	28.99 ± 0.13	25.49 ± 0.37
Amylopectin	56.72 ± 0.34	52.74 ± 0.37

Makhana contains various essential minerals, including phosphorus, potassium, calcium, magnesium, iron, sodium, manganese and zinc. The amount of these minerals may differ between raw and popped makhana. Such variations can be influenced by differences in the samples and processing conditions, so the reported values need to be interpreted carefully. Although makhana can contribute to the intake of essential minerals, its nutritional importance as a source of a particular mineral should be determined by comparing its content with that of other foods.

Table 2: Mineral composition of raw kernel and popped makhana (Devi *et al*.,2020 [4])

Mineral (mg/100 g, dry matter basis)	Raw kernel	Popped makhana
Calcium	14.50	20.94
Sodium	2.92	4.06
Potassium	50.25	48.39
Magnesium	13.83	12.71
Phosphorus	132.53	124.01
Iron	5.73	2.67
Manganese	1.30	1.24
Zinc	1.50	1.04

Nutritional Implications

Low intrinsic lipid content is one of makhana's distinguishing compositional features compared with many fried snack products. However, the nutritional profile of a finished snack depends on added oil or ghee, salt, sugar, coatings and portion size. A lightly seasoned roasted product and a heavily coated or fat-added product should not be assumed to have the same energy or sodium profile.

Bioactive Compounds and Antioxidant Activity

Makhana has gained research interest because of its phenolic compounds, flavonoids (quercetin and kaempferol) and associated antioxidant properties. These constituents have been investigated for their ability to scavenge free radicals under experimental conditions. However, the quantity measured in an extract, the activity observed in a chemical assay and the effect after human consumption represent different kinds of evidence. Bioavailability, digestion, metabolism and the quantity consumed influence whether laboratory findings translate into measurable physiological effects [11, 10].

Effect of Popping and Roasting

Popping can influence the antioxidant properties of makhana, while the bran separated during processing may also provide useful nutritional components. Compared with popped makhana, the bran has been reported to contain more dietary fibre, phenolic compounds and flavonoids. This suggests that makhana bran could be used to develop value-added food products instead of being discarded as waste [4].

Roasting may also influence the bioactive compounds present in makhana. Roasted fox nuts have shown higher measured levels of phenolic compounds, flavonoids and antioxidant activity than unroasted samples. These changes may occur because heating affects how these compounds are released and extracted during analysis. However, the results depend on the roasting temperature, duration and composition of the raw material. Therefore, the effects observed under particular experimental conditions may not be the same for every makhana product or roasting method [14].

Potential Health Relevance: Evidence and Limitations

1. Glycaemic Response

Roasted makhana was reported to have a glycaemic index (GI) of approximately 37 in a small human study. However, the glycaemic response may vary with roasting conditions, portion size, accompanying foods and individual differences. Therefore, further research is needed before generalising this finding to all makhana products. Products containing added sugar may produce different responses from plain roasted makhana[14].

2. Cardiometabolic and Weight-Management Claims

Makhana's low intrinsic lipid content makes it a potential ingredient for developing reduced-fat snack products. However, its effects on weight management depend on energy intake, portion size and overall dietary patterns. Studies have also investigated the potential antidiabetic, antihyperlipidaemic and cardioprotective properties of Euryale ferox; however, these effects remain insufficiently established in humans and require further clinical validation [10].

3. Gluten-Free Suitability

Makhana is naturally gluten-free, making it a suitable ingredient for developing gluten-free food products.

However, to ensure suitability for individuals with coeliac disease, cross-contact with gluten-containing cereals must be prevented during harvesting, processing, milling, transportation and packaging. Appropriate handling practices and compliance with applicable gluten-free labelling requirements are therefore essential.

Research on makhana has examined its nutritional composition, potential health-related properties and applications in food and other industries. Studies have investigated its protein content, essential amino acids and antioxidant compounds, along with its possible antidiabetic, cardioprotective and anticancer effects. However, further research is required to establish these health-related effects in humans. Investigations into gluten-free food formulations, resistant starch and pharmaceutical applications have also highlighted the potential for wider utilisation of makhana.

Research Advances in the Nutritional, Functional and Food Applications of Makhana

Recent research has expanded the understanding of makhana beyond its traditional role as a food. Studies have focused on its nutritional characteristics, functional properties, the effects of processing and its suitability for developing value-added food products. Research has also explored the potential applications of makhana starch and its use in different industrial sectors. The major findings from selected studies are summarised in Table 3.

Table 3: Summary of research on the nutritional, functional and food applications of makhana

Research focus	Major findings and potential applications	Reference
Nutritional, medicinal and industrial importance	Reported an essential amino acid index of 93.63% and discussed the potential biological activities of makhana bioactive compounds. Its possible industrial applications include use as an adsorbent and in drug delivery systems.	[15]
Enzyme-assisted resistant starch production	Reported an increase in resistant starch content to 14.88% and amylose content to 12.33%, along with changes in crystallinity and starch digestibility. The findings indicate potential for developing food ingredients with modified functional properties.	[3]
Nutraceutical potential	Discussed the bioactive constituents of makhana and their proposed antioxidant, metabolic and other health-related effects. These applications require further scientific validation, particularly through human studies.	[18]
Physicochemical properties of *Euryale ferox* kernel starch	Reported an A-type diffraction pattern, low swelling power and temperature-dependent solubility. The study also explored the incorporation of kernel starch into bread formulations, with acceptable sensory characteristics reported at inclusion levels up to 20%.	[5]
Nutritional characteristics of roasted fox nuts	Reported a reduction in moisture content and changes in protein, phenolic compounds, flavonoids and mineral content following roasting. The study also assessed antioxidant activity and glycaemic index.	[14]
Nutritional, pharmaceutical and economic importance	Reviewed the nutritional composition of makhana, its antioxidant potential and biological activities reported in experimental research. The authors also discussed its possible applications in functional foods and pharmaceutical research.	[10]
Nutritional, therapeutic and market potential	Discussed the nutritional and traditional medicinal importance of makhana, its potential biological activities, and opportunities for export and value-added product development.	[16]
Development of gluten-free pasta	Developed a gluten-free pasta using semi-popped makhana flour, water chestnut flour and potato flour with carrot juice. The product exhibited reported nutritional and antioxidant characteristics, acceptable sensory scores and six-month storage stability under the conditions studied.	[19]

The findings presented in Table 3 indicate several important directions in makhana research. Studies on roasting have investigated changes in its nutritional composition, while investigations into kernel starch have explored its structural and functional properties for food processing. Enzyme-assisted resistant starch production represents another area of interest because it can modify starch digestibility and functional characteristics. In product development, the incorporation of semi-popped makhana flour into gluten-free pasta demonstrates the potential for diversifying its use beyond conventional roasted snacks.

Although several studies have discussed the antioxidant and other potential health-related properties of makhana, these findings should be interpreted according to the type of evidence available. Laboratory observations and experimental findings do not necessarily establish the same effects in humans. Further research is therefore needed to evaluate the bioavailability of bioactive compounds, the effects of processing on nutritional quality, and the health implications of regular consumption.

Overall, the available research highlights the potential of makhana as a versatile ingredient for developing value-added food products. Further investigations into processing techniques, ingredient functionality, sensory acceptability, storage stability and consumer preferences could support its wider application in the food industry.

Food-Industry Applications and Product Development

1. Roasted and Flavoured Snack Products

Roasting and seasoning can improve the sensory appeal of makhana and provide opportunities to develop different snack varieties. Roasted and flavoured samples have been reported to receive better sensory scores for texture, flavour, crispness and overall acceptability than unroasted samples. However, consumer preferences vary, and the levels of added salt, oil and seasonings should be considered during product development. Roasting also affects moisture content, colour, texture and bioactive properties, while shelf life depends on packaging, water activity, oxygen exposure and storage conditions [14].

2. Bakery Products: Cookies Containing Makhana Powder

Makhana powder has been used to replace 15%, 20% and 25% of refined wheat flour in cookie preparation. Among these formulations, cookies with 25% makhana powder received the highest overall acceptance score. The study also found differences in nutritional composition, mineral content, phenolic and flavonoid levels, antioxidant activity and selected amino acids compared with the control. Adding makhana powder offers an opportunity to develop new bakery products, but it may also affect dough handling,

spread, colour, texture and flavour. The most suitable level of incorporation may vary depending on the recipe and processing conditions. Further studies are needed to understand the product's shelf life, consumer preferences, production costs and nutritional quality before it is considered for wider commercial use [9].

Makhana can be used to prepare a range of food products, such as roasted and flavoured snacks, snack mixes, cookies, other bakery items, extruded snacks, cereal bars, convenience foods and traditional sweets. Makhana flour can also be combined with other flours to develop new products. However, its performance may vary depending on the type of food and the processing method used. Its porous structure, particle size and ability to absorb water and oil can affect the texture, processing and overall quality of the finished product. Therefore, each product needs to be tested and standardised to achieve the desired quality before commercial production.

The bran produced during popping is another possible ingredient stream. Since it has comparatively high fibre and phenolic content in this fraction, it may have potential for fibre enrichment [4]. Before commercial use, researchers should establish compositional consistency, microbial and chemical safety, sensory acceptability, functionality in different food matrices and an economically feasible collection system.

Packaging, Storage and Food Safety

Popped makhana is popular for its light and crispy texture, but it can become soft if it absorbs moisture from the air. Proper packaging is therefore necessary to maintain its crispness and protect it from dust, breakage and contamination. Packaging that limits exposure to oxygen and light may also help preserve quality, especially in flavoured products containing added fats or seasonings.

The effectiveness of packaging should be checked through shelf-life studies under suitable storage conditions. During these studies, changes in moisture, crispness, colour, flavour, chemical quality and microbial levels should be monitored. Different storage temperatures and humidity levels should also be considered to understand how they affect product quality over time.

Maintaining cleanliness during processing, using properly cleaned equipment and following hygienic handling practices are equally important. Although makhana is a dry product, poor handling, moisture exposure or damaged packaging can still lead to quality deterioration and contamination. Therefore, the shelf life should be established through testing of the actual product in its intended packaging rather than being assumed in advance.

Commercial Opportunities and Government Support

Makhana offers commercial opportunities through value-added products such as flavoured snacks, bakery products and traditional sweets. Product differentiation through regional identity, grading, roasting methods, flavours and attractive packaging can benefit farmers, processors, small enterprises and established food brands. However, the industry faces challenges such as geographically concentrated production, labour-intensive harvesting and processing, variable seed quality, limited mechanisation, and high transportation and storage costs. Improved processing equipment, quality grading, hygienic facilities, moisture-resistant packaging and reliable procurement systems can help reduce losses and improve market access.

The Government of India's initiatives for makhana development aim to improve production and productivity, modernise processing, encourage value addition, provide technical training and strengthen supply chains. The reported allocation of ₹476.03 crore for the Makhana Board in Bihar during 2025-26 should be verified against an official government source before publication. These initiatives also seek to strengthen domestic and international branding, improve packaging and expand export opportunities. Government support and market projections should be discussed using dated, reliable sources, with forecasts clearly identified as estimates [1].

Future Scope

Further research is needed to improve the processing, quality and commercial use of makhana-based foods. Raw materials should be standardised based on variety, maturity, moisture content and storage conditions, while roasting and popping methods need to be refined to achieve better expansion, texture, colour and nutrient retention. Consistent analytical methods are also important for obtaining reliable nutritional data. Further studies should examine how bioactive compounds change during processing, storage and digestion and larger human studies are needed to confirm potential health benefits.

The use of makhana bran and other processing by-products could also be explored to increase fibre content in foods and reduce waste. Suitable packaging and shelf-life studies under Indian storage conditions are needed to maintain product quality. In addition, consumer preferences, affordability, production costs, environmental effects and benefits to farmers should be considered when developing new products. Any nutrition or health claims made on product labels must be supported by scientific evidence and comply with applicable regulations. These efforts can help develop safe, consistent and commercially viable makhana-based products**.**

Conclusion

Makhana has been consumed traditionally for many years and offers opportunities for developing a variety of modern food products. Its carbohydrate-rich composition, low fat content and suitability for roasting and flour-based applications make it useful in snack and bakery product development. Studies have shown that processing methods such as roasting and popping can affect its texture, moisture content and measured bioactive properties. Makhana has also been successfully incorporated into roasted snacks and cookies with acceptable sensory quality.

However, maintaining consistent product quality requires suitable processing methods, hygienic handling, effective quality control and proper packaging. Further research is needed to better understand its potential health benefits. With improved processing techniques, reliable scientific evidence and better cooperation between farmers and processors, makhana can find wider applications in the food industry and support the development of diverse value-added products.

"Makhana bridges tradition and modern nutrition, positioning itself as a promising functional superfood for the future"**.**

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