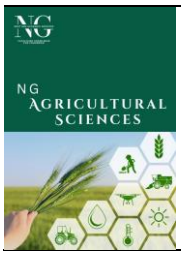

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Review Article

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A Review on Nutritional Quality, Bioactive Compounds and Value-Addition Potential of Kaji Nemu

Neha Saha[1], Hemlata Singh[1]*, Neelam Kumari[1], Jyostnarani Pradhan[2]

[1]College of Community Science, Dr. Rajendra Prasad Central Agricultural University, Pusa, Bihar, 848125, India
[2]College of Basic Sciences and Humanities, Dr. Rajendra Prasad Central Agricultural University, Pusa, Bihar, 848125, India

*Corresponding author email ID: hemlata@rpcau.ac.in

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ABSTRACT

Kaji Nemu or Assam lemon (*Citrus limon* L. Burm. f.) is an indigenous citrus type of Assam recognised for its elongated fruit shape, near-seedless character, strong aroma, high juice recovery and distinctive biochemical profile. Its Geographical Indication recognition and subsequent declaration as the State Fruit of Assam have increased scientific, commercial and policy interest in this crop. This narrative review synthesises the available literature on the origin, agroecological requirements, morphological uniqueness, nutritional composition, phytochemical constituents, therapeutic relevance, post-harvest handling, processing opportunities, and value chain prospects of Kaji Nemu. Evidence from recent studies indicates that the fruit is a valuable source of vitamin C, minerals, dietary fibre, pectin, phenolics, flavonoids and volatile compounds, particularly limonene-rich peel essential oil. These constituents support its potential use as a functional food ingredient, a natural flavouring agent, a nutraceutical resource, and a raw material for value-added products. However, claims related to disease prevention and curative effects require cautious interpretation because most available evidence is compositional, in vitro or based on broader citrus literature. Major constraints include limited standardisation of planting material, post-harvest losses, insufficient processing infrastructure, weak organised marketing and limited clinical validation of health benefits. Strengthening quality planting material systems, scientific post-harvest protocols, farmer-level processing, GI-based branding and evidence-based product development can enhance the economic and nutritional importance of Kaji Nemu while protecting its regional identity.

1. INTRODUCTION

Citrus fruits occupy an important position in human diets because they provide organic acids, vitamin C, minerals, fibre, flavour compounds and diverse secondary metabolites. Within this group, Kaji Nemu, popularly known as Assam lemon, has a special identity in North-Eastern India. It is deeply embedded in Assamese food culture and is commonly consumed with meals, fish preparations and traditional preserved products. Unlike many commercial lemons, Kaji Nemu is widely appreciated for its oblong shape, high juice content, pleasant yet intense aroma, low seediness, and characteristic acidity. These traits explain why it has moved beyond household use and is now discussed in relation to nutrition, nutraceuticals, food processing, essential oil extraction, GI-based branding and rural livelihood promotion.

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The current literature indicates that Kaji Nemu is not merely a culinary citrus fruit but a region-specific bioresource shaped by Assam's agro-climatic conditions. Reports cited by the authors show that the crop performs well under humid subtropical conditions, in slightly acidic alluvial soils, and in high-rainfall environments. Its biochemical value is linked to vitamin C, pectin, phenolic compounds, flavonoids, and peel essential oils, which are dominated by monoterpenes such as limonene. These compounds are relevant for antioxidant activity, flavour development, antimicrobial applications and food-product formulation. At the same time, the fruit's high moisture content and perishability create substantial post-harvest challenges, especially when production is concentrated during peak seasons and cold-chain access remains limited.

As an editorially publishable review article, the subject requires more than a descriptive account of recipes and crop features. A review must organise the evidence, identify what is known, distinguish scientifically supported claims from traditional uses, and indicate research and development gaps. Therefore, this rewritten article synthesises the authors' references and presents Kaji Nemu within a coherent review framework covering identity, production ecology, nutritional and phytochemical quality, health relevance, post-harvest management, value addition, and future research priorities.

2. REVIEW APPROACH AND SCOPE

This article follows a narrative review approach based on the references supplied by the authors. The literature includes scientific articles, book chapters, institutional reports, postgraduate research, and recent studies on Assam lemon morphology, nutritional composition, essential oil chemistry, antimicrobial activity, production trends, post-harvest management, and value addition. The review does not claim to be a systematic review because search databases, inclusion criteria, exclusion criteria and quality appraisal procedures were not originally documented. Instead, the article consolidates available evidence thematically and highlights areas where stronger experimental or clinical evidence is still required.

Table 1. Evidence mapping of cited literature on Kaji Nemu/Assam lemon

Theme	source	Key findings	Practical implication
Morphological and biochemical variability	Akhtar et al. (2024)	Reported variation in morphological traits, biochemical parameters, and seed availability pattern among Assam lemon accessions across Assam.	Supports germplasm characterisation, selection of superior accessions, and varietal improvement.
Nutritional and phytochemical value	Imchen et al. (2025); Rathour et al. (2024)	Assam lemon is described as a source of vitamin C, minerals, acidity, pectin, and bioactive compounds.	Helps position Kaji Nemu as a functional citrus fruit with nutritional and value-addition potential.
Antioxidant potential	Kumari et al. (2013)	Ripened and unripe citrus samples from Assam showed antioxidant activity associated with bioactive constituents.	Provides biochemical support for the development of nutraceutical and health-oriented products.
Essential oil composition	Paw et al. (2020); Deka et al. (2025)	Peel essential oil contains major volatile compounds, such as limonene and other monoterpenes, which contribute to its aroma and antimicrobial potential.	Supports the use of peel as a resource for food, cosmetic, pharmaceutical, and natural preservative applications.
Antimicrobial potential	Buragohain et al. (2023); Deka et al. (2025)	Endophytic bacteria and essential oils associated with Kaji Nemu showed inhibitory effects against selected microbial pathogens.	Indicates possible application in natural antimicrobial formulations and bioactive ingredient development.
Agro-climatic suitability and production ecology	Handique et al. (2022); Rathour et al. (2023); Imchen et al. (2025)	Suitable cultivation requires a subtropical humid climate, well-drained, fertile soils, and a slightly acidic soil pH.	Useful for area expansion, crop zoning, and climate-suitable production planning.

Area, production, and productivity trends	Baruah et al. (2025); Gogoi (2023); Swargiary et al. (2025)	Assam's lemon cultivation is showing increased area, production, and productivity in selected districts, such as Tinsukia.	Indicates commercial potential and scope for strengthening supply chains and farmer entrepreneurship.
Production and marketing constraints	Baruah et al. (2024)	Farmers face constraints in the production and marketing of indigenous Assam lemons.	Provides evidence for extension interventions, market linkage support, and policy assistance.
Post-harvest management and processing	Kashyap et al. (2023); Chetia et al. (2023)	Shrink wrapping, juice preservation, essential oil extraction, and coating applications can improve shelf life and reduce post-harvest losses.	Supports development of value-added products, peel utilisation, and loss-reduction strategies.
GI status, market identity, and value addition	Barua and Bharadwaj (2017); Baruah et al. (2024); Rathour et al. (2024)	Assam lemon has a unique identity, market positioning potential, and cultural value strengthened by GI recognition.	GI branding can enhance premium marketing, traceability, farmer income, and regional identity.
Seedlessness and reproductive biology	Zhang et al. (2012)	Seedlessness in lemon is associated with reproductive mechanisms such as parthenocarpy and related floral/fruit developmental traits.	Provides a conceptual basis for understanding seedless fruit development and breeding priorities.
Human health relevance of phenolics	Rahman et al. (2021)	Phenolic compounds have been reported to have roles in antioxidant activity and disease-related biological pathways.	Provides background justification for discussing phenolics in the context of functional foods.

3. ORIGIN, IDENTITY AND GEOGRAPHICAL SIGNIFICANCE

Kaji Nemu is described as an indigenous citrus type associated with Assam and the wider North-Eastern region. Rathour et al. (2023) traced its emergence to a clonal horticultural selection developed from material collected under the name China-kaghi and later vegetatively propagated as Kaji Nemu. The crop has acquired formal recognition through its Geographical Indication status, and the authors' draft notes that it was declared the State Fruit of Assam. These recognitions are important because they connect the fruit's biological uniqueness with territorial identity, farmer livelihoods, branding and market differentiation.

The GI identity is especially relevant for a crop whose quality is strongly linked to place. The aroma, acidity, rind character, juice content and consumer preference associated with Kaji Nemu are not independent of its production environment. Soil pH, rainfall, humidity, temperature, sunlight, nutrient status and cultivar purity can affect fruit quality. GI-based promotion, however, must be supported by quality standards, traceability systems and farmer-level awareness. Without such systems, GI recognition may remain symbolic and may not translate into premium pricing or export competitiveness.

4. AGRO-ECOLOGICAL REQUIREMENTS AND PRODUCTION CONTEXT

Assam lemon grows best under humid subtropical conditions with well-drained, fertile and slightly acidic soils. The pH range of 5.5-7.5 reported by Rathour et al. (2023) indicates the crop's suitability for many alluvial soils of Assam, provided waterlogging is avoided and nutrient management is balanced. Environmental conditions influence vegetative growth, flowering, fruit set, juice development, total soluble solids and acidity. Imchen et al. (2025) also emphasized that spatial variation in soil composition and climate can alter fruit quality parameters across districts.

The production context indicates increasing commercial relevance. The manuscript cites district-level evidence from Tinsukia showing expansion in area, production and productivity over recent years. Baruah et al. (2025) and Swargiary et al. (2025) further point toward the entrepreneurial and commercial potential of the crop. Yet expansion must be managed carefully. Increased area without quality planting

material, pest and disease management, post-harvest infrastructure and assured markets can increase farmer risk. Commercial development should therefore combine production intensification with processing, grading, aggregation and market-linkage interventions.

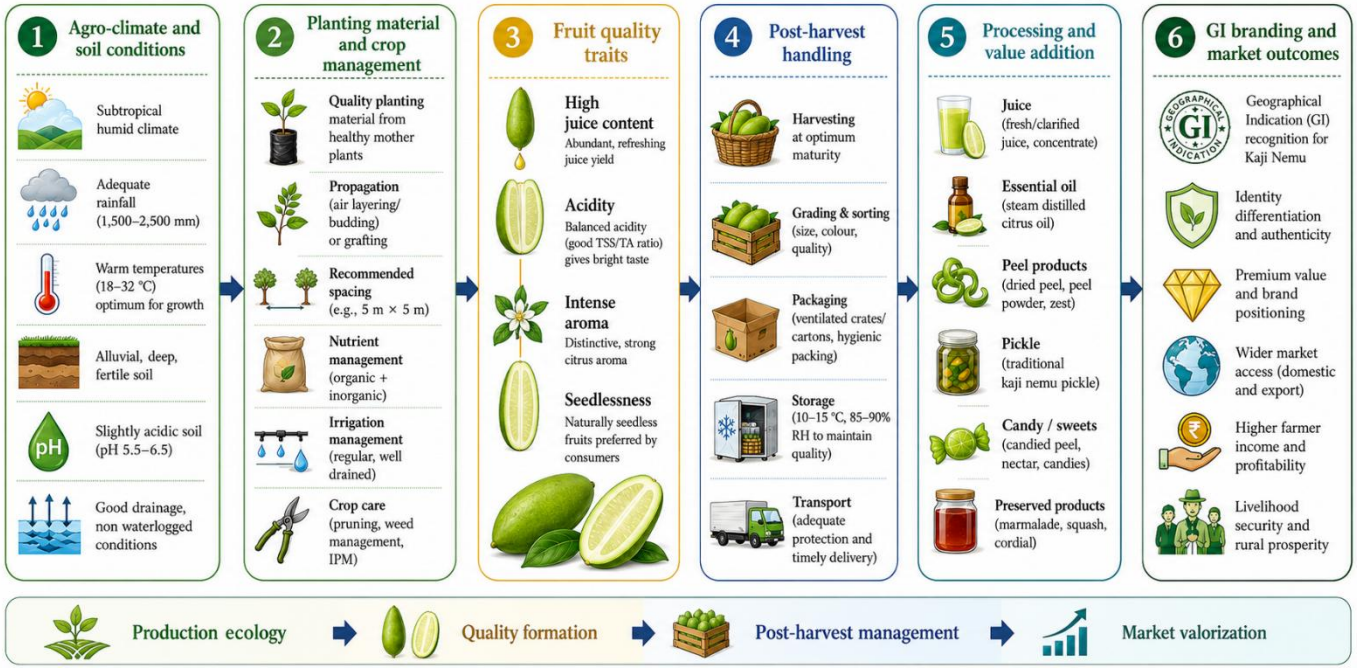

Figure 1. Agro-ecological and value-chain framework for Kaji Nemu

5. BOTANICAL AND MORPHOLOGICAL DISTINCTIVENESS

The distinctiveness of Kaji Nemu lies in a combination of morphological and sensory traits. The fruit is generally oblong or elongated, juicy, aromatic and nearly seedless. Akhtar et al. (2024) evaluated morphological traits, biochemical parameters and seed availability patterns among Assam lemon accessions, indicating that variability exists within available germplasm. Such variability is important for crop improvement because elite accessions may differ in fruit size, rind thickness, juice recovery, acidity, seediness and biochemical composition.

Seedlessness is one of the major consumer-preferred traits. The authors connect seedlessness with parthenocarpy, citing Zhang et al. (2012) on the mechanisms of seedlessness in lemon. While this provides a useful biological explanation, direct validation in Kaji Nemu accessions would strengthen the claim. From a breeding and propagation perspective, maintaining the desired near-seedless character requires clonal fidelity, careful selection of mother plants and avoidance of uncontrolled seedling propagation. Vegetative propagation through cutting, layering, budding or grafting is therefore more appropriate for commercial orchards than seed propagation when varietal uniformity is required.

6. NUTRITIONAL COMPOSITION AND FUNCTIONAL FOOD RELEVANCE

Kaji Nemu is nutritionally important because it contributes vitamin C, organic acids, minerals, dietary fibre and bioactive compounds. The data reproduced by Rathour et al. (2024) show higher vitamin C, fibre and calcium values when the fruit is considered with peel than without peel, which is consistent with the concentration of fibre, pectin and phytochemicals in citrus rind. The juice is acidic and low in sugar, making it useful as a flavouring and dietary ingredient. However, the nutritional interpretation should avoid overly broad language unless supported by comparative studies across multiple commercial lemon varieties. Vitamin C is a central nutritional attribute of citrus fruits. In Kaji Nemu, reported vitamin C values differ across studies due to maturity stage, sampling location, analytical method, peel inclusion, storage duration, and processing conditions. The review should therefore present values as ranges or source-specific estimates rather than fixed universal claims. Similarly, minerals such as potassium, calcium, phosphorus, magnesium, zinc, iron and copper may be present, but their nutritional contribution depends on actual intake quantity. Since lemon is consumed in small amounts, its role is more appropriately described as a micronutrient- and phytochemical-rich dietary adjunct rather than a stand-alone source of daily nutrient requirements.

Table 2. Nutritional composition of Kaji Nemu/Assam lemon

Nutrient	Reported value	Unit	Reference	Interpretation
Carbohydrates	10.70	g/100 g	Rathour et al. (2024)	moderate carbohydrate when peel is included.
Fat	0.31	g/100 g	Rathour et al. (2024)	Very low-fat content; low-fat fruit ingredient.
Fibre	4.70	g/100 g	Rathour et al. (2024)	Higher fibre level due to peel/rind contribution; supports peel-based value addition.
Calorific value	20.00	kcal/100 g	Rathour et al. (2024)	Low-energy fruit component; useful for low-calorie formulations.
Calorific value	29.00	kcal/100 g	Rathour et al. (2024)	Still low in calories, supporting dietary and functional food positioning.
Moisture	87.35	g/100 g	Rathour et al. (2024)	High moisture content explains juiciness but also indicates perishability.
Vitamin C	77.00	mg/100 g	Rathour et al. (2024)	Strong vitamin C contribution, especially when peel-associated components are considered.
Vitamin C	50–60	mg/100 ml	Imchen et al. (2025)	Supports its classification as a nutritionally valuable citrus fruit.
Pantothenic acid	0.23	mg/100 g	Rathour et al. (2024)	Minor contribution to B-vitamin intake.
Vitamin B6	0.10	mg/100 g	Rathour et al. (2024)	Low-level B6 contribution.
Calcium	62.00	mg/100 g	Rathour et al. (2024)	Peel inclusion substantially increases calcium value.
Potassium	144.00	mg/100 g	Rathour et al. (2024)	Potassium is one of the notable minerals in Kaji Nemu.
Phosphorus	15.00	mg/100 g	Rathour et al. (2024)	Minor phosphorus contribution.
Acidity as citric acid	44.61	mg/ml	Kumari et al. (2013)	High citric acid content contributes to sourness, preservation potential, and sensory identity.
Total acidity	3.0–3.3	% citric acid	Jyoti and Tanti (2024)	Confirms strong acidic character, important for flavour and processing suitability.
pH	2.0–3.0	pH scale	Jyoti and Tanti (2024)	Low pH supports sour taste and may help inhibit some spoilage organisms, though proper processing is still required.
TSS: acidity ratio	≥1.51	Ratio	Imchen et al. (2025)	Useful indicator of flavour balance and fruit maturity.
Pectin	NR	NR	Imchen et al. (2025)	Peel/rind is identified as a valuable pectin source for gelling and stabilising applications, but the exact value is not reported in the manuscript.

7. PHYTOCHEMICALS, PECTIN AND ESSENTIAL OIL CONSTITUENTS

The phytochemical profile of Kaji Nemu is central to its review value. Phenolic compounds and flavonoids are reported in citrus fruits and are associated with antioxidant activity. Rahman et al. (2021) discussed the role of phenolic compounds in human disease, but this evidence should be used as a mechanistic background rather than direct clinical proof for Kaji Nemu. Kumari et al. (2013) reported antioxidant activities in unripe and ripe citrus samples from Assam, supporting the view that maturity stage influences bioactive composition.

Pectin is another important component, especially in the rind. Citrus peel is a recognised source of pectin used for gelling, thickening and stabilising in food systems. Imchen et al. (2025) highlighted the relevance of pectin in Assam lemon, including its potential industrial applications. From a value-addition perspective, peel utilisation can reduce waste and generate additional products such as pectin extracts, candied peel, dehydrated rind powder and functional ingredients. Future studies should quantify pectin yield, degree of esterification, gel strength and extraction efficiency from Kaji Nemu peel under standardised conditions.

Table 3. Major phytochemicals and bioactive constituents reported in Kaji Nemu/Assam lemon

Compound	Plant part	Reported level or relative abundance where available	Functional relevance	Reference
Vitamin C / ascorbic acid	Fruit juice; whole fruit with and without peel	77 mg/100 g with peel; 53 mg/100 g without peel; approximately 50–60 mg/100 ml juice	Major antioxidant nutrient; supports nutritional value and functional-food positioning of Kaji Nemu.	Rathour et al. (2024); Imchen et al. (2025)
Phenolic compounds	Juice and edible fruit portion	NR	Contribute to antioxidant activity, free-radical scavenging and broader nutraceutical relevance.	Kumari et al. (2013); Rahman et al. (2021); Imchen et al. (2025)
Flavonoids	Juice, peel and edible fruit portion	NR	Associated with antioxidant, anti-inflammatory and cardioprotective potential in citrus-based diets.	Kumari et al. (2013); Rahman et al. (2021); Imchen et al. (2025)
Pectin	Rind/peel	NR; described as higher in peel/rind and valuable for gelling/stabilising applications	Useful as a natural thickening, gelling and stabilising agent in food processing; supports peel-based value addition.	Imchen et al. (2025); Rathour et al. (2024)
Essential oil fraction	Peel/flavedo	Over 40 compounds have been reported in the peel essential oil	Responsible for the characteristic citrus aroma and potential antimicrobial/value-added applications.	Paw et al. (2020); Deka et al. (2025); Chetia et al. (2023)
Limonene	Peel essential oil/flavedo	55.40% of the peel essential oil	The principal volatile compound contributing to citrus aroma, relevant for flavour, fragrance, cosmetic and antimicrobial applications.	Deka et al. (2025); Paw et al. (2020)
Neral	Peel essential oil/flavedo	10.39% of peel essential oil	Oxygenated monoterpene contributing to citrus aroma and possible bioactivity.	Deka et al. (2025)
Trans-verbenol	Peel essential oil/flavedo	6.43% of the peel essential oil	Contributes to the volatile profile and aromatic complexity of Kaji Nemu peel oil.	Deka et al. (2025)
Decanal	Peel essential oil/flavedo	3.25% of peel essential oil	Aldehydic volatile compounds contribute to fresh citrus aroma and sensory quality.	Deka et al. (2025)
Endophyte-associated antimicrobial metabolites	Fruit-associated endophytic bacteria	NR	Reported inhibition of selected microbial pathogens, suggesting possible natural antimicrobial potential.	Buragohain et al. (2023)

Essential oils extracted from the peel provide the aroma that distinguishes Kaji Nemu from many other lemons. Paw et al. (2020) and Deka et al. (2025) reported volatile oil composition, with limonene identified as a major component. Other constituents, such as nerol, trans-verbenol, and decanal, contribute to the sensory and antimicrobial profiles. Chetia et al. (2023) further demonstrated the application of Assam lemon peel essential oil in chitosan-based coating for maintaining grape quality, showing that the crop has relevance beyond direct consumption. These studies justify positioning Kaji Nemu peel as a functional by-product for food preservation, natural flavouring, packaging and cosmetic applications.

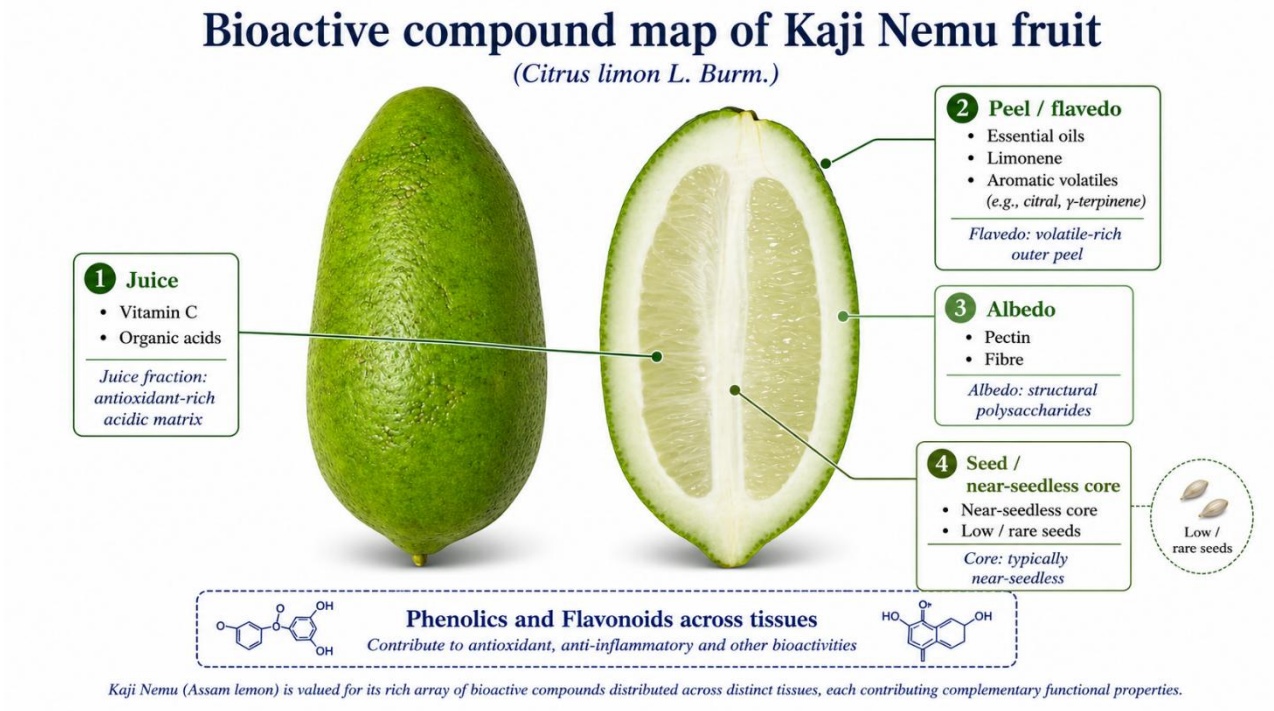

Figure 2. Bioactive compound map of Kaji Nemu fruit

8. HEALTH-PROMOTING POTENTIAL: EVIDENCE AND CAUTION

Kaji Nemu is traditionally valued for its digestive properties, freshness, appetite stimulation, and general wellness. Scientifically, its health-promoting potential is linked to vitamin C, organic acids, phenolics, flavonoids, fibre, pectin and essential oils. These constituents may contribute to antioxidant capacity, microbial inhibition, support of lipid metabolism, and improved palatability of diets. Nevertheless, an editor should ensure that the article does not present traditional or in vitro observations as established clinical effects. Terms such as 'curative', 'anti-cancerous' or 'disease-preventing' should be replaced with 'potential', 'reported', 'associated with' or 'requires further validation' unless human intervention trials are available.

The antioxidant relevance of Kaji Nemu can be discussed in terms of its vitamin C and phenolic content. These compounds can neutralise reactive oxygen species in chemical or cellular systems, but human health outcomes depend on bioavailability, dose, regular dietary intake and overall diet quality. Similarly, the antimicrobial activity reported for essential oils and endophyte-derived compounds is promising for food preservation and the development of natural antimicrobials, but it does not justify direct claims that eating Kaji Nemu treats infections. Buragohain et al. (2023) provide a useful basis for discussing microbial inhibition by compounds synthesised by endophytes associated with Citrus limon, while Deka et al. (2025) support the discussion of antimicrobial potential of peel essential oils.

Digestive benefits may arise from acidity, aroma, saliva stimulation and traditional dietary use, but strong therapeutic claims require controlled studies. Weight-management claims must also be framed cautiously. Lemon is low in calories and sugar, and its flavour may help improve the acceptability of low-energy diets, but it is not a weight-loss agent on its own. A publishable review should therefore treat Kaji Nemu as a functional dietary ingredient and nutraceutical candidate rather than as a proven medicine.

9. POST-HARVEST HANDLING, STORAGE AND QUALITY RETENTION

Post-harvest management is a critical weakness in the current Kaji Nemu value chain. The fruit has high moisture content and is susceptible to weight loss, shrivelling, mechanical injury, fungal spoilage and quality decline during storage. Kashyap et al. (2023) reported that shrink-wrapping individual fruits stored at room temperature can increase shelf life while helping retain freshness and firmness. Such low-cost technologies are relevant for farmers, traders and small processors because they can reduce loss without requiring sophisticated cold storage. Cold storage may not always be straightforward for lemons, as chilling injury, rind disorders, and

moisture loss can occur when temperature and humidity are not properly controlled. Therefore, post-harvest recommendations should include careful harvesting at appropriate maturity, avoidance of mechanical damage, field heat removal, sorting and grading, sanitation, suitable packaging, humidity management and market-oriented storage protocols. Where fresh marketing is difficult, processing into juice, pickle, dehydrated slices, peel candy, essential oil and pectin can reduce distress sales during glut periods.

Table 4. Post-harvest and processing options for Kaji Nemu/Assam lemon

Product	Raw material	Expected benefit	Suitable actor	Reference/source
Shrink wrapping of fresh fruits	Mature fresh Kaji Nemu fruits	Extends shelf life, reduces moisture loss, maintains firmness, freshness, and external appearance.	Farmer, FPO, local trader, processor	Kashyap et al. (2023)
Fresh juice extraction	Mature fruit juice	Converts surplus fruits into a usable liquid product; reduces raw-fruit wastage during peak season.	SHG, FPO, small processor	Kashyap et al. (2023); Rathour et al. (2024)
Juice pasteurization	Extracted Kaji Nemu juice	Improves safety and shelf life compared with untreated juice.	SHG, FPO, processor	Kashyap et al. (2023)
KMS-preserved juice	Extracted Kaji Nemu juice	Enhances microbial stability, delays spoilage, and supports longer storage of processed juice.	Processor, licensed FPO unit	Kashyap et al. (2023)
Sun-dried Kaji Nemu pickle	Whole fruit pieces with peel/rind	Traditional value-added product with longer shelf life, strong local identity, and household-level enterprise potential.	Farmer household, SHG, micro-enterprise	Traditional product described in manuscript; Rathour et al. (2024)
Peel candy/candied rind	Kaji Nemu peel/rind	Utilizes peel waste, creates a shelf-stable confectionery product, and improves value recovery from processing residues.	SHG, micro-enterprise, processor	Traditional/value-addition product described in manuscript; Rathour et al. (2024)
Essential oil extraction	Peel/flavedo	Produces aromatic oil for food flavouring, cosmetics, coatings, fragrance, and antimicrobial applications.	Processor, start-up, FPO with technical support	Paw et al. (2020); Chetia et al. (2023); Deka et al. (2025)
Pectin extraction	Peel/albedo/rind	Converts peel waste into a high-value gelling, stabilizing, and thickening ingredient for food processing.	Processor, research-backed FPO, food ingredient enterprise	Imchen et al. (2025); Rathour et al. (2024)
Dehydrated peel powder	Peel/rind after juice extraction	Provides a low-cost ingredient for flavouring, bakery, beverages, nutraceutical blends, and pectin/fibre-rich formulations.	SHG, FPO, small processor	Imchen et al. (2025); Rathour et al. (2024); Kashyap et al. (2023)
Chitosan-based coating using Assam lemon essential oil	Essential oil from peel; coating material	Demonstrates potential for natural coating systems and quality maintenance in perishable produce.	Processor, research institution, start-up	Chetia et al. (2023)

10. PROCESSING AND VALUE-ADDITION POTENTIAL

Processing is essential for converting Kaji Nemu from a seasonal fresh fruit into a year-round value-chain resource. The author's original manuscript included recipes for sun-dried pickle and rind candy. These should not dominate a review article, but they can be reframed as examples of value addition. Kaji Nemu pickle represents a traditional fermented or oil-based preservation approach, while peel candy demonstrates waste-to-value utilisation of rind. Both products have potential for household enterprises, self-help groups and small-scale food businesses if hygiene, packaging, labelling and shelf-life testing are standardised.

Juice preservation is another promising pathway. Kashyap et al. (2023) indicated that heat treatment and potassium metabisulfite can extend juice shelf life by reducing microbial spoilage, although storage can reduce ascorbic acid and alter pH, acidity and total soluble solids. This highlights the trade-off between safety, shelf life and nutrient retention. Future product development should compare pasteurisation, cold filling, chemical preservation, freezing, high-pressure processing and natural preservative systems in terms of sensory quality, microbial safety, vitamin retention and consumer acceptance.

Peel-based value addition deserves stronger scientific and commercial attention. Essential oil extraction can support applications in flavour, cosmetics, aromatherapy, and edible coatings. Pectin extraction can support the food industry. Dehydrated peel powder may be used as a flavouring, a fibre-rich ingredient, or a natural preservative. However, all such products require quality standards, residue testing, extraction optimisation, packaging compatibility and market feasibility analysis before large-scale commercialisation.

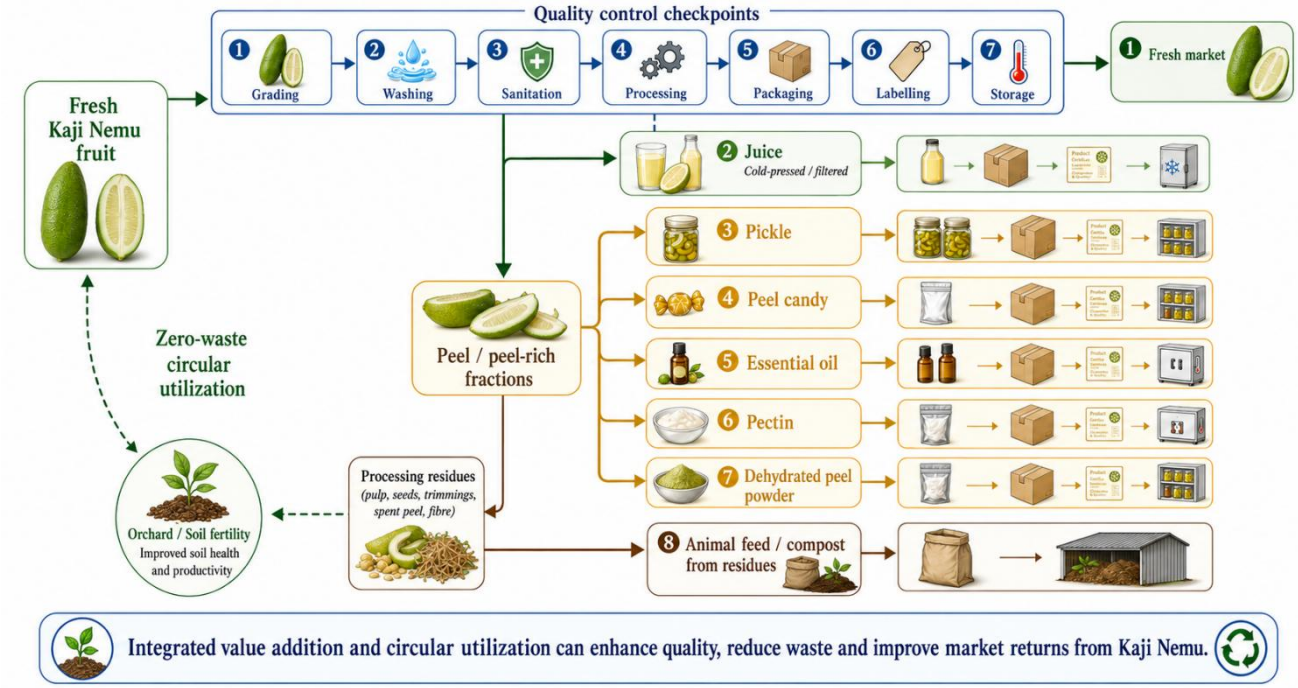

Figure 3. Kaji Nemu value-addition pathway

11. MARKET, GI BRANDING AND LIVELIHOOD OPPORTUNITIES

The commercial future of Kaji Nemu depends on aligning production with market systems. GI status can provide differentiation, but it does not automatically ensure farmer income. Branding must be accompanied by producer registration, traceability, quality grading, standard packaging, collective marketing and protection against misuse of the name. Farmer Producer Organisations, self-help groups and small processors can play important roles in aggregation, primary processing, branding and direct marketing.

Baruah et al. (2024) discussed constraints in the production and marketing of indigenous Assam lemon farming. Such constraints are likely to include input access, technical knowledge, price fluctuations, post-harvest losses, processing limitations, and market intermediaries. Addressing these constraints requires extension support, training on orchard management, nursery certification, low-cost storage,

value-addition entrepreneurship and digital market linkages. A well-designed GI value chain should ensure that the benefits of regional branding reach growers rather than being captured only by traders or downstream firms.

12. RESEARCH GAPS AND FUTURE PRIORITIES

Although the available literature supports the uniqueness and value of Kaji Nemu, several research gaps remain. First, varietal identity and clonal purity need stronger documentation through morphological descriptors and molecular characterisation. Second, nutritional and phytochemical values should be reported using standardised sampling, maturity stages and analytical protocols. Third, comparative studies are needed to determine how Kaji Nemu differs from other lemons in terms of vitamin C, acidity, volatile composition, pectin quality, and sensory acceptability. Fourth, health-related claims require cell-based, animal and human studies before nutraceutical positioning can be made responsibly.

Post-harvest and processing research should focus on low-cost technologies that are usable by farmers and small enterprises. Shelf-life studies should include microbial safety, weight loss, firmness, colour, sensory quality, acidity and vitamin C retention. Product development studies should examine consumer acceptance, packaging, labelling, food safety compliance, and cost-benefit analysis. Finally, socio-economic research should assess profitability, the adoption of recommended practices, marketing constraints, women-led processing enterprises, and the real income effect of GI branding.

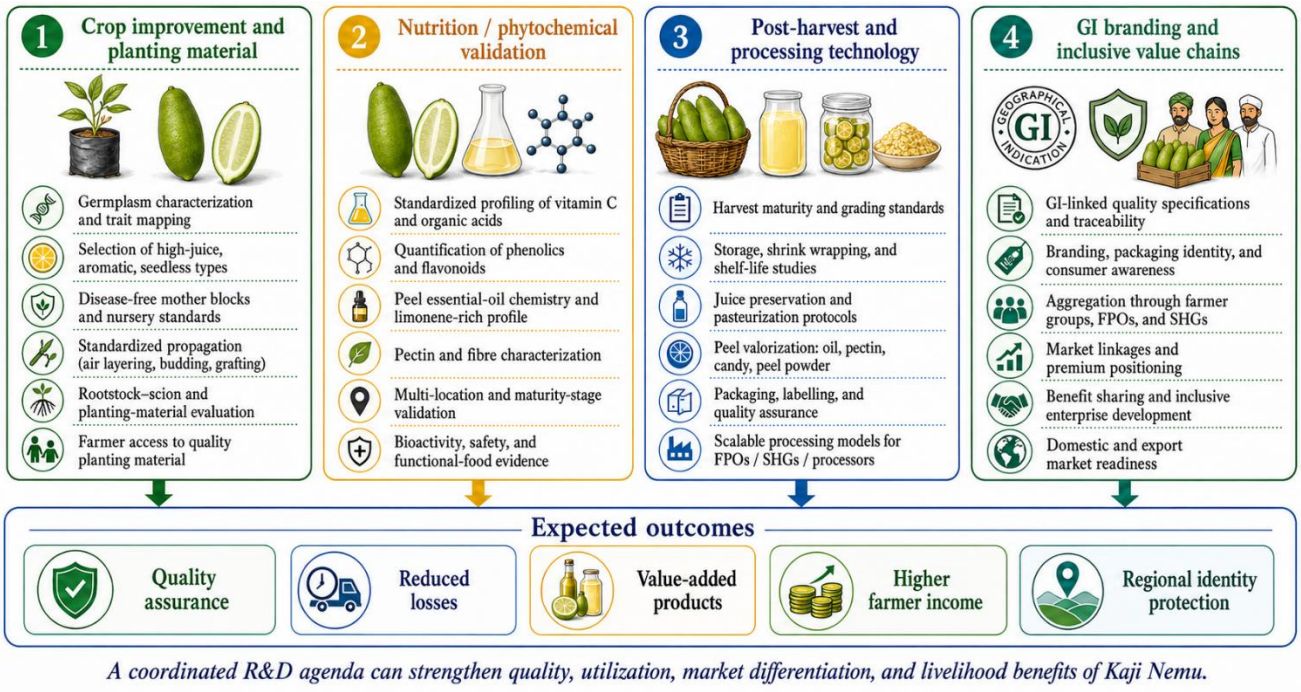

Figure 4. Research and development roadmap for Kaji Nemu

13. CONCLUSIONS

Kaji Nemu is a culturally significant and commercially promising citrus fruit of Assam with distinctive morphological, sensory, nutritional and phytochemical attributes. Its GI recognition and status as the State Fruit of Assam provide a strong foundation for regional branding, but scientific and market development must now move beyond descriptive appreciation. The available evidence supports its value as a vitamin C-rich, aromatic, low-sugar and phytochemical-containing citrus fruit with potential applications in functional foods, natural flavouring, essential oil extraction, pectin production and small-scale value-added products. However, therapeutic claims must be expressed cautiously until supported by stronger biological and clinical evidence. The most practical pathway for strengthening Kaji Nemu is an integrated strategy combining high-quality planting material, improved orchard management, post-harvest loss reduction, hygienic processing, utilisation of peel by-products, GI-based branding, and farmer-centred value-chain development. With appropriate research, extension and enterprise support, Kaji Nemu can become not only a symbol of Assamese food heritage but also a scientifically validated and economically viable citrus resource.

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