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Development of Quality Criteria and Proposed Specification Limits for Moringa Leaf Powder Through an Integrated Stakeholder and Evidence-Based Approach

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Abstract: The absence of quality standards for moringa leaf powder has caused product variability, limiting consistency, competitiveness, and industrial use. This study developed quality criteria using the FACTS framework, integrating stakeholder priorities (via Exponential Comparison Method across 24 participants) with laboratory characterization of samples from five Indonesian regions. Stakeholders prioritized food safety, sensory quality, and nutritional consistency. However, food safety parameters were excluded as they are already regulated by Indonesian Food and Drug Authority (BPOM). Laboratory data revealed high variability in fineness (CV = 28.83%) and acid-insoluble ash (CV = 52.67%). Benchmarking against Kenya Standard KS 2848:2019 confirmed compliance for moisture and acid-insoluble ash, while fineness, ash, protein, and color required local specifications. Using Adopt–Adapt–Originate, acid insoluble ash was adopted (≤ 0.5%); moisture and fineness adapted; and ash, protein, and color originated. Stakeholder expectations (protein ≥ 27%; moisture ≤ 8%) exceeded empirical thresholds (≥ 23%; ≤ 10%), resolved through inclusive limits supporting a future tiered system. Proposed specifications, i.e. color (green to bright green), moisture (≤ 10%), ash (≤ 13%), acid-insoluble ash (≤ 0.5%), protein (≥ 23%), and fineness (≥ 80% passing 100-mesh) provide a scientific foundation for moringa powder standard in national level.

Keywords: FACTS framework; Moringa leaf powder; Quality criteria; Specification limits; Standard development

Introduction

Moringa (*Moringa oleifera*) leaf powder has gained increasing attention as a promising functional food ingredient due to its high nutritional value and rich bioactive compound content (Yang et al., 2023). Produced through drying and milling processes, moringa leaf powder possesses a relatively long shelf life and can be incorporated into a wide range of food products. The powder is recognized as a valuable source of protein, essential minerals such as calcium, iron, and magnesium, and various bioactive compounds including flavonoids, polyphenols, and provitamin A, all of which contribute to its nutritional and functional properties (Aminah et al., 2015; Helmiati et al., 2020; Pawenrusi et al., 2019; Yadav, 2023).

These characteristics position moringa leaf powder as a strategic raw material for developing nutrient-enriched food products, particularly those intended to address nutritional deficiencies and support public health interventions aligned with national nutrition programs. The incorporation of moringa leaf powder into food products has been shown to improve nutritional quality while maintaining acceptable physicochemical and functional characteristics, supporting its role as a fortification ingredient in diverse food matrices, including bread and other baked goods where moringa leaf powder has been shown to improve nutritional composition while maintaining consumer

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acceptability (Chaniago et al., 2025; Govender & Siwela, 2020; Pawenrusi et al., 2019; Sinaga et al., 2023; Tafu & Jideani, 2022; Trigo et al., 2023).

In Indonesia, the relevance of nutrient-dense food ingredients is further emphasized by persistent nutritional challenges, including stunting, which remained at 21.5% in 2023, exceeding the national target established in the National Medium-Term Development Plan (RPJMN) (KEMENKES RI, 2023). As a locally available resource with high nutritional potential, moringa offers an attractive option for supporting food diversification and nutrition improvement programs. Moreover, moringa cultivation is well suited to Indonesian agroecological conditions, requiring relatively low agricultural inputs and allowing year-round harvesting, and can be propagated efficiently through stem cuttings under various growing media and plant growth regulator treatments (Refiyani et al., 2021). These advantages provide opportunities for value addition and agro-industrial development, particularly among Small and Medium Industries (SMIs). Several community-based programs have demonstrated moringa leaf powder's potential as a complementary food ingredient to address stunting and micronutrient deficiencies among toddlers in Indonesia (Afriza et al., 2023; Agus & Ismawati, 2018; Jannah et al., 2023; Putri et al., 2026; Sukenti et al., 2020). However, inconsistent product quality resulting from the absence of clear quality standards could undermine the effectiveness of moringa-based nutritional interventions, as variable protein and nutrient content would lead to inconsistent dosage delivery in stunting management and supplementation programs.

Beyond its domestic significance, moringa leaf powder also demonstrates considerable economic potential in international markets, aligning with SDG 8 (Decent Work and Economic Growth), SDG 9 (Industry, Innovation and Infrastructure), and SDG 12 (Responsible Consumption and Production). The global moringa market continues to expand, driven by increasing consumer demand for plant-based and health-oriented products. Although Indonesia has experienced growth in moringa exports in recent years, product competitiveness remains constrained by inconsistent quality and the absence of harmonized quality specifications. In international trade, compliance with recognized quality requirements is essential not only for market access but also for maintaining product credibility, consumer trust, and supply chain consistency (Kaa, 2023; Susanto et al., 2017). The development of a national quality standard for moringa leaf powder is therefore a necessary step toward supporting sustainable agro-industrial development and enhancing Indonesia's position in the global market.

One of the central challenges impeding the sustainable commercialization of moringa leaf powder is the substantial variability in product quality among producers. Differences in cultivation practices, post-harvest handling, drying techniques, milling operations, and storage conditions can significantly affect the physicochemical, nutritional, sensory, and safety characteristics of the final product (Firdausiyah & Hariono, 2024; Paramita et al., 2021; Tjalo et al., 2024). Bassey (2024) reported that only a small proportion of commercial moringa products exhibited phytochemical profiles consistent with authentic moringa leaves, highlighting concerns regarding product quality and authenticity. Similarly, variations in flavonoid content have been observed among moringa samples originating from different geographical regions, indicating that environmental and processing factors may contribute to significant differences in product composition (Jayani et al., 2020). Such variability presents fundamental challenges for producers, regulators, and consumers seeking assurance of product quality and consistency, and underscores the urgent need for a comprehensive, evidence-based quality standard (Purwoko et al., 2020).

From a quality engineering perspective, the absence of a comprehensive and scientifically validated national standard for moringa leaf powder represents a critical gap in the product development and commercialization pathway. While existing Indonesian Food and Drug Authority (BPOM) regulations address certain food safety requirements, they provide limited guidance on physicochemical specifications, nutritional quality criteria, and acceptable ranges of product variability (Susanto et al., 2019). As a result, producers often rely on individual quality practices, leading to inconsistent products, difficulties in establishing uniform benchmarks, and barriers to industrial-scale adoption, market competitiveness, and export expansion.

Despite the growing body of research on the nutritional composition, bioactive compounds, functional properties, and food applications of moringa leaf powder, previous studies have primarily focused on product characterization and utilization rather than the development of comprehensive quality criteria and specification limits. Although several international organizations have established quality requirements for moringa products, such as Kenya Standard KS 2848:2019 and Philippine National Standard PNS/BAFPS 109:2012, these standards vary considerably in scope, and no comprehensive national standard integrating physicochemical specifications, nutritional quality criteria, and sensory requirements has been formulated in the Indonesian context. This represents a significant gap: existing BPOM safety regulations and scattered international references do not collectively provide the structured, evidence-based foundation necessary for

Indonesian moringa leaf powder standardization. Moreover, no previous study has combined stakeholder prioritization, laboratory characterization, and international benchmarking within a single standard-development framework for this product.

To address this gap, the present study adopts an integrated stakeholder- and evidence-based approach to develop quality criteria and proposed specification limits for moringa leaf powder. The study is structured using the Framework for Analysis, Comparison, and Testing of Standards (FACTS), which provides a systematic pathway for standard development through stakeholder analysis, technical evaluation, standard comparison, and validation processes (Susanto & Kristiningrum, 2021). Within this framework, stakeholder prioritization using the Exponential Comparison Method (MPE), laboratory characterization of moringa leaf powder samples from five Indonesian production regions, international benchmarking against recognized standards, and stakeholder validation are integrated to establish scientifically justified and practically applicable quality specifications. The novelty of this study lies in its systematic integration of multi-stakeholder priorities, empirical laboratory evidence, and international benchmarking within the FACTS framework using the Adopt–Adapt–Originate classification approach, a combination not previously applied to moringa leaf powder standardization in Indonesia. The findings are intended to provide a scientific foundation for future national standard development, improve product consistency across the moringa industry, facilitate regulatory alignment, and enhance the competitiveness of Indonesian moringa leaf powder in both domestic and international markets, thereby contributing to the sustainable development goals related to nutrition security, responsible production, and inclusive industrial growth.

Method

Study Design and Research Framework

This study employed a mixed-methods approach that combined qualitative and quantitative data to develop quality criteria and proposed specification limits for moringa leaf powder. The research was guided by the Framework for Analysis, Comparison, and Testing of Standards (FACTS), a standard development framework adapted from the National Institute of Standards and Technology (NIST) and previously applied in standards-related studies (Susanto et al., 2019, 2020). FACTS was selected because it offers a structured and evidence-based process for developing standards by integrating stakeholder perspectives, scientific findings, benchmark references, and validation activities (Suprapto et al., 2020).

The overall research framework is presented in Figure 1. In line with the FACTS framework, the study was carried out through four interconnected stages: stakeholder analysis, technical analysis, standard comparison, and standard testing and refinement. The process began with stakeholder analysis, which aimed to identify and prioritize quality attributes considered important for moringa leaf powder. Information was gathered through literature review, stakeholder interviews, focus group discussions (FGDs), and prioritization using the Exponential Comparison Method (MPE).

The next stage focused on technical analysis through laboratory characterization of moringa leaf powder samples collected from different production regions in Indonesia. The laboratory results provided empirical evidence on the physicochemical characteristics and quality variation of products currently available in the market. These findings were then compared with relevant international standards and market requirements through a benchmarking process to identify appropriate quality references and specification ranges.

The final stage involved testing and refinement of the proposed specifications through stakeholder validation. At this stage, the Adopt–Adapt–Originate (A–A–O) approach was used to determine whether existing quality requirements should be directly adopted, adjusted to local conditions, or developed based on empirical evidence and stakeholder consensus. Through this process, the study produced quality criteria and proposed specification limits that reflect both scientific considerations and practical industry needs.

By bringing together stakeholder input, laboratory evidence, international benchmarking, and validation activities within a single framework, the FACTS approach provided a comprehensive basis for developing quality specifications for moringa leaf powder. This integration helped ensure that the proposed criteria were not only scientifically sound but also relevant, feasible, and aligned with the needs of the Indonesian moringa industry.

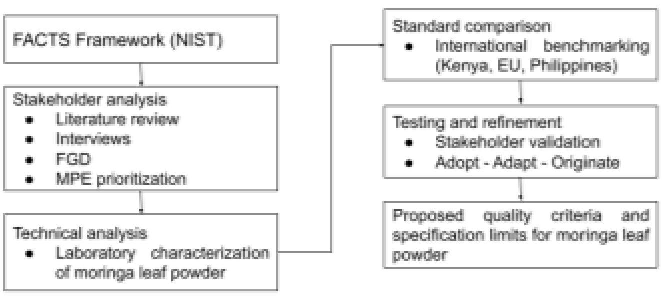

Figure 1. Research framework

Study Area, Participants, and Sample Collection

The study was conducted between December 2025 and May 2026. Moringa leaf powder samples were collected from five major production regions in Indonesia, namely Medan (North Sumatra), Blora (Central Java), Karangasem (Bali), Kupang (East Nusa Tenggara), and Palu (Central Sulawesi). These locations were selected purposively to represent different geographical conditions, production practices, and agro-industrial characteristics. Stakeholder data were collected from 24 purposively selected participants representing four stakeholder groups involved in the moringa value chain, namely consumers, producers, government representatives, and experts. The purposive sampling approach was used to ensure that participants possessed relevant knowledge, experience, or involvement in moringa production, utilization, regulation, or quality assessment.

Laboratory analyses were conducted at the Center for Standardization and Agro Industry Services (BBIA), Bogor, Indonesia. Five independent samples were collected from different producers to represent regional variability in Moringa leaf powder quality. During transportation and storage, the samples were packed in food-grade airtight bags and protected with light-impermeable packaging to minimize exposure to oxygen, moisture, and light, thereby preserving their quality and nutritional characteristics. The samples were stored in a cool, dry environment away from direct light and analyzed as soon as possible. Each independent sample was analyzed in duplicate to ensure analytical reliability. Consequently, a total of ten analytical determinations (n = 10) were obtained for each quality parameter.

Data Sources and Collection Procedures

Both primary and secondary data were utilized in this study. Primary data were obtained through stakeholder interviews, focus group discussions (FGDs), and laboratory analyses of moringa leaf powder samples. Secondary data were collected from Indonesian National Standards (SNI), international standards, scientific publications, technical regulations, and other relevant reference documents. The study began with a literature review to identify quality parameters commonly used for moringa leaf powder evaluation, analytical methods, and benchmark quality requirements. Information was compiled from SNI documents, international standards, AOAC official methods, scientific literature, and market requirements from major importing countries. The review provided the initial basis for identifying potential quality attributes and benchmark criteria.

Stakeholder engagement was subsequently conducted through semi-structured interviews and FGDs. Participants were asked to evaluate the importance of various quality factors and parameters, identify acceptable quality levels, and provide input regarding practical implementation of quality standards. Qualitative information obtained from these activities was used to validate and refine the quality attributes identified from the literature review. Laboratory characterization was performed on moringa leaf powder samples obtained from the five production regions. The analyses focused on selected physicochemical parameters prioritized during stakeholder consultations. Standardized analytical procedures were applied, and each parameter was tested in duplicate to improve measurement reliability. The laboratory results provided empirical evidence regarding the quality variation of moringa leaf powder currently available in Indonesia.

Data Analysis

Qualitative data obtained from interviews and FGDs were analyzed using thematic analysis. Responses were coded, categorized, and synthesized to identify recurring themes and stakeholder perspectives regarding important quality attributes and quality requirements for moringa leaf powder. Quantitative data were analyzed using descriptive statistical methods, including mean, median, standard deviation, coefficient of variation, minimum value, maximum value, and percentile distribution. These analyses were performed using Microsoft Excel and R Studio to describe the variability and distribution of each quality parameter. The Exponential Comparison Method (MPE) was applied to determine the relative importance of quality factors and quality parameters. MPE is a multi-criteria decision-making approach that uses an exponential function to amplify differences between alternatives, producing extreme contrast and providing clearer prioritization compared to linear methods such as SAW or AHP. In the MPE formula, each criterion score is raised to the power of its assigned weight (importance rank), and the results are summed to obtain the total score for each alternative (Yusnita et al., 2024). The total score for each alternative was calculated using Equation (1).

$$\mathrm{TN_i} = \sum_{j=1}^{m} (\mathrm{RK_{ij}})^{\mathrm{TKKj}} \tag{1}$$

Where:

TN_i = total score of alternatives i

RK_{ij} = Relative degree of importance of criterion j for decision alternative i

TKK_j = Relative degree of importance (weight) of criterion j; $TKK_j > 0$

n = number of decision alternatives

m = number of decision criteria
i = 1, 2, 3, …, n
j = 1, 2, 3, …, m

After calculating the total scores, the results were normalized and ranked to classify the quality parameters into primary and supporting attributes for the development of standard concepts. An integrative analysis was subsequently conducted by combining stakeholder priorities, laboratory findings, and international benchmark standards. Benchmarking was performed against selected international references, including Kenya Standard KS 2848:2019, Philippine National Standard PNS/BAFPS 109:2012, and requirements for the European moringa market (Bureau of Product Standards, 2012; Centre for the Promotion of Imports from developing countries (CBI), 2022; Kenya Bureau of Standards, 2019). Finally, an Adopt–Adapt–Originate (A–A–O) approach was applied to formulate proposed quality criteria and specification limits. Parameters supported by established international standards were adopted directly, parameters requiring contextual adjustment were adapted, and parameters lacking benchmark specifications were originated based on laboratory evidence and stakeholder consensus. This approach enabled the development of quality criteria that were scientifically grounded, contextually relevant, and feasible for implementation within the Indonesian moringa industry.

Result and Discussion

Stakeholder Composition and Perception

The study involved 24 purposively selected stakeholders representing four key groups in the moringa leaf powder value chain, namely consumers, business actors, government representatives, and experts. The composition consisted of 7 consumers (29%), 5 business actors (21%), 5 government representatives (21%), and 7 experts (29%), indicating a relatively balanced representation across regulatory, industrial, scientific, and end-user perspectives. The stakeholder composition is presented in Figure 2.

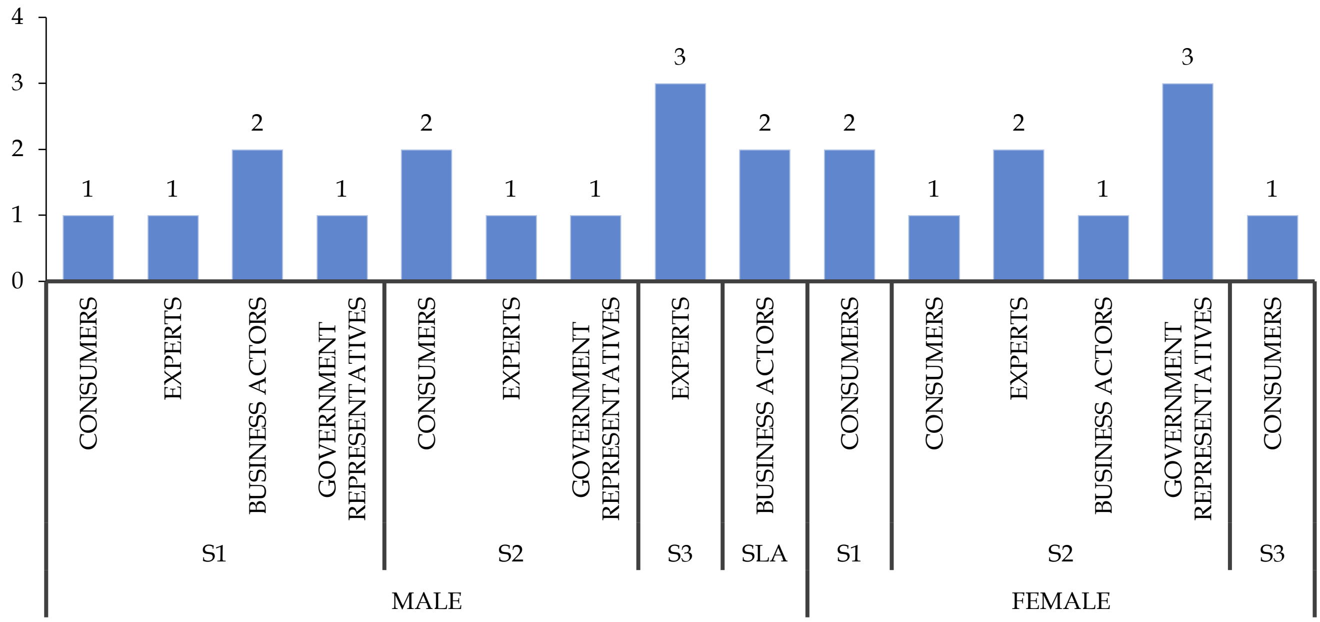

Figure 2. Stakeholder composition

This balanced stakeholder structure plays an important role in developing the concept of quality standards, because standard formulation is not only about technical accuracy, but also about how well it can work in real practice. A good standard needs to consider several things at once, including technical feasibility, regulatory requirements, industry capabilities, and consumer expectations. In the Indonesian National Standard (SNI) system, this kind of multi-stakeholder and consensus-based approach is essential so that the final standard is not only scientifically valid, but also acceptable and implementable in the field (Badan Standardisasi Nasional, 2022).

Each stakeholder group brings a different but equally important perspective. Consumers generally focus on sensory aspects such as taste, aroma, appearance, and perceived safety. Producers tend to emphasize production efficiency, consistency, and cost considerations. Government representatives are more concerned with regulatory compliance and alignment with national standards, while experts contribute scientific justification and methodological accuracy. When these perspectives are combined, they help ensure that the proposed standard is more balanced, realistic, and applicable across different contexts. In addition to evaluating the importance of developing a quality standard for moringa leaf powder, respondents were also asked about the type of standard they consider most appropriate for implementation. This is important because the form of the standard will determine how flexible and practical it is when applied in the industry. The options given included a single standard and a graded (tiered) standard. The results show a very strong agreement on the need for a formal quality standard, with all respondents (100%) supporting its development. Most of them (79%) considered it is very important, while the remaining 21% rated it as important; as shown in Figure 3.

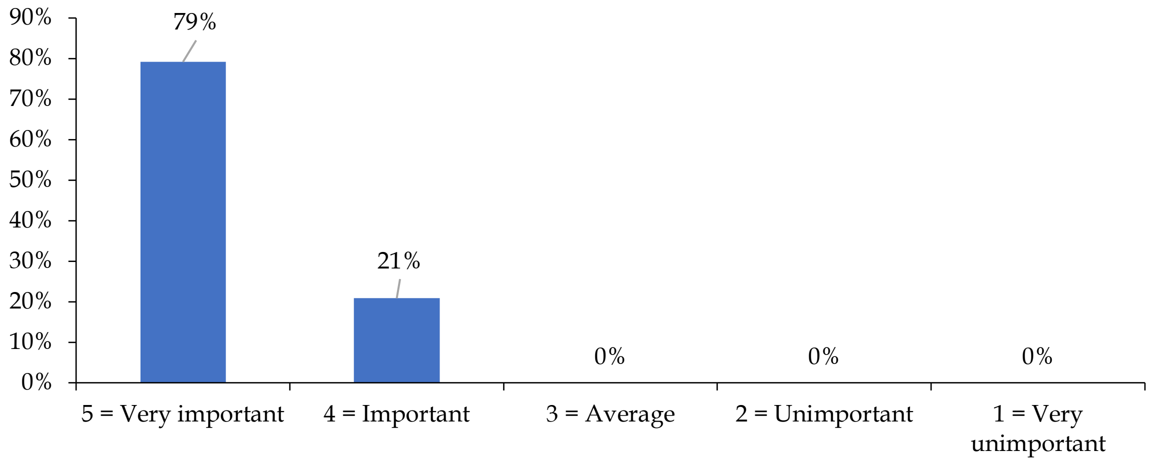

Figure 3. Level of importance of standard development

Regarding the preferred form of standardization, 71% of respondents indicated a preference for a graded (tiered) standard system, while 29% favored a single standard, as shown in Figure 4.

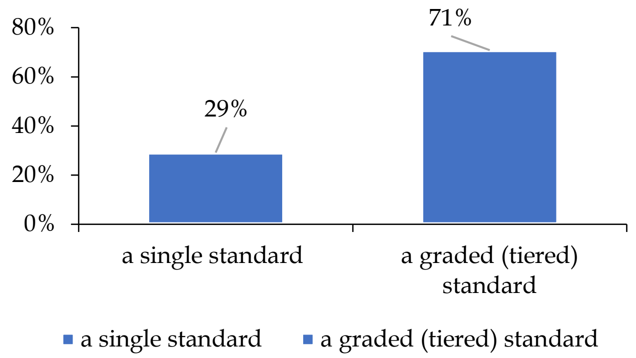

Figure 4. Standard form preferences

This indicates that most stakeholders feel a graded standard is more practical and realistic for moringa leaf powder products. A tiered system is seen as more flexible because it can accommodate differences in production scale, processing technology, and target markets. In practice, this means that producers with different capabilities can still comply with the standard without being excluded, while at the same time maintaining a clear quality classification. As a result, a graded standard is considered more suitable to support both industry development and broader market acceptance.

The implementation of a tiered standard may also increase the likelihood of standard adoption among SMEs, as producers can align quality targets with their existing production capabilities. Furthermore, such a system enables product differentiation based on quality levels, which can enhance market competitiveness and create additional economic value for producers capable of achieving higher quality standards (Kaa, 2023; Susanto et al., 2026).

Priority of Quality Factors

The first stage of the analysis aimed to identify the relative importance of the major quality factors considered in the development of quality standards for moringa leaf powder. Stakeholders evaluated the importance of five quality dimensions, namely food safety, sensory attributes, proximate composition, essential minerals, and bioactive compounds. The mean importance scores were used to rank the quality factors according to stakeholder preferences. The resulting rankings were subsequently used as importance levels in the Exponential Comparison Method (MPE) for prioritizing individual quality parameters. The results of the factor prioritization are shown in Table 1.

Table 1. Ranking of quality factors

Factors	Score	Rank
Food safety	4.79	1
Sensory attributes	4.62	2
Proximate	4.58	3
Essential minerals	4.54	4
Bioactive compounds	4.42	5

Food safety dominance reflects its fundamental role as a non-negotiable requirement in food standardization. Moringa leaf powder is particularly vulnerable to microbial contamination and heavy metal accumulation due to post-harvest handling, drying, and storage processes. Therefore, safety constitutes the primary threshold for standard compliance.

Sensory attributes ranked second, demonstrating that stakeholders place considerable importance on characteristics that directly influence consumer perception and product acceptability. Consumers often rely on observable characteristics such as color, aroma, and overall appearance when assessing product quality. Consistent with this finding, studies on moringa-based food products have reported that sensory characteristics are among the most important determinants of consumer preference and acceptance, which subsequently influence purchasing behavior (Adewumi et al., 2022; Rodrigues et al., 2023). Therefore, the inclusion of sensory attributes within quality standards is essential not only to ensure product consistency but also to support market acceptance and competitiveness.

Proximate composition was ranked third, reflecting stakeholder concerns regarding product stability and nutritional consistency. Parameters such as moisture and protein content are commonly used to evaluate the nutritional value and storage stability of plant-based food products (Kou et al., 2018; Rahmah et al., 2025; Sultana, 2020). Consistent proximate composition is particularly important for moringa leaf powder because the product is frequently promoted as a nutrient-rich functional food ingredient.

Essential minerals and bioactive compounds received slightly lower rankings compared with the other quality factors. Nevertheless, stakeholders still considered these factors important because they contribute to the nutritional and functional value of moringa leaf powder. The relatively lower priority suggests that stakeholders viewed food safety, sensory quality, and basic nutritional consistency as more immediate requirements for standardization, whereas mineral and bioactive characteristics were regarded as complementary quality attributes.

Overall, the results indicate that stakeholders prioritize quality factors that directly influence product safety, consumer acceptance, and consistency. These findings provide an important foundation for determining the quality parameters that should be considered in the subsequent stages of standard development.

Priority of Quality Parameters

The second stage of the analysis focused on identifying priority quality parameters using the Exponential Comparison Method (MPE). The ranking of the five quality factors obtained in the previous stage was incorporated into the MPE calculation as exponent values, allowing parameters associated with higher-priority factors to receive greater emphasis in the final evaluation. This approach ensured that the resulting parameter priorities remained aligned with stakeholder preferences regarding the relative importance of each quality dimension. The ranking results are presented in Table 2.

Table 2. Ranking of quality parameters based on MPE analysis

Parameters	MPE Score	Rank	Related Factor
Microbial contaminations	2641.75	1	Food safety
Heavy metal contaminations	2641.75	2	Food safety
Aroma	513.07	3	Sensory attributes
Color	478.27	4	Sensory attributes
Taste	414.06	5	Sensory attributes
Moisture	108.38	6	Proximate
Protein	105.63	7	Proximate
Acid insoluble ash	90.16	8	Proximate
Water soluble solid	83.05	9	Proximate
Iron	23.14	10	Essential minerals
Calcium	23.14	11	Essential minerals
Magnesium	21.71	12	Essential minerals
Flavonoid	8.46	13	Bioactive compounds
Polyphenols	8.33	14	Bioactive compounds
Vitamin A	8.21	15	Bioactive compounds

Food safety parameters occupied the two highest positions, with microbial contamination and heavy metal contamination obtaining the largest MPE scores. This finding is consistent with the factor level analysis, which identified food safety as the most important quality dimension. The result reflects stakeholder concerns regarding consumer protection, regulatory compliance, and product reliability, emphasizing that safety remains the primary requirement in the development of moringa leaf powder standards. However, despite their high priority, microbial contamination and heavy metal contamination were not included in the proposed specification limits developed in this study. These parameters are already regulated under existing Indonesian food safety regulations issued by the National Agency of Drug and Food Control (BPOM). Moringa leaf powder has been shown to possess inherent antimicrobial properties that may contribute to its microbial stability during storage (Muharraran et al., 2023). However, compliance with BPOM safety thresholds remains mandatory regardless of these natural properties (Roza et al., 2025). Therefore, the present study focused on developing complementary physicochemical quality criteria that are not yet specifically standardized for moringa leaf powder.

Among the remaining parameters, color, protein content, moisture content, and acid-insoluble ash emerged as important attributes that directly influence product quality, functionality, and consumer acceptance. Color is commonly regarded as an indicator of raw material quality and processing conditions, while moisture content affects storage stability and shelf life. Protein content was prioritized because moringa leaf powder is widely marketed as a nutrient-dense functional food ingredient, making nutritional consistency an essential quality consideration (Kou et al., 2018; Satria et al., 2016). Likewise, acid-insoluble ash serves as an indicator of contamination by soil and other extraneous materials, thereby reflecting the effectiveness of post-harvest handling and processing practices (Artati et al., 2025). Although aroma and taste were highly ranked by stakeholders, these parameters were not included in the final specification limits because of the absence of standardized and objective measurement methods suitable for routine quality control. Instead, they were considered supporting sensory attributes that complement the physicochemical quality requirements.

Overall, the prioritization results provided a basis for selecting quality parameters for subsequent laboratory characterization, benchmarking, and standard development. The final set of proposed quality criteria was determined not only by stakeholder priorities but also by laboratory evidence, international benchmarking results, regulatory considerations, and stakeholder validation conducted within the FACTS framework. This integrative approach ensured that the proposed specification limits were scientifically justified, practically measurable, and feasible for implementation within the Indonesian moringa leaf powder industry.

Laboratory Characterization of Moringa Leaf Powder

The laboratory analysis focused on parameters selected based on the previously established quality parameter ranking, ranging from sensory attributes such as color to chemical indicators including acid-insoluble ash. In addition, parameters such as particle size (degree of fineness) and total ash content were incorporated in accordance with stakeholder input obtained from the FGD, as these were considered relevant indicators of processing consistency and product quality. Sensory evaluation in this study was limited to color, which was assessed through organoleptic testing involving trained panelists based on SNI 01-2891-1992. This decision was made following FGD input, which identified color as the most relevant and observable sensory indicator for product quality consistency, whereas aroma and taste were not included in the present sensory assessment.

The organoleptic evaluation indicated that the color of all samples was rated as “normal”. This finding suggests that the products exhibited acceptable visual quality characteristics without signs of discoloration or deviation from expected appearance standards. The consistency of the results across samples further indicates relatively uniform processing conditions, particularly in drying and storage stages, which are critical factors affecting color stability. Color stability is closely related to drying temperature and duration, as well as the initial quality of raw material (Artati et al., 2025; Evanuarini & Nidhal, 2025). It is also important to note that microbial contamination and heavy metal content were not included in the laboratory testing in this study. This decision was made because both parameters are already regulated under existing Indonesian Food and Drug Authority (BPOM) regulations (Kurnia, 2023), and therefore are treated as mandatory safety requirements outside the scope of comparative product evaluation in this analysis. The results of the laboratory analyses are reported in Table 3, excluding previously presented sensory data.

Among the evaluated parameters, fineness and acid-insoluble ash exhibited the highest variability, with coefficients of variation (CV) of 28.83% and 52.67%, respectively. Fineness ranged from 48.71% to 99.99%, indicating substantial differences in milling and sieving practices. Similarly, the broad variation observed in acid-insoluble ash suggests differences in raw material cleanliness, handling practices, and the effectiveness of processing operations in removing extraneous materials.

The high variability observed in fineness is particularly important because particle size influences dispersibility, texture, appearance, and incorporation into food formulations. Products with inconsistent particle size distributions may exhibit differences in functionality and consumer acceptance, highlighting the need for more standardized milling and sieving procedures (Baihaqi et al., 2025; Paramita et al., 2021; Rahmiati et al., 2016; Simamora et al., 2026). Likewise, acid-insoluble ash serves as an indicator of contamination from soil and other inorganic materials; therefore, its variability reflects differences in raw material handling and post-harvest management among producers.

In contrast, moisture content and protein content showed relatively low variability across samples. Moisture content ranged from 7.03% to 9.53%, with a CV of 12.64%, indicating that drying practices were generally well controlled. Maintaining appropriate moisture levels is essential because moisture directly affects microbial stability, shelf life, and storage quality. Moisture content has long been recognized as one of the most critical quality indicators for powdered moringa products due to its direct relationship with water activity, storage stability, and shelf life (Rébufa et al., 2018). The observed values suggest that most producers have already implemented drying processes capable of maintaining moisture content within ranges commonly accepted in international standards. Protein content exhibited the lowest relative variability (CV = 7.94%), suggesting that the nutritional characteristics of moringa leaf powder remained relatively consistent despite differences in geographical origin and processing conditions. Protein content is widely used as a nutritional quality indicator because moringa leaf powder is valued for its high protein concentration and its potential contribution to food fortification strategies (Adriana et al., 2019; Rébufa et al., 2018). This consistency supports the use of protein content as one of the key nutritional indicators in future quality standard development.

The percentile analysis (P5–P95) further supported these findings. The broad percentile ranges observed for fineness and acid-insoluble ash indicate that the variability was not limited to a small number of extreme observations but was distributed across a large proportion of the samples. This pattern suggests that the observed differences reflect systematic variations in production practices rather than isolated cases. Overall, the laboratory characterization demonstrates that while several quality attributes are relatively consistent across producers, substantial variability remains in parameters related to processing and raw material handling. These findings provide an important empirical basis for establishing realistic, measurable, and achievable quality specifications in the subsequent standard development process.

Table 3. Laboratory result

Parameters	Mean	Median	SD	CV	Min	Max	Range	P5	P95
Fineness (100-mesh sieve pass) (%)	81.64	99.14	23.53	28.83	48.71	99.99	51.28	48.73	99.99
Moisture content (%)	8.14	8.05	1.03	12.64	7.03	9.53	2.50	7.06	9.51
Ash content (%)	10.40	10.02	1.41	13.56	9.28	13.00	3.72	9.30	12.99
Acid-insoluble ash (%)	0.06	0.05	0.03	52.67	0.01	0.11	0.10	0.01	0.10
Protein content (%)	25.81	25.61	2.05	7.94	22.71	28.03	5.32	22.77	27.99

Benchmarking Against International Standards

The physicochemical characteristics of the samples were evaluated against several internationally recognized standards, including Kenya Standard KS 2848:2019 (Kenya Bureau of Standards, 2019), requirements for entering the European moringa market (Centre for the Promotion of Imports from developing countries (CBI), 2022), and the Philippine National Standard PNS/BAFPS 109:2012 (Bureau of Product Standards, 2012). This comparative assessment was conducted to determine the degree of compliance of the studied product with established international quality and safety requirements, particularly in the context of its potential for broader commercial application. Overall, the results indicate that the samples generally comply with key safety related parameters, particularly moisture content. The measured moisture content falls within the acceptable range specified by the referenced standards (≤8–10%), which is critical for ensuring product stability, reducing the risk of microbial growth, and extending shelf life (Tjalo et al., 2024).

Ash content and acid-insoluble ash values also largely met the requirements specified in KS 2848:2019, indicating adequate control of raw material cleanliness and processing operations. These findings suggest that most producers have implemented basic handling and cleaning practices capable of minimizing contamination from soil and other extraneous materials.

In contrast, fineness emerged as the parameter showing the greatest variation among samples. While international references generally describe moringa leaf powder as a fine powder, quantitative specifications vary considerably across standards. The observed variability indicates differences in milling and sieving practices among producers, which may affect product functionality, dispersibility, appearance, and suitability for food applications. As particle size is closely related to both consumer acceptance and industrial performance, improving consistency in this parameter remains an important challenge for future quality standard implementation.

Figure 5 provides an integrated visualization of the physicochemical quality profile of moringa leaf powder relative to international benchmark values. The radar chart shows that moisture content and acid-insoluble ash generally align with internationally accepted requirements, whereas fineness displays the largest deviation and variability among samples. This pattern confirms the results of the laboratory characterization, which identified particle size distribution as one of the least standardized aspects of current production practices.

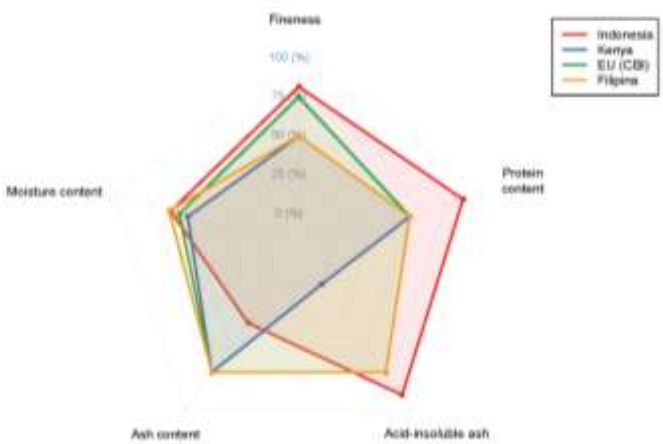

Figure 5. Radar chart of physicochemical quality parameters relative to international benchmark values

The benchmarking results indicate that most samples comply with internationally recognized moisture content requirements, demonstrating a satisfactory level of control over product stability and preservation. Compliance with acid-insoluble ash specifications also suggests that contamination from soil and extraneous materials is generally well managed during production. Nevertheless, substantial variability in fineness highlights an area where Indonesian moringa leaf powder production has yet to achieve consistent alignment with international expectations. While many standards describe moringa powder as a fine powder, the absence of harmonized quantitative criteria creates challenges for quality assessment and product comparison. These findings emphasize the importance of establishing nationally relevant specifications that maintain compatibility with international quality expectations while reflecting local production realities.

Development of Quality Criteria Using the Adopt–Adapt–Originate Framework

The development of quality criteria and proposed specification limits was guided by an Adopt–Adapt–Originate (A–A–O) framework. This framework was applied to integrate laboratory evidence, stakeholder priorities, and international benchmark standards into a structured decision-making process. Given the variation in the availability and consistency of international references for moringa leaf powder, the A–A–O framework provided a practical approach for determining whether existing standards could be directly adopted, required contextual adjustment, or needed to be developed based on local evidence.

The classification of each quality parameter is presented in Table 4. Parameters with well-established international requirements and clear regulatory thresholds were categorized under the Adopt approach. Parameters supported by international references but requiring adjustment to reflect local production conditions were classified as Adapt. Meanwhile, parameters lacking specific international numerical standards were assigned to the Originate category, where specification limits were developed using empirical laboratory data and stakeholder expectations.

Table 4. Classification of parameters

Parameter	Laboratory Data	Benchmark	Approach
Moisture (%)	7.03–9.53	Kenya ≤10; EU 8–10; Philippines ≤8	Adapt
Ash (%)	9.28–13.00	Not available	Originate
Acid-insoluble ash (%)	0.01–0.11	Kenya ≤0.5	Adopt
Protein (%)	22.71–28.03	Not available	Originate
Fineness (% passing 100 mesh)	48.71–99.99	50–100µm (general)	Adapt
Color	Green	Green–Bright Green	Originate

Acid-insoluble ash was classified under the Adopt category because a clear numerical specification is available in KS 2848:2019, which establishes a maximum limit of 0.5%. The laboratory results obtained in this study were substantially below this threshold, indicating that the existing requirement is both applicable and achievable under Indonesian production conditions. Therefore, no further modification was considered necessary.

The Adapt category includes moisture content and fineness, both of which are addressed by international references but exhibit considerable variation in specification approaches. Moisture requirements range from ≤8% to ≤10% across different standards, while particle size specifications are often expressed qualitatively or through broad ranges. Stakeholders expressed a preference for a stricter moisture limit of ≤8%, reflecting concerns about microbial safety and extended shelf life; however, this threshold represents the lower bound of the international range and would be difficult for a considerable proportion of current Indonesian producers to consistently achieve. The laboratory results showed that Indonesian moringa leaf powder generally complies with these requirements but also reflects production variability that should be considered during standard development. Accordingly, a moisture limit of ≤10%, corresponding to the upper bound of the international range, was adopted as an inclusive baseline, while ≤8% is proposed as a premium tier target for future grading purposes, consistent with the tiered standard framework favored by 71% of stakeholders. Consequently, adapted specification limits were deemed more appropriate than direct adoption to ensure both product quality and industrial feasibility.

In contrast, ash content, protein content, and color were categorized as Originate because no widely accepted international numerical limits were identified for these parameters. For ash and protein, specification limits were derived from laboratory data distributions and supported by stakeholder expectations regarding product quality and nutritional value. Color was also included in this category because existing references primarily provide qualitative descriptions without measurable criteria. Establishing locally relevant specifications for these parameters therefore required the integration of empirical evidence and stakeholder consensus.

The application of the A–A–O framework demonstrates that quality standard development for emerging functional food products cannot rely solely on the direct adoption of international standards. Differences in production systems, raw material characteristics, and industry capabilities often require contextual adjustment or the creation of new specifications. By integrating stakeholder priorities, laboratory evidence, and international benchmarking results, the framework provided a systematic basis for developing quality criteria that are scientifically justified, practically measurable, and relevant to the Indonesian moringa leaf powder industry. These classifications subsequently served as the foundation for establishing the proposed specification limits presented in the following section.

Stakeholder Validation and Proposed Quality Criteria

Stakeholder validation was conducted to assess the relevance, practicality, and feasibility of the proposed quality criteria developed through laboratory characterization, international benchmarking, and the Adopt–Adapt–Originate framework. Overall, stakeholders agreed that the proposed parameters were appropriate for inclusion in a future quality standard for moringa leaf powder. Nevertheless, several recommendations were provided to improve the applicability of the proposed specifications under current industrial conditions.

One of the key recommendations concerned product terminology. Stakeholders agreed that the term moringa leaf powder more accurately reflects the processing method used in the industry than moringa leaf flour. Since the product is obtained through drying and milling of leaves without the characteristics typically associated with flour production, the use of powder was considered more consistent with both industrial practice and commercial terminology.

Stakeholders also emphasized the importance of ensuring that technical requirements remain achievable across different production scales. In particular, particle size specifications received considerable attention during the validation process. Laboratory results revealed substantial variability in the percentage of material passing a 100-mesh sieve, indicating differences in milling and sieving practices among producers. Consequently, stakeholders suggested that particle size requirements should balance product consistency with practical feasibility to encourage wider adoption of the proposed standard.

The final proposed quality criteria resulting from the validation process are presented in Table 5.

Table 5. Proposed quality criteria and specification limits for Moringa leaf powder

Parameter	Proposed Requirement	Basis of Determination
Color	Green to bright green	Laboratory observation, stakeholder validation
Moisture content (%)	≤ 10.0	Adapted from international standards, laboratory data, stakeholder validation
Ash content (%)	≤ 13.0	Derived from laboratory distribution and stakeholder validation
Acid-insoluble ash (%)	≤ 0.5	Adopted from KS 2848:2019
Protein content (%)	≥ 23.0	Derived from laboratory distribution and stakeholder validation
Fineness (% passing 100 mesh)	≥ 80	Adapted from laboratory results and stakeholder validation

The proposed specification limits were established using different sources of evidence depending on the characteristics of each parameter. Moisture content and acid-insoluble ash were primarily informed by international references, whereas ash content and protein content were derived from the distribution of laboratory results and subsequently refined through stakeholder validation.

The proposed protein threshold of ≥23% was derived from the minimum observed laboratory value (22.71%) and the overall distribution of results, ensuring that the majority of Indonesian moringa leaf powder producers can meet this requirement while maintaining a meaningful nutritional quality baseline. Consistent protein content at this threshold is also important from a health perspective, as moringa leaf powder supplementation has been associated with measurable reductions in blood glucose and cholesterol levels in clinical settings (Kahirah et al., 2024). This approach aligns with standard-setting principles that prioritize inclusivity without compromising quality, allowing SMIs to participate while incentivizing improvement toward higher nutritional performance.

Although stakeholders initially indicated a preferred minimum protein content of ≥27%, reflecting expectations for a high-quality, nutritionally superior product, laboratory data revealed that only a small proportion of samples (approximately the top quartile) achieved this level. Setting ≥27% as a mandatory minimum would effectively exclude the majority of current Indonesian moringa leaf powder producers from standard compliance, potentially hindering industry participation and standard adoption. Accordingly, a minimum threshold of ≥23% was established based on the fifth percentile of the laboratory distribution, representing a scientifically grounded, achievable baseline, while ≥27% was retained as a recommended target for premium-grade classification within a tiered standard framework. This approach aligns with the preference expressed by 71% of stakeholders for a graded standard system, wherein the minimum specification ensures broad compliance and the premium tier provides an incentive for quality improvement.

Following the same logic, the ash content limit of ≤13% was selected to encompass the observed variability while maintaining product quality and consistency. High ash content may indicate the presence of non-leaf plant material or processing contaminants, which can negatively affect both product quality and consumer perception (Apriliyani et al., 2021; Kusnandar et al., 2022). For fineness, the proposed minimum value of 80% passing a 100-mesh sieve represents a compromise between laboratory observations and industrial feasibility, acknowledging the variability currently present among producers.

Overall, the integration of stakeholder priorities, laboratory evidence, international benchmarking, and validation activities demonstrates the value of the FACTS framework as a systematic approach for quality standard development. The resulting quality criteria and proposed specification limits provide a scientifically grounded, contextually relevant, and operationally feasible foundation for future national standardization efforts for moringa leaf powder. Similar methodological approaches, combining laboratory evidence, stakeholder input, and international benchmarking—have been successfully applied to develop SNI standards for other Indonesian food products (Suprapto et al., 2020; Susanto & Kristiningrum, 2021), supporting the broader applicability of this integrative framework.

The validation process highlighted that effective quality standards must balance scientific rigor with practical implementation. Stakeholder involvement and implementation feasibility have been recognized as critical factors influencing the acceptance and adoption of quality standards, particularly when standards are intended for application across industries with diverse production capacities (Kaa, 2023).

Conclusion

This study successfully developed a set of evidence-based quality criteria for moringa leaf powder, specifically addressing the physicochemical and nutritional parameters that currently lack national standardization in Indonesia. While stakeholders identified food safety as their highest priority, this aspect was excluded from the proposed criteria as it is already comprehensively regulated by the Indonesian Food and Drug Authority (BPOM). The focus was instead directed toward defining quantitative specifications for moisture content, ash content, acid-insoluble ash, protein content, color, and fineness. The analytical work demonstrated that local product attributes for moisture content and acid-insoluble ash are already competitive, as they align with internationally recognized standards, such as the Kenya Standard KS 2848:2019. However, for parameters like ash content, protein content, fineness and color, international benchmarks were either lacking or not directly applicable, necessitating the development of locally derived, or "originated," thresholds. The proposed specifications are as follows: color (green to bright green), moisture content (≤ 10%), total ash content (≤ 13%), acid-insoluble ash (≤ 0.5%), protein content (≥23%), and fineness (≥ 80% passing a 100-mesh sieve). This minimum threshold for protein content (≥ 23%) was strategically chosen as an inclusive baseline to ensure broad compliance among current producers, while a higher premium target (≥ 27%) is recommended to encourage continuous quality improvement. Similarly, the moisture limit of ≤ 10% was adopted as a pragmatic balance between scientific rigor and the operational realities of diverse producers, particularly SMIs. Furthermore, subsequent studies should assess the tangible impact of adopting such standards on SMIs competitiveness and the overall performance of Indonesia's moringa export market.

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Author Contributions

Conceptualization, methodology, writing—review and editing, W.W. M.R., and M.; validation, supervision, M.R. and M.; formal analysis, investigation, data curation, visualization, writing—original draft preparation, W.W. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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