Development and Sensory Evaluation of Tamarind Vinegar as a Souring Ingredient in a Standardized Pickled-Fruit Preparation

ABSTRACT

Tamarind (*Tamarindus indica* L.) is widely used as a source of sourness in culinary practice, yet its development as a vinegar-based souring ingredient remains less visible than its use in direct or minimally processed forms. This study examined whether tamarind vinegar could function as a souring ingredient in a finished food preparation and compared the sensory performance of selected formulations in a standardized pickled-fruit preparation. The study was designed as a product-development investigation with a quantitative comparative sensory component. Three tamarind vinegar formulations were developed under comparable substrate conditions, after which two selected formulations were incorporated into a standardized pickled-fruit preparation adapted from the seasoning logic of *Asinan Bogor*. Sensory evaluation covered taste, color, aroma, and texture using a small informed panel; 15 panelists were recruited, and 13 complete responses were retained for descriptive analysis. Differences observed during vinegar development remained evident after application in the finished product. Among the applied formulations, F1, developed without added sugar, produced the clearest and more favorable sensory profile, particularly in taste, color, and aroma, whereas texture contributed relatively little to differentiation between samples. These findings support formulation discrimination within product development but should not be generalized directly to broader consumer populations or other food applications. Overall, the study shows that tamarind vinegar can be developed and evaluated through a culinary application model and that, under the conditions tested, the formulation developed without added sugar performed more favorably as a souring ingredient in pickled fruit.

Keywords: *tamarind vinegar; sensory evaluation; pickled fruit*

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INTRODUCTION

In culinary applications, vinegar is valued not only for its acidity but also for its contribution to flavor development, balance, and overall product character (G.-L. Chen et al., 2023). Its role becomes especially important in foods that depend on a distinct sour profile, where acidity influences not only taste perception but also the sensory identity of the final product (F. Chen et al., 2025; Feng et al.,

2025). In this sense, vinegar functions not merely as a preservative or seasoning agent, but also as a souring ingredient whose selection can shape product perception and consumer acceptance (G.-L. Chen et al., 2023).

Tamarind (*Tamarindus indica* L.) is directly relevant in this context. Its distinctive sweet-sour profile has long made it a recognizable and versatile source of acidity in cooking and flavor formulation (Chitra & Parthiban, 2024; Mansingh et al., 2021). Its broad availability and established culinary familiarity further strengthen its relevance as a raw material for product development. Even so, recent literature has continued to place greater emphasis on tamarind in direct or minimally processed forms, including beverages, syrups, concentrates, and powders (Bayoï & Bianra, 2023; Sudha et al., 2022), than on tamarind as a deliberately developed fermented ingredient with a defined souring role in food formulation. As a result, although tamarind is already well recognized as a source of sourness, its application as a vinegar-like souring agent remains less visible in recent culinary and food-use literature than its use in direct-form products (Keṣa et al., 2021).

A more rigorous test of tamarind vinegar lies not in the fermented liquid alone, but in its performance within a finished food system. Pickled-fruit preparations are particularly suitable for this purpose because acidity in such products must interact with sweetness, fruit character, and the seasoned pickling liquid to produce an acceptable overall sensory balance. The issue, therefore, is not simply whether tamarind can be fermented into vinegar, but whether the resulting vinegar can deliver a sour profile that remains coherent, usable, and sensorially appropriate in the finished preparation (Dupas de Matos et al., 2019). This is especially relevant in the Indonesian culinary context of Asinan Bogor, a distinctive pickled-fruit preparation whose identity is shaped more by the character of its seasoned liquid than by one fixed fruit combination (Mela et al., 2021; Putri et al., 2024). For that reason, Asinan Bogor provides an appropriate culinary model for evaluating tamarind vinegar in actual use. Tamarind itself further supports this choice because it is widely available, has a distinctive taste, and offers potential as a more natural acidic ingredient in vinegar production, thereby supporting efforts to reduce reliance on glacial vinegar in pickled-fruit preparations (Khaeril Sungkawa et al., 2024).

Seen from this perspective, the issue is not merely the production of tamarind vinegar, but its performance within an actual food system. The present study therefore developed and compared three tamarind vinegar formulations and evaluated the selected formulations in a standardized pickled-fruit preparation adapted from the culinary profile and seasoning logic of *Asinan Bogor*. In doing so, it examined whether tamarind-derived acidity could serve as a souring ingredient within a defined culinary application and support favorable sensory performance in the finished product, rather than treating tamarind vinegar solely as an isolated fermented liquid (Cabello-Olmo et al., 2023; Świąder & Marczewska, 2021).

METHOD

Conducted at the Practical Kitchen Laboratory of Politeknik Pariwisata Makassar from April to May 2024, this study proceeded in two sequential stages. The first stage consisted of the comparative development of three tamarind vinegar formulations for culinary application,

whereas the second involved the incorporation of the selected formulations into pickled fruit and their subsequent evaluation through comparative sensory assessment of the finished products. Methodologically, the study was positioned as a product-development investigation with a quantitative comparative sensory component rather than as a true experimental study (Cabello-Olmo et al., 2023; Świąder & Marczewska, 2021). The overall workflow of the study is presented in Table 1.

Table 1

Procedural Workflow of Tamarind Vinegar Development and Evaluation

Stage	Main procedure	Output
Formulation design	Three tamarind vinegar formulations were prepared from the same basic substrate to allow comparison under comparable starting conditions. Each formulation used 500 g of ripe tamarind pulp and 500 mL of water. F0 included 4 g of yeast, F1 contained no added yeast or sugar, and F2 contained 30 g of granulated sugar without added yeast.	Three formulations were established for development-stage comparison.
Preparation	Tamarind pulp was separated from the shell and seeds, transferred into clean plastic jars with water, and combined with the designated additions for each formulation.	All formulations were prepared under the same initial substrate conditions.
Fermentation and monitoring	The jars were covered with cloth and kept in a dim, odor-free room at approximately 23–26°C. During the first week, each mixture was inspected and stirred once daily.	Fermentation was monitored under comparable room conditions across F0, F1, and F2.
Filtration and continuation	When visible fermentation activity had clearly declined, each mixture was filtered to remove solids and transferred into a clean container for continued development in the liquid phase.	Clearer liquid fractions were obtained for continued development.
Development-stage review	Fermentation duration, visible progression, end-point appearance, aroma, taste tendency, and approximate yield were recorded for all three formulations.	The three formulations were reviewed for suitability to proceed to product application.
Selection for application	F1 and F2 were advanced to the application stage, whereas F0 was retained only within the development-stage observations and was not included in the final sensory comparison.	Two formulations were selected for incorporation into pickled fruit and comparative sensory evaluation.
Application in pickled fruit	The selected formulations were incorporated into a standardized pickled-fruit preparation so that their performance could be assessed in a finished product rather than as stand-alone vinegar samples.	Finished pickled-fruit samples were prepared for sensory evaluation.
Sensory evaluation and descriptive analysis	The finished samples prepared with F1 and F2 were evaluated sensorially using a structured questionnaire covering taste, color, aroma, and texture. Responses were analyzed descriptively by formulation and attribute.	Comparative sensory findings were obtained for the finished pickled-fruit samples.

Source. Compiled by the authors from the present study.

All three formulations were prepared from the same substrate to minimize variation in the starting material and allow differences in development to be interpreted in relation to the addition or omission of yeast and sugar. After preparation, the mixtures were fermented under comparable room conditions. Fermentation progress was monitored not only by elapsed time but also by visible indicators, including surface bubbling, changes in overall mixture condition, and the stage at which the solid fraction was no longer retained for

continued fermentation, in line with process-based monitoring in fruit-vinegar production, where development is tracked through changes in activity and product evolution rather than by calendar time alone (Hammouda et al., 2023; Ousaaid et al., 2021; Saelee et al., 2023). To maintain consistency, all preparations were monitored regularly, and each mixture was stirred once daily during the first week. Rather than applying a fixed calendar duration, the point for filtration was determined using the same operational criteria across formulations. The initial phase was considered ready for filtration when visible fermentation activity had clearly declined, as indicated by a marked reduction in surface bubbling, clearer separation between the liquid and solid portions, and the absence of renewed visible activity on the following day. After filtration and transfer, development was considered complete when the liquid phase showed no further major visible changes in activity and had reached a stable endpoint appearance suitable for final observation and product characterization.

The three formulations were not advanced in the same manner. F0 was retained within the development stage because its endpoint profile was less suitable for culinary application, showing a sharper aroma, slight bitterness, and a more turbid appearance than the other formulations. By contrast, F1 and F2 showed clearer liquid development and more acceptable endpoint sensory tendencies for incorporation into the standardized pickled-fruit preparation. The transition from three formulations in the development stage to two in the application stage therefore functioned as an internal selection step based on comparative endpoint suitability for culinary use rather than as a separate experiment.

Table 2

Reference Sources and Formulation Basis Used in Product Development and Application

Reference source	Methodological role	How it informed this study
Saelee et al. (2023) mixed-culture fruit vinegar fermentation	Reference for starter-assisted vinegar development	Used as a comparative formulation reference for F0, the formulation developed with added yeast.
Hammouda et al. (2023), spontaneous fruit vinegar fermentation	Reference for non-starter vinegar development	Used as a comparative formulation reference for F1 and F2, the formulations prepared without added yeast.
Indrati et al. (2022), traditional sweet pickled mango production process	Product-application reference	Used as a practical reference for the processing logic of the standardized pickled-fruit application in which the selected vinegar formulations were evaluated in a finished preparation.
Ousaaid et al. (2021), fruit-vinegar quality characteristics review	General interpretive benchmark	Used only as a general interpretive reference for commonly discussed fruit-vinegar characteristics in the study context and not to establish formal compliance of the developed product.

Source. Compiled by the authors from Saelee et al. (2023), Hammouda et al. (2023), Indrati et al. (2022), and Ousaaid et al. (2021).

To provide methodological grounding for both stages, the study did not rely solely on exploratory formulation. Published sources were used to support the development of tamarind vinegar, the design of the pickled-fruit application stage, and the broader interpretation of fruit-vinegar characteristics. Saelee et al. (2023) informed the positioning of F0 as a starter-assisted vinegar formulation, whereas Hammouda et al. (2023) provided the basis for treating F1 and F2 as non-starter fruit-vinegar formulations. Indrati et al. (2022) informed the processing logic of the pickled-fruit application stage, and Ousaaid et al. (2021)

served as a general interpretive reference for fruit-vinegar characteristics. The roles of these sources are summarized in Table 2.

For the application stage, F1 and F2 were incorporated into a standardized pickled-fruit preparation adapted from the culinary profile and seasoning logic of *Asinan Bogor*. This product was selected as the application model because *Asinan Bogor* is a distinctive Indonesian pickled-fruit preparation in which the pickling liquid plays a central role in determining sourness, balance, and overall product character, even though the fruit combination may vary across preparations (Mela et al., 2021; Putri et al., 2024). It therefore provided a relevant culinary context for evaluating tamarind vinegar as a functional souring agent within a finished product rather than as a stand-alone liquid. The choice was also supported by the characteristics of tamarind itself, which is widely available, has a distinctive taste, and shows potential as a natural acidic ingredient for vinegar production, thereby supporting efforts to reduce reliance on glacial vinegar in fruit-pickling preparations. Previous work has likewise supported the use of recipe standardization in *Asinan Bogor*-related culinary formulation (Khaeril Sungkawa et al., 2024). Accordingly, the fruit combination and ingredient proportions were standardized by the authors, while the broader product format and seasoning logic were retained from *Asinan Bogor*. The standardized pickled-fruit formulation used in this study is presented in Table 3.

Table 3

Standardized Pickled-Fruit Formulation Used in the Application Stage

Ingredient	Quantity used in this study	Functional role in the preparation
Ripe apple	300 g	Fruit component
Ripe pineapple	400 g	Fruit component
Green mango	250 g	Fruit component
Water	1000 mL	Base of pickling liquid
Tamarind vinegar formulation (F1 or F2)	60 mL	Acidifying component in the pickling liquid
Curly chili	10 g	Heat and flavor contribution
Bird's-eye chili	10 g	Heat and flavor contribution
Palm sugar	100 g	Sweetness and flavor depth
Granulated sugar	180 g	Sweetness adjustment
Shrimp paste	10 g	Savory depth
Salt	60 g	Salinity and balance
White pepper	1 g	Final seasoning adjustment

Source. Standardized by the authors and adapted from the culinary profile of Asinan Bogor as discussed by Khaeril Sungkawa et al. (2024), Mela et al. (2021), Putri et al. (2024).

Note. The ingredient composition presented here was standardized for the purposes of this study and should not be interpreted as a verbatim reproduction of any single published Asinan Bogor recipe. Rather, the elements adopted from Asinan Bogor were the mixed-fruit asinan format and the sweet-sour-salty-spicy seasoning logic structured around the pickling liquid.

The recipe, preparation steps, and portioning were standardized across samples so that the tamarind vinegar formulation remained the only intended source of variation between the finished products. In the standardized preparation, the fruit was washed, peeled as needed, and cut into uniformly sized pieces before being combined with the pickling liquid. The seasoning liquid was prepared separately by dissolving and mixing the non-fruit ingredients until homogeneous, after which it was poured over the fruit until fully submerged. The preparation was then left at room temperature for 15 min and stored under refrigeration for approximately 3 days before sensory evaluation. This stage was included to

evaluate the selected tamarind vinegar formulations not merely as developed liquid products, but in terms of their performance within a finished preparation, where sourness had to interact with sweetness, fruit character, and the pickling medium as a whole. Accordingly, tamarind vinegar was assessed as a functional souring agent in use rather than as a stand-alone product.

For sensory evaluation, each panelist received two coded samples corresponding to the pickled-fruit preparations made with F1 and F2. The formulations were presented under blind conditions using sample codes A and B, and their identities were not disclosed to the panelists. Portion size was standardized at 50 g of fruit with 30 mL of pickling liquid per serving container, and both samples were presented in identical containers under the same serving conditions. The samples were served chilled after 10 min of equilibration following removal from refrigeration. To minimize carry-over effects between evaluations, plain drinking water was provided as a palate cleanser.

Sensory evaluation was conducted on finished pickled-fruit samples prepared with F1 and F2 using a 15-member panel drawn from the Culinary Arts program at Poltekpar Makassar. The panel consisted of five teaching staff members and 10 final-semester Diploma 3 Culinary Arts students. This panel composition was selected to suit the exploratory and comparative purpose of the sensory stage, which was positioned within product development rather than consumer-acceptance testing aimed at population-level generalization. In current sensory literature, product-oriented analytical assessment is distinguished from consumer-focused affective testing, with the former typically relying on smaller trained or informed panels; recent reviews indicate that trained panels may include up to 15 participants and semi-trained panels up to 30, whereas consumer panels are generally much larger (Djekic et al., 2021; Drake et al., 2023; Hellwig et al., 2022). Teaching staff were included for their stronger experience in culinary preparation and product evaluation, while the student panelists were selected because, as final-semester students, they had completed most of their practical training and were already familiar with judging food products in applied classroom and kitchen settings. The use of participants with culinary experience is also supported by sensory studies of applied food products that have involved assessors accustomed to observing and evaluating food and its sensory attributes (Herdenstam et al., 2022).

A questionnaire-based sensory instrument was used to assess taste, color, aroma, and texture, with each attribute rated on a four-point categorical scale. Rather than relying on fixed universal standards, the response categories were constructed as product-specific sensory descriptors, consistent with sensory-evaluation literature that recognizes taste, aroma, color, and texture as core dimensions of food assessment while allowing descriptors to be adapted to the characteristics of the product under study (Kim et al., 2023; Marques et al., 2022; Mihafu et al., 2020). In this study, taste and aroma categories were organized according to the perceived intensity of sourness, as sourness represented the principal functional attribute expected from tamarind vinegar in the finished product. Color categories reflected the observable hue range of the samples, whereas texture categories

described the apparent consistency of the pickling system. This product-specific categorization was considered appropriate because the aim was to distinguish formulation performance within the finished pickled-fruit product rather than to apply a standardized lexicon developed for a different product category (Dupas de Matos et al., 2019). The response categories used in the sensory questionnaire are presented in Table 4.

Sensory evaluation was conducted in the lobby of the Practical Kitchen Laboratory at Politeknik Pariwisata Makassar. Because the space could not accommodate the full panel comfortably at one time, the assessment was carried out in three sessions of five panelists each. Sessions were scheduled at 09:00, 10:00, and 11:00 Central Indonesia Time (WITA, UTC+8) and completed before lunch to minimize potential variation in attention and sensory responsiveness. All assessments took place in the same room under comparable conditions, with identical sample portions, sample presentation, questionnaire format, and assessment procedures across sessions. A blind evaluation format was used, and the identities of the formulations were not disclosed to panelists. The room provided clear visual conditions through evenly distributed white fluorescent lighting, and panelists were informed in advance of their assigned session times.

Table 4

Product-Specific Sensory Response Categories Used in the Sensory Questionnaire

Sensory attribute	Basis for categorization	Response categories
Taste	Perceived intensity of sourness	Very distinct sour taste; distinct sour taste; less distinct sour taste; no distinct sour taste
Aroma	Perceived intensity of sourness	Very distinct sour aroma; distinct sour aroma; less distinct sour aroma; no distinct sour aroma
Color	Observable hue range of the finished samples	Bright orange; dark orange; reddish orange; brownish orange
Texture	Apparent consistency of the pickling system	Liquid; less liquid; thick; very thick

Source. Adapted by the authors from Dupas de Matos et al. (2019), D. Kim et al. (2023), Marques et al. (2022), and Mihafu et al. (2020).

Note. This table was developed by the authors rather than adopted from a single published instrument. Its response categories were derived from sensory-evaluation literature on core food attributes and product-specific descriptor construction, then adapted to the characteristics of the finished pickled-fruit samples prepared with tamarind vinegar.

After the sensory sessions, completed questionnaires were compiled and entered into IBM SPSS Statistics 26 for analysis. The data were analyzed descriptively by formulation and sensory attribute, allowing panel responses for taste, color, aroma, and texture to be compared across the finished pickled-fruit samples (Cabello-Olmo et al., 2023; Mihafu et al., 2020). Frequency counts and percentages were treated as the primary basis for comparison, while mean scores were used only as supplementary descriptive indicators of overall response tendency across categories (Kortei et al., 2020). This analytical approach was considered appropriate because the sensory stage was intended to support exploratory formulation comparison within a product-development context rather than inferential generalization to a wider population (Drake et al., 2023; Świąder & Marczewska, 2021).

RESULTS

The development-stage findings are presented first for the three tamarind vinegar formulations, followed by the application-stage findings from the standardized pickled-fruit preparation in which the selected formulations were assessed through sensory evaluation in the finished product.

Fermentation-Stage Results

Despite sharing the same basic substrate, the three tamarind vinegar formulations showed distinct fermentation patterns during the development stage. The observations covered fermentation duration, visible changes before filtration and transfer, and the final characteristics recorded at the end of development. These findings are summarized in Table 5.

Table 5

Fermentation Characteristics of F0, F1, and F2 During the Development Stage

Formulation	Added component	Fermentation period (days)	Fermentation progress	Filtration/ transfer point	Final characteristics	Yield (mL)
F0	4 g yeast	14	Early bubble formation, followed by a visible decline in activity during the first week; a surface layer appeared later in the process	After visible fermentation activity had slowed	Sharp aroma, sour taste with slight bitterness, light yellow and cloudy liquid	250
F1	None	21	Bubble formation during the first week, followed by slower activity and a clearer liquid after transfer	After visible fermentation activity had slowed	Strong sour aroma and taste, light brown and relatively clear liquid	150
F2	30 g granulated sugar	21	Visible fermentation in the early stage, followed by slower activity and a clearer liquid after transfer	After visible fermentation activity had slowed	Sour aroma, moderately sour taste, light brown and relatively clear liquid	150

Source. Research data, processed by the authors.

Note. Fermentation period, yield, and final characteristics were compiled from observations recorded during the product-development stage.

Figure 1 shows the endpoint appearance of the three formulations. F0 reached its recorded endpoint on day 14, whereas F1 and F2 continued to day 21. The images also reflect the differences in color and visual clarity reported in Table 5.

Table 5 and Figure 1 together indicate that the three formulations did not reach the same endpoint profile. F0 reached its recorded endpoint earlier and remained lighter in color with a more turbid appearance, whereas F1 and F2 underwent longer development and yielded darker liquids with relatively greater clarity. The difference in fermentation duration reflected the observed course of development in each formulation rather than a

fixed stopping point established in advance. In F0, visible fermentation activity had already declined by day 8, after which filtration and transfer were carried out, and the endpoint was recorded on day 14. In contrast, activity in F1 and F2 had slowed by around days 9–10, but the final development-stage observations for both formulations were recorded only on day 21. Even so, the two 21-day formulations did not converge on the same final sensory character, as F1 showed a stronger sour aroma and taste than F2. These development-stage differences formed the basis for advancing F1 and F2 to the application stage.

Figure 1

Endpoint Appearance of F0, F1, and F2 During the Development Stage

Source. Research data, processed by the authors.

Pickled-Fruit Application and Sensory Results

The application-stage analysis centers on F1 and F2, the two formulations advanced from product development and incorporated into the standardized pickled-fruit preparation. Although 15 panelists were initially scheduled for the sensory session, only 13 completed the assessment and were retained for analysis. The findings reported in this subsection therefore compare the finished samples on the basis of those 13 complete responses across four sensory attributes: taste, color, aroma, and texture.

Sensory responses were distributed differently between the two formulations. Across the four evaluated attributes, F1 was more often represented in the higher response categories for taste, color, and aroma, whereas both formulations were predominantly classified in the liquid category for texture. Table 6 summarizes these attribute-specific distributions based on the 13 complete panel responses retained for analysis.

Table 6 shows that F1 was more often represented in the higher response categories than F2 for three of the four evaluated sensory attributes. For taste, responses for F1 were concentrated in Categories 4 and 3, whereas F2 was concentrated mainly in Category 2. A similar pattern was observed for color and aroma, with F1 occurring more frequently in the higher categories and F2 appearing more often in the middle or lower categories. Texture showed a different pattern, as both formulations were rated predominantly in Category 4, indicating that both were generally perceived as liquid in the finished pickled-fruit preparation.

The descriptive summary values in Table 6 reflected the same overall pattern. F1 received higher mean ratings than F2 for taste (3.70 vs. 2.38), color (3.23 vs. 2.77), and aroma (3.23 vs. 2.92), consistent with a stronger sour taste, a brighter orange appearance, and a more distinct sour aroma in the finished product. By contrast, the two formulations were

more similar in texture, as both were interpreted as liquid despite the slightly higher mean recorded for F2 (3.92 vs. 3.77). Overall, the descriptive results indicate clearer differences between the formulations in taste, color, and aroma than in texture.

Table 6

Attribute-Specific Sensory Response Distributions for F1 and F2 in the Standardized Pickled-Fruit Preparation

Attribute	Formulation	Category 4 n (%)	Category 3 n (%)	Category 2 n (%)	Category 1 n (%)	Mean	Endpoint characteristic
Taste	F1	9 (69.2)	4 (30.8)	0 (0.0)	0 (0.0)	3.70	Very distinct sour taste
	F2	1 (7.7)	3 (23.1)	9 (69.2)	0 (0.0)	2.38	Less distinct sour taste
Color	F1	6 (46.2)	4 (30.8)	3 (23.1)	0 (0.0)	3.23	Bright orange
	F2	3 (23.1)	5 (38.5)	4 (30.8)	1 (7.7)	2.77	Dark orange
Aroma	F1	5 (38.5)	6 (46.2)	2 (15.4)	0 (0.0)	3.23	Distinct sour aroma
	F2	4 (30.8)	4 (30.8)	5 (38.5)	0 (0.0)	2.92	Less distinct sour aroma
Texture	F1	10 (76.9)	3 (23.1)	0 (0.0)	0 (0.0)	3.77	Liquid
	F2	12 (92.3)	1 (7.7)	0 (0.0)	0 (0.0)	3.92	Liquid

Source. Research data, processed by the authors.

Note. Distributions are based on 13 complete panel responses. For taste, Category 4 to Category 1 corresponded to very distinct sour taste, distinct sour taste, less distinct sour taste, and no distinct sour taste. For color, Category 4 to Category 1 corresponded to bright orange, dark orange, reddish orange, and brownish orange. For aroma, Category 4 to Category 1 corresponded to very distinct sour aroma, distinct sour aroma, less distinct sour aroma, and no distinct sour aroma. For texture, Category 4 to Category 1 corresponded to liquid, less liquid, thick, and very thick.

Of the 15 panelists originally assigned to the sensory session, 13 completed the assessment and were retained in the final dataset. One panelist withdrew before the session was completed because of an urgent matter, whereas another did not continue tasting because of a stomach-related concern. No replacements were introduced once the session had begun, as doing so would have required additional tasting outside the original schedule and altered the composition of the small panel under otherwise standardized serving conditions. Given the exploratory purpose of the sensory stage and the use of an informed small-panel design rather than a consumer test, the 13 complete responses were considered sufficient for descriptive comparison of the finished samples within this product-development context (Djekic et al., 2021; Drake et al., 2023; Hellwig et al., 2022).

Across the analyzed responses, the two formulations were not distinguished equally across all four sensory attributes. The clearest differences emerged in taste, color, and aroma, where F1 showed a more favorable response profile and higher descriptive mean values. Texture, however, contributed much less to the distinction between samples, as both formulations were largely perceived as liquid. Overall, the application-stage findings descriptively indicate that F1 was the more favorably rated formulation in the finished pickled-fruit preparation.

DISCUSSION

The differences that emerged during vinegar development remained apparent after the selected formulations were applied in the standardized pickled-fruit preparation. In the finished product, the clearest contrasts appeared in taste, color, and aroma, with F1 showing

the stronger descriptive profile. Such differences are meaningful because the sensory role of a souring ingredient is expressed through its interaction with sweetness, fruit character, and aroma release within the composite food matrix rather than in isolation (Gonzalez-Estanol et al., 2024; Le Quéré & Schoumacker, 2023). Accordingly, the two tamarind vinegar formulations did not perform in the same way, even when incorporated into the same standardized product base. These results reinforce the importance of evaluating tamarind vinegar within its intended culinary matrix rather than as a stand-alone fermented liquid, especially when sensory assessment is meant to reflect how the product is actually used and perceived (Drake et al., 2023).

The stronger sensory profile of F1 suggests that sugar addition during vinegar development did not necessarily result in a more favorable outcome once the vinegar was applied in the standardized pickled-fruit preparation. In fruit-vinegar systems, formulation effects are expressed less through substrate addition alone than through fermentation-related changes in perceived sourness, color characteristics, and aroma compounds (Xie et al., 2022; Yin et al., 2024). Seen in this context, the milder sour taste and less distinct aroma observed in F2 indicate that the sugar-added formulation did not provide greater sensory definition in the finished product. F1, by contrast, retained a more distinct sensory contribution after application, suggesting that, under the conditions of this study, the formulation without added sugar carried its sour and aromatic character more clearly into the final preparation.

Texture showed a different pattern from taste, color, and aroma. In the finished pickled-fruit preparation, both formulations were perceived largely as liquid, leaving little descriptive separation between F1 and F2 for this attribute. Such a pattern is plausible because, in liquid and composite foods, perceived consistency and oral processing depend primarily on the textural, mechanical, and lubrication properties of the shared food matrix rather than on differences in taste intensity alone (Gonzalez-Estanol et al., 2024). Once both vinegars were incorporated into the same standardized pickling system, the overall textural impression appears to have been shaped more by the common preparation matrix than by the formulation difference itself. As a result, texture contributed relatively little to formulation discrimination, whereas the influence of the vinegar remained more evident in attributes more closely tied to souring performance, particularly taste and aroma (Drake et al., 2023; Forde & Bolhuis, 2022).

The interpretation of these findings is closely tied to the design of the application stage. Rather than being assessed in an abstract tasting setting, tamarind vinegar was evaluated within a standardized pickled-fruit preparation adapted from the seasoning logic of *Asinan Bogor*, where the pickling liquid is central to the product's balance and sensory character (Mela et al., 2021; Putri et al., 2024). This design strengthens the meaning of the comparison because both vinegars were examined within the same finished food system rather than under separate tasting conditions, and sensory expression in composite foods is shaped through interaction with the surrounding matrix during actual consumption (Gonzalez-Estanol et al., 2024; van Eck et al., 2021). Within that shared matrix, the more favorable

profile of F1 cannot be understood as a matter of sourness alone, but as the result of how the formulation functioned in relation to sweetness, fruit character, and the seasoned liquid as an integrated whole. In this sense, the culinary value of tamarind vinegar becomes clearest when it is evaluated in the product context for which it is intended.

These findings should be interpreted within the limits of the sensory design used in this study. The comparison drew on 13 complete responses from a small informed panel and was intended to distinguish between formulations within a product-development context rather than estimate consumer acceptance at the population level, consistent with the methodological distinction between analytical sensory assessment and large-scale affective testing (Djekic et al., 2021; Hellwig et al., 2022). Accordingly, the four-category descriptors are best understood as comparative indicators within this standardized pickled-fruit preparation, not as universal descriptors of tamarind vinegar across different product settings. Within those limits, the findings support a bounded conclusion: under the conditions established in this application model, F1 produced a more favorable and more clearly expressed sensory profile than F2.

Tamarind's long-established culinary role as a souring ingredient also gives these findings significance beyond the immediate comparison between F1 and F2. Rather than remaining confined to pulp, extract, or other minimally processed forms, tamarind can also be developed into a vinegar format that retains a meaningful function in a finished preparation when both formulation and application are carefully controlled (Chitra & Parthiban, 2024; Mansingh et al., 2021). This is important for product innovation because vinegar does not contribute to food as acidity in the abstract; its culinary value depends on how that acidity is integrated into flavor balance, aroma expression, and the sensory character of the product as consumed (Le Quéré & Schoumacker, 2023; van Eck et al., 2021). In this respect, the study does more than position tamarind vinegar as another possible tamarind-based product. It shows, more specifically, that tamarind vinegar can be developed and evaluated through a culinary application model in which its functional role becomes observable in the finished product.

A further contribution of the study lies in the way tamarind vinegar was evaluated. Much of the fruit-vinegar literature remains centered on fermentation progress and physicochemical or volatile characterization, whereas the present work carried the ingredient into a finished preparation and assessed its performance there, where culinary function becomes more visible and practically interpretable (Xie et al., 2022; Yin et al., 2024). This distinction matters because the value of an ingredient in food development is not established by production alone, but by whether it continues to perform once incorporated into an actual serving context, where sensory expression is shaped by the surrounding food matrix during consumption (van Eck et al., 2021). Within this design, tamarind vinegar was evaluated not simply as a fermented derivative of tamarind, but as a souring ingredient whose usefulness depended on how clearly it contributed to the sensory profile of the final preparation.

Several limitations should be kept in view when interpreting these results. The sensory evidence was based on 13 complete responses from a small informed panel and was intended to support formulation comparison within a product-development context rather than consumer generalization across broader populations or market settings. The application stage was also restricted to a single standardized pickled-fruit model, so the present findings cannot be assumed to extend automatically to other food systems, where tamarind vinegar may behave differently under different flavor balances, textural conditions, or serving contexts. In addition, formulation performance was assessed through fermentation-stage observations and sensory responses in the finished product, not through detailed physicochemical or volatile characterization. The study can therefore indicate which formulation performed more favorably under the conditions tested, but it does not yet explain that difference at a more precise compositional level.

Conclusion

Ultimately, the significance of this study lies not merely in showing that tamarind can be fermented into vinegar, but in showing that the resulting vinegar does not function in the same way once incorporated into food. The three formulations followed different developmental trajectories, and those differences remained evident after incorporation into the standardized pickled-fruit preparation rather than disappearing during application. Under the conditions used here, F1, the formulation developed without added sugar, gave the clearest sensory contribution, especially in taste, color, and aroma, while texture contributed comparatively little to differentiation at the application stage. Although these findings should not be generalized beyond the present application model, they support one practical conclusion: tamarind vinegar can function as a souring ingredient in pickled fruit, and in this study the formulation without added sugar performed more favorably than the sugar-added alternative.

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