



Challenges in Cultivation and Market Integration: An Analytical Review of the Agronomic and Commercialization Hurdles Facing *Cucumis metuliferus*

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ABSTRACT

Cucumis metuliferus (Kiwano, Horned Melon, African Horned Cucumber) is a novel fruit crop originating from sub-Saharan Africa, recognized for its distinctive appearance, nutritional potential and inherent resilience. Despite these promising attributes, its widespread commercialization and optimized agronomic management remain significantly underdeveloped compared to established cucurbit crops. This analytical literature review synthesizes current knowledge to identify and critically examine the primary problems impeding the transition of *C. metuliferus* from a minor, specialty item to a broadly cultivated and commercially successful crop. Key agronomic challenges include overcoming substantial genetic variability, optimizing cultivar selection for commercially desirable traits (uniformity, flavour, yield), developing standardized cultivation practices suitable for diverse environments, managing species-specific and general cucurbit pests and diseases and addressing pollination requirements. From a commercialization perspective, the hurdles are equally significant, encompassing limited consumer awareness and acceptance, establishing efficient and cost-effective supply chains for a highly perishable product, navigating inconsistent market demand and pricing and a general lack of infrastructure supporting minor crop development. The intricate interplay between suboptimal agronomy leading to inconsistent supply and quality and market immaturity hindering investment in cultivation improvements, creates a detrimental feedback loop. Furthermore, the limited depth of dedicated research compared to major crops restricts the availability of empirical data needed for evidence-based decision-making in both cultivation and market development. This review highlights the urgent need for targeted research efforts focusing on plant breeding, sustainable agronomic systems, post-harvest technology and market analysis to unlock the full commercial potential of *C. metuliferus*.

Key words: Climate-smart crop, Commercialization, *Cucumis metuliferus*, Plant breeding, Post-harvest, Value-chain challenges.

Crop species that are underutilized constitute an important repository of genetic material and adaptive potential especially given the global climate change and the urgent agricultural diversification imperative. One of them, *Cucumis metuliferus* E. Mey. ex Naudin (also known as kiwano, horned melon, or African horned cucumber), a species of the family Cucurbitaceae endemic to arid and semi-arid areas of sub-Saharan Africa has become a species of vital modern concern (Ling *et al.*, 2021). Although it is historically treasured as a drought-resistant staple food and important source of water, it has in the last few decades become an exotic novelty fruit with developing niche markets in Europe, North America, Australia and New Zealand (Mwanza *et al.*, 2023). The visual impression of it, however, the orange, spiny, rind and green, jelly-like pulp, has fixed its position in the history of decorative and gastronomic interest.

In addition to its novelty, *C. metuliferus* has a set of agronomic and nutritional characteristics which stress its potential as a robust and useful crop. It is relatively resistant to abiotic stresses like drought and heat, as well as their resistance to certain soil pathogens, which make it suitable to grow in more and more variable climatic conditions (Sebati *et al.*, 2024). The fruit contains a lot of water, the necessary minerals (potassium, magnesium), vitamin C and antioxidant carotenoids, which is beneficial in terms

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of nutrition (Soare *et al.*, 2024). Besides, its genetic profile has valuable breeding programs as a possible source of resistance genes that can be used to make other related commercial species more resistant such as *C. sativus* (cucumber) and *C. melo* (melon) more than their resistance gene sources (McCarthy *et al.*, 2010). All of these features

make *C. metuliferus* a viable crop diversification option, which would lead to nutritional security and agricultural sustainability both in temperate and tropical ecosystems (Chis-Junior *et al.*, 2015; Mutetwa *et al.*, 2026).

However, the achievement of this potential is limited by a complicated system of interconnected agronomic and commercial obstacles. Agronomic challenges comprise the inability to predict the yield, inconsistent quality of the fruit and absence of efficient procedures of intensive or machine-based farming (Diouf and Sambou, 2023; Mutetwa *et al.*, 2025a). A low shelf-life, physical sensitivity and lack of cold-chain infrastructure are post-harvest issues with the potential to severely restrict scalable distribution and export potential (Makule *et al.*, 2022). In the business world, *C. metuliferus* has not been able to expand into mainstream markets due to lack of standardized grading, disjointed value chain and limited awareness about the product (Manjunathagowda and Pitchaimuthu, 2023; Mutetwa *et al.*, 2025).

Thus, it is high time to integrate what is known so far and critically examine these complex issues in order to find some possible ways of development. The proposed analytical review will be an attempt to critically analyze the agronomic and commercialization challenges that confront the move of *C. metuliferus* as a promising underutilized species to a commercial crop. With a combination of contemporary studies on its cultivation, genetics, post-harvest management and market dynamics, this paper aims to clarify the major interdependencies within the production-consumption system, reveal the key research and policy gaps and suggest the priorities in applying *C. metuliferus* to more resilient and sustainable agricultural systems.

Conceptual framework and research design

Conceptual framework

The review is guided by a conceptual framework according to which commercialization of *C. metuliferus* is the complex system limited by a circle of interconnected problems. The model is constructed on the assumption that agronomic and market viability are dependent on each other. Limitations in one area are directly reinforced by weaknesses in the other which further strengthens the self-perpetuating obstacle to mainstream adoption. The framework is in essence based on a vital stagnation cycle where agronomic problems remain unresolved like non-standardized cultivation methods, unreliable yields and post-picking losses, all result in an unreliable and infrequent supply of quality fruit. This unreliable supply deters investment by participants in the value chain creating a poorly developed infrastructure in the market, no grading mechanisms and low consumer awareness. These poor market signals and unpredictable returns, in their turn, provide minimal economic motivation to farmers or researchers to work on solving the underlying agronomic issues. The only way out of this cycle is focused and synergistic developments in three interdependent pillars:

Agronomic and genetic innovation: Increasing the stability of yields, quality of fruits and their post-harvest life by means of elevated standards of cultivation criteria, breeding and control.

Development of market systems: The development of efficient value chains, the establishment of quality standards, the establishment of market linkages and the generation of consumer demand.

Supportive institutional climate: Policies, research agenda and extension services should be developed to be active in empowering and encouraging the production and marketing process.

The framework is the analytical tool of the current review and it coordinates the available literature to locate the points of bottlenecks in this cycle as well as the points of strategic leverage that could be used to make interventions.

Research design

The methodology used in the paper is an analytical literature review, which is aimed at synthesizing and critically assessing the status quo of knowledge on *C. metuliferus*. In contrast to a systematic review, thematic and narrative synthesis of a wide variety of sources is to be prioritized in this approach in order to create a coherent picture of the field, the predominant themes of the literature and to determine gaps and contradictions in the literature.

Extensive search of the available academic and grey literature was performed through the participation of major scientific databases (such as Scopus, Web of Science and Google Scholar) and materials of related agricultural organisations. Search terms were based on the scientific or common name of the species along with the words concerning the area of cultivation, agronomy, after the harvesting period, the market and commercialization. The literature review focuses on the last 20 years, although foundational studies are also provided where applicable.

Thematic analysis was done on the identified literature. The main results were identified and based on the pillars of the conceptual framework (agronomic, market, institutional), they were consensus-based, evidence-based and applicable. This narrative synthesis makes it possible to combine various kinds of evidence-controlled agronomic experiments and socioeconomic case studies, respectively, to form a comprehensive vision of the obstacles to commercialization. The result is the critical analysis identifying the current body of knowledge, explaining the interdependence of the existing issues and offering a justifiable background about the future research and development priorities in order to promote *C. metuliferus* as a sustainable commercial crop.

Agronomic challenges

The subject of transformation of *C. metuliferus* as an abandoned, semi domesticated agronomic crop to an economically viable and permanent agronomic commodity is a complicated matter due to complicated factors of agronomic problems. These are those problems that affect all its production processes that entail safeguarding its genetic features, successful germination of the plants, the

adequate administration of the resources needed, the problem of the toxic pests and maintenance of quality upon harvesting. The overall knowledge of such confining conditions is highly significant in the creation of sufficient cultivation policies that could be put to the use of generating quality and cumulative harvests persistently. Since *C. metuliferus* is at the rather young phases of agricultural evolution, as compared with other more well-developed cucurbits, it is of particular difficulty in terms of the genetic system, precise physiological requirements and the interaction with the environment.

Genetic variability and cultivar development

C. metuliferus possesses high genetic variation that is a tremendous drawback in chances of commercialization. Being a relatively wild species, it is not homogenous in its physical traits and the latter does not vary even when commercially-obtained seeds were used (Maluleke, 2022; Grumet *et al.*, 2021). This variation affects virtually all the agronomically essential traits, such as the size and shape of fruits, their colour, taste, produce and maturity duration (Soare *et al.*, 2024; Owino *et al.*, 2020). The availability of this rich gene pool is an asset to the breeders, however, it is a huge burden to the producer who desires uniformity in sorting and packaging and consumers need to meet the demand of the market.

This lack of uniformity can be reduced to the fact that the crop was not given much attention during the conventional breeding methods. *C. metuliferus* has not undergone extensive genetic augmentation compared to the highly sophisticated foods, e.g. cucumbers (*Cucumis sativus*) or melons (*Cucumis melo*). The situation that has come about has been non-heterogeneous seed population by the growers or random local decision with no extensive information on its performance in different environments. Breeding, with reduced seediness, color-uniformity, improved flavour, resistance to particular pests and diseases and extended shelf life, will be a highly prioritized and heavily financed endeavor to come up with elite cultivars to sell to the modern market. It is fundamental to determine the varieties that are adapted to the pests, diseases and environmental conditions that do not exist in its native habitat.

The development of such improved cultivars is a long process limited by the high costs as well as the biology of the plant. The rate of improvement is slowed down by factors like prolific seed production, long selection cycles and complicated genetics of desirable traits. Modern methods such as molecular breeding may be used to hasten the process, but they are still in the early phases of their application in *C. metuliferus*. As a result, the issue of attaining consistent quality of fruits and effective production has been the major constraint to the success of the crop along the value chain.

Optimizing cultivation practices

C. metuliferus has no obvious and standardized cultivation practices unlike its close relatives in the cucurbit family.

Although the plant will grow well in warm and semi-arid climates (Muthoni and Shimelis, 2024), we are yet to comprehend its optimal growing conditions. Vital specifications; like preferred temperature range, day length sensitivity, specific water requirement and nutrient requirements have not been well stipulated.

Soil and water management

C. metuliferus can survive drought conditions, but commercial production requires constant irrigation of high yields and quality fruit (Ozbahçe *et al.*, 2014). Unstable soil moisture may inhibit growth, decrease fruit set and decrease the quality of the pulp (Atique-ur-Rehman *et al.*, 2025). On the other hand, overwatered or poor drainage situations in irrigated areas may cause waterlogged soils that favor root diseases and other physiological problems (Café-Filho, 2019). The lack of research on the water-use efficiency of the crop and the timing of irrigation that is the most crucial is the reason why one of the primary challenges is the development of evidence-based water management procedures.

Nutrient management

Information on the optimal fertilization of *C. metuliferus* is also not available. Growers typically extrapolate fertilizer programs from other cucurbit crops, an approach which has not been scientifically proven for this crop. When nutrients are applied inappropriately, the fruit may grow poorly, with excessive foliage, off-flavours and low marketable yields. Moreover, scheduling operations to coincide with the growth periods of the plant is mostly an estimate, which in most cases leads to inefficient nutrient acquisition and the wastage of resources. In order to enhance sustainable agriculture, it is necessary to conduct research on the specific soil fertility requirements of this crop. However, like many other smallholder farmers, most do not test the soil due to poor awareness and the cost associated with soil testing (Dabesa *et al.*, 2022).

Canopy management and support systems

As a vining plant, *C. metuliferus* requires either significant ground space or a support structure for a healthy canopy. Trellising offers clear advantages, including improved air circulation to reduce disease, cleaner fruit kept off the soil and easier harvesting. However, its high material and labor costs can be prohibitive for many small-scale producer. The less expensive alternative of ground cultivation increases the risk of soil-borne diseases, fruit damage and pest problems (Victor and Julius, 2018). Therefore, research comparing the economic and agronomic trade-offs of various training systems is crucial to guide producers at all scales.

Pest and disease management

Despite its relative durability within the cucurbit family, *C. metuliferus* is vulnerable to a host of pests and diseases, including common insects and various fungal and viral infections (Lebeda *et al.*, 2024). This vulnerability is

heightened in monoculture farming, where the plant's natural defenses can be overcome.

Protecting the crop is hindered by a lack of specific research, forcing a reliance on management strategies borrowed from other cucurbits like cucumbers. This approach is potentially flawed, as the distinct biology of *C. metuliferus* could lead to different interactions with pathogens and treatments. Consequently, robust Integrated Pest Management (IPM) programs are underdeveloped, with significant knowledge gaps concerning resistant cultivars, economic thresholds and safe control options.

A further complication is the absence of specifically approved pesticides, which compels growers to use products 'off-label', a practice that raises safety, environmental and legal concerns. Foundational research into disease epidemiology, vector dynamics and genetic resistance is therefore essential for developing effective breeding programs and IPM strategies.

Pollination issues

Although *C. metuliferus* produces both male and female flowers (Sebati *et al.*, 2024), it depends on insects, primarily bees, for fruit production. A successful harvest, therefore, relies on a healthy pollinator population and suitable environmental conditions to support it (Rweyemamu *et al.*, 2024). Pollination and fruit retention are severely limited when bee activity is low or when adverse weather, such as extreme heat, heavy rain, or high winds, disrupts flowering.

This dependence on pollinators creates significant risk for farmers, particularly in enclosed environments like greenhouses that exclude insects. The main alternative, hand-pollination, is a labor-intensive process that is impractical for large-scale operations. As global pollinator populations decline, ensuring reliable crop pollination is an increasingly critical challenge. Research into viable alternatives, such as introducing managed bee colonies or using attractants, remains scarce but is vital for future crop stability.

Harvesting and post-harvest handling

Post-harvest handling and harvesting

Some of the challenges that are linked to the post-harvest management of *C. metuliferus* include the following: Its prickly covering should be manipulated thoughtfully so as not to injure the workers and spoil the product, itself (Seregelj *et al.*, 2022). Defining the best time to harvest is a difficult process because the fruit does not become ready simultaneously, the color is not appropriate measure and the fruit is eaten as a vegetable and fruits when immature and matured, respectively. The outcome of this uncertainty is typically early harvesting which leads to poor flavor, or late harvesting which leads to over-softening and rotting.

Besides, the species is highly sensitive after picking. Saving the fruit at low temperatures could lead to chilling injury; rind pitting, off-flavors and enhanced microbial spoilage. On the other hand, warm weather accelerates

the metabolic degradation (Muthoni and Shimelis, 2024). Despite these sensibilities, little has been addressed in the research of the optimum conditions of storage like temperature and humidity besides packaging. The fruit is also difficult to carry because of its prickly skin that is easily punctured or abraded in the normal containers.

This kind of inconsistent quality following harvest is an extreme limit to market expansion since retailers desire uniform shelf existence, uniform look and inferior product replacement (Adewoyin *et al.*, 2022). After all, the quantity of production can never increase to reach higher commercial success without the development of trustworthy post-harvest commercial returns.

Commercialization challenges

Even though one may ignore agronomic issues, a distinct group of issues is involved when introducing *C. metuliferus* to a greater market in terms of consumer perception, supply chain management logistics and market-economic factors.

Market acceptance and consumer awareness

C. metuliferus is a comparatively new product in the world market despite the fact that it has been cultivated in sub-Saharan-African countries since long ago. The visual appearance of the fruit, which is spiny and of an orange color, is not only good but also repulsive. Its ripeness, taste or even how it is cooked is not familiar to the first time consumer hence they are not sure how they can appraise its ripeness. This lack of direction may discourage a number of impulse purchases, along with reducing the chances of a consumer making a repeat purchase (Barcanu *et al.*, 2022).

C. metuliferus lacks a definite place in the cuisines of most nations compared to common fruits which have their predetermined uses. This food will be less accepted because the consumers cannot incorporate the fruit into their daily diets due to the lack of a clear undertaking in the kitchen. The knowledge gap can be filled by outreach to consumers in the form of recipes, nutrition and taste demonstrations. However, such promotion activities require financial investments, which in most cases are impossible to make by these small-scale producers and niche distributors where most of its supply chain resides (Chen *et al.*, 2021). Moreover, the low level of production that is in place fails to introduce significant individual investment in marketing and it becomes a vicious circle of consumer little recognition and low demand.

Supply chain and logistics

Securing a reliable supply of *C. metuliferus* is significantly hampered by its biological traits and current farming practices. Production is often fragmented, occurring on many small, spread-out farms or in very specific environments (Mabhaudhi *et al.*, 2017). This scattered approach naturally leads to variable and unpredictable yields (Sebati *et al.*, 2024), making it difficult to meet the steady quantities and consistent quality demanded by both retailers and wholesalers.

After harvest, additional hurdles arise, especially due to the fruit's delicate nature. While its thorny skin protects it on the vine, it also makes the fruit prone to damage during transport if not carefully packaged. Moreover, maintaining quality post-harvest requires storage under controlled temperatures to prevent dehydration and spoilage. However, in many growing areas, the necessary cold-chain facilities are either scarce or too expensive for farmers to afford. These combined logistical demands drive up the cost per fruit for packaging and shipping. Consequently, profit margins shrink and the fruit struggles to compete with established crops that benefit from more streamlined supply chains.

Economic viability and market volatility

The economic feasibility of cultivating *C. metuliferus* on a large scale faces considerable doubt due to elevated operational expenditures and unpredictable market conditions. This crop necessitates meticulous, labor-intensive cultivation practices. A substantial portion of the financial outlay is attributed to tasks such as the construction and maintenance of trellises, the intricate process of harvesting, diligent pest management, crucial post-harvest treatments and, in certain instances, manual pollination (Dhillon and Moncur, 2023). These inherent costs are amplified by the crop's variable yields, which are highly susceptible to environmental factors like weather fluctuations, the prevalence of pest infestations and the inherent genetic variability within the species. For those engaged in cultivation, this interplay of significant upfront investment and inconsistent output translates into a considerable financial risk.

This budgetary risk is enhanced by the fact that the fruit is a niche product in the high-end market. Consumer demand in this industry is volatile and easily influenced by the changing trends, time of the year buying patterns and media coverage. This brings a fluctuating market where prices swing. An excess will lead to price fall because of absence of wide and uniform consumer demand. On the other hand, unreliable supply will build mistrust towards the retailer as they will be reluctant to hold the fruit.

Making this risk more severe is the fact that, in general, there is no support system that can protect producers against market volatility, e.g., marketing boards, forward contracts or guaranteed pricing arrangements. This exposes the producers and naturally, they are hesitant to increase their businesses without better guarantees of making a good and consistent profit on their investment.

Lack of standardized grading and quality metrics

The major issue that is present in the *C. metuliferus* market is lack of standard grading system; a tool that is central to most other market crops. In the absence of a consensus on the physical traits of such products as dimension, coloring, maturity and defects, quality measurement is subjective (Prasad *et al.*, 2018). This causes disputes

between what is thought of as a good product by farmers, distributors and consumers. This complicates the business process, increases the logistics expenses and tends to create tension regarding the acceptance of products (Natarajan and Ponnusamy, 2023). The research world is not an exception to this problem. The unavailability of objective measurements serves as a dead end to breeders of plants and physiologists, who require tangible measurements to monitor genetic gains and determine whether new methods of farming are indeed effective.

Competition from established fruits

The introduction of *C. metuliferus* into the commercial fresh produce sector places it in direct competition with mature market segments, specifically those occupied by globally recognized staples such as melons, citrus, stone fruits and established exotic varieties. These incumbent commodities benefit from substantial historical investment spanning decades, resulting in optimized sensory characteristics, streamlined production efficiencies and deeply established brand loyalty (Marappan *et al.*, 2025). This comprehensive optimization ensures product consistency and competitive pricing, thereby satisfying fundamental consumer expectations for reliability and cost-effectiveness.

While the inherent novelty of *C. metuliferus* may generate transient consumer interest, this initial curiosity is generally insufficient to establish persistent market traction. Successful integration into the mainstream requires the communication of a clear and distinct competitive advantage. This differentiation must manifest as a tangible benefit, such as superior nutritional density, unique flavor profiles, or specific functional properties.

A critical challenge rests in effectively communicating these unique attributes to the target audience to overcome the pre-existing barrier of unfamiliarity. In the absence of substantial promotional funding or a proactive market outreach strategy, *C. metuliferus* is likely to be overshadowed by established products within comparable pricing tiers. This dynamic severely limits its capacity for achieving widespread commercial scaling, irrespective of its unique sensory and nutritional composition.

Interplay between agronomy and commercialization

The challenges facing *C. metuliferus* in terms of agronomy and commercialization are inextricably linked, rather than independent. Inadequate agronomic knowledge and practices directly contribute to inconsistent yields, variable fruit quality and increased production costs (Gammanpila *et al.*, 2024; Ngoone and Shelton, 2020). These resulting inefficiencies and expenses consequently impede the development of reliable supply chains and the ability to offer the product at competitive market prices (de Brauw and Bulte, 2021).

Conversely, the restricted size and inherent uncertainty of the commercial market deter significant investment in agronomic research, breeding programs and critical

infrastructure, such as specialized packing houses and cold storage (Ayele *et al.*, 2020). Growers, therefore, show less inclination to adopt potentially costly best practices (e.g., trellising or specific IPM strategies) when market returns are either uncertain or insufficient to offset the added expenditure (Do *et al.*, 2020). This situation establishes a detrimental feedback loop where agronomic limitations inhibit market expansion and market constraints, in turn, hinder agronomic improvement. Overcoming this cycle demands coordinated efforts spanning the research, production and marketing sectors.

Potential solutions and future directions

To successfully bring *C. metuliferus* to the wider market, we must address its limitations through a unified, multi-faceted strategy. This involves synergizing developments in plant breeding, cultivation methods, post-harvest technology and the organization of its supply chain. The crop's difficulties are rooted in both its biology and its economics; therefore, building a sustainable future for it means creating a bridge between research, farming, processing and sales. By connecting these areas we can escape the current situation where poor output and a lack of investment reinforce one another.

Plant breeding and selection

One of the long term goals in the development of agriculture is to produce improved varieties that are specifically geared towards the large commercial production of agriculture. This need is highlighted by the global food security challenges that are being enhanced by the increasing population and hence the over exploitation of the genetic resources. Nonetheless, these important resources are being depleted at a rate of alarm because of anthropogenic factors, such as climate changes, pollution, genetic extinction and mismanagement Zerihun, (2022). Present germ vegetable matter of *C. metuliferus* exhibits high genetic heterogeneity (Esteras *et al.*, 2011). This natural variability directly leads to variability in the size and coloring of the fruits, as well as inconsistencies in the taste and even ripening, which do not meet the demands of consumers, who need a consistent quality of products (Grumet *et al.*, 2021).

Accordingly, future breeding initiatives ought to concentrate on developing cultivars that exhibit greater uniformity, intensified flavor, a reduced seed count and prolonged post-harvest viability (Sebati *et al.*, 2024; Muthoni and Shimelis, 2024). Furthermore, establishing robust resistance to significant pests and diseases is crucial, especially when the species is cultivated outside its native habitat. By harnessing the genetic diversity present in natural populations and integrating advanced breeding techniques, such as marker-assisted selection and genomic selection, the creation of high-performing cultivars suitable for modern agricultural systems can be considerably expedited (Sharma *et al.*, 2025). These genetic advancements are anticipated to mitigate risks associated with cultivation, guarantee consistent fruit quality and strengthen industry confidence.

Optimized agronomic research

Achieving reliable and high-volume *C. metuliferus* output necessitates addressing fundamental gaps in its cultivation knowledge. Given the species' distinct physiological characteristics, established horticultural guidance for related cucurbit crops proves insufficient. Therefore, conducting focused field trials across diverse agro-ecological zones is crucial to define optimal agronomic practices, including irrigation, fertilization regimes, plant spacing, structural support and integrated pest management strategies (Bashyala *et al.*, 2022). Furthermore, migrating cultivation into controlled environments, such as greenhouses, presents a promising avenue (Ahmed *et al.*, 2024). Such settings permit precise regulation of temperature, humidity and pest pressures, which could significantly enhance yield consistency and extend the harvesting period (Nakayama *et al.*, 2024). These research endeavors are essential for generating the empirical data required to elevate this crop from its current semi-wild status to a commercially viable and dependable agricultural product.

Advances in post-harvest technology

Improving the transformation of the *C. metuliferus* fruit from farm to consumer critically depends on enhancing post-harvest handling. A significant challenge lies in the fruit's inherent vulnerability to deterioration and damage from thermal fluctuations. To mitigate this, future investigations should prioritize establishing objective criteria for determining peak harvest ripeness, moving beyond the current reliance on subjective visual cues which contributes to inconsistent product quality (Geerthik *et al.*, 2024).

Controlled environment studies are imperative to identify the ideal storage parameters, specifically temperature, humidity and atmospheric composition, that will effectively decelerate senescence and maintain the fruit's organoleptic and nutritional integrity during transit. Additionally, engineering specialized packaging that buffers the fruit from physical abrasion, particularly due to its spiky exocarp, would substantially reduce post-harvest waste and enhance consumer appeal (Lin *et al.*, 2022).

Implementing standardized, quantifiable quality assessment tools, potentially utilizing metrics such as colorimetry, firmness measurements, or spectral analysis, would introduce greater uniformity throughout the supply chain. This would not only optimize operational workflows and minimize disputes among stakeholders but also foster increased consumer trust and confidence in the product.

Market development and consumer education

A primary barrier to the widespread adoption of *C. metuliferus* is limited consumer awareness, which necessitates proactive market development initiatives (Tee, 2014). Key efforts should focus on communicating the fruit's versatility in culinary applications, its distinctive sensory profile and its nutritional benefits. To accelerate its assimilation into mainstream gastronomy, promotion can be

achieved through expert cuisine demonstrations, strategic partnerships within the restaurant industry and engagement with digital food media platforms. Moreover, providing clear, informative retail labeling that includes preparation instructions, recipe suggestions and storage guidelines can alleviate consumer fears. Such interventions are vital for both stimulating initial purchases and fostering repeat consumption (Bomfim *et al.*, 2020).

Value-added processing and product diversification

Developing a varied portfolio of fruit-derived products presents a compelling strategy for stabilizing market demand and mitigating the inherent volatility of the fresh fruit sector, often exacerbated by seasonal fluctuations. Such diversification could encompass the creation of fruit-based beverages, preserved goods, savory accompaniments, fermented items, fruit pulps and natural flavoring agents. Moreover, fruit processing offers a viable avenue for utilizing produce that falls short of stringent fresh market quality standards, thereby reducing post-harvest waste (Goswami *et al.*, 2024). To fully realize this potential, further investigation is warranted into the behavior of key constituents, including bioactive compounds, natural colorants and aroma compounds, throughout the processing and storage phases. The establishment of successful fruit processing enterprises also has the capacity to stimulate economic development within agricultural communities, leading to enhanced financial returns for growers and providing a vital safeguard against unpredictable market dynamics (Shubalyi and Kosinski, 2020).

Economic analysis and decision-support tools

For growers to commit resources to cultivating a new crop, they require actionable economic insights. An analysis detailing input expenses, labor requirements, the break-even point and financial risks associated with market volatility empowers farmers to make informed decisions regarding crop viability. Furthermore, simulating the economic implications of different cultivation methodologies, such as trellising versus ground-level farming, or open-field versus greenhouse environments, can identify optimal strategies for enhancing productivity. This type of data serves a dual function, it provides the evidentiary basis for attracting private investment and assists policymakers in formulating targeted support initiatives.

Collaboration, policy support and knowledge transfer

The transition of a crop from laboratory development to market realization necessitates a coordinated, collective endeavor. This collaborative process requires the synergistic engagement of researchers, farmers, agricultural extension agents, industry stakeholders and governmental representatives. Through mutual cooperation, these entities can jointly develop practical cultivation guidance tailored to the specific needs of the crop, forge stronger market linkages and accelerate the adoption of novel technologies

Governmental support, whether through research funding, incentives for value-adding enterprises, or investment in refrigerated supply chains, is indispensable for overcoming the initial challenges of scaling production. Moreover, establishing formal mechanisms for knowledge exchange, such as grower associations or participatory research projects, will enhance our capacity to adapt practices based on evolving understanding.

CONCLUSION

The species *C. metuliferus* currently represents an underutilized agricultural commodity, yet one with substantial inherent value due to its demonstrated cultivation stability, promising nutritional profile and favorable commercial attributes. Despite this recognized potential, broad-scale commercial development is significantly impeded by a confluence of interdependent challenges. These constraints include extensive genotypic heterogeneity, the lack of well-established best practices for field management (suboptimal agronomic protocols), rapid deterioration after harvest and underdeveloped supply chain infrastructure. Collectively, these limitations perpetuate a negative feedback loop characterized by suppressed yields and inadequate business investment. To realize its capacity, focused, coordinated interventions are essential. This requires critical investments in genetic improvement programs (germplasm enhancement), adaptive research to refine production techniques and innovations in post-harvest handling and preservation technologies. Moreover, enhancing market viability mandates concurrent efforts to improve consumer literacy, establish value-added processing capabilities and secure supportive regulatory and policy mechanisms. Therefore, the implementation of specific, interdisciplinary initiatives, bridging expertise in plant breeding, sustainable production systems and value chain establishment, is required to successfully transform *C. metuliferus* from a localized specialty item into a resilient crop contributing substantially to agricultural diversification, nutritional security and broader ecological sustainability.

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Informed consent

This is a review article based on published literature and does not involve any human or animal participants, therefore informed consent is not applicable.

Conflict of interest

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