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Nasha: A culturally embedded sorghum-based weaning food for infants in humanitarian settings

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ABSTRACT

Child malnutrition remains a major public health challenge in Sudan, partly due to limited access to nutrient-dense, complementary foods. Traditional sorghum-based thin gruels, such as *Nasha*, are widely consumed; however, their sensory and nutritional potentials have not been scientifically evaluated. This study aimed to assess the sensory acceptability and caregiver–child responses to *Nasha* formulations prepared from five sorghum cultivars and their blends, including the biofortified Dahab cultivar. Fifty-four caregivers and their children participated in the sensory evaluation of the nine *Nasha* formulations. Attributes such as color, taste, texture, aroma, mouthfeel, and overall liking were assessed using a 9-point hedonic scale, and children's emotional responses were recorded during feeding sessions. Statistical analyses included one-way analysis of variance, internal preference mapping (IPM), and partial least squares (PLS) regression. The blended Dahab + Dabar formulation received the highest liking score (8.1), whereas Dahab + Wad Ahmed and Dahab + Arfagadamek-8 showed strong acceptability. Both caregiver and child responses consistently favored these blends, indicating both sensory appeal and cultural acceptance. These findings suggest that biofortified sorghum-based gruels, such as *Nasha*, provide a culturally appropriate, affordable, and nutrient-dense complementary food option. Integrating sensory science into local food design could support sustainable strategies to improve child nutrition and strengthen dietary resilience in resource-limited settings.

1. Introduction

Sudan is currently experiencing one of the most severe humanitarian crises in the world, driven by protracted armed conflict, economic collapse, and escalating climate shocks (Mohamed and Lucero-Prisno, 2025; Otekunrin, 2025). This multifaceted emergency has significantly deepened the country's food and nutrition crisis, leading to widespread hunger and alarming levels of malnutrition (Hemmeda, 2025; Mohamed and Homeida, 2024). According to the *Sudan Humanitarian Situation Report, No. 28* (February 2025) by the United Nations Children's Fund (UNICEF), over 770,000 children are at immediate risk of severe wasting, with acute malnutrition rates surpassing emergency thresholds and exceeding 30 % in some regions, indicating conditions that could lead to famine. These overlapping shocks have crippled national food systems and health infrastructure, placing infants and children at a heightened risk of life-threatening malnutrition and critical micronutrient deficiencies (Mohamed and Homeida, 2024).

The increasing inaccessibility of commercial weaning foods is driven by insecurity, import dependency, and the collapse of cold-chain logistics, which has further exacerbated the vulnerability of infant nutrition. The inability to access safe and nutritionally adequate complementary foods during the critical weaning period poses a serious threat to child survival, particularly in conflict-affected and resource-limited areas (Nassanga et al., 2018). These intersecting challenges highlight the importance of developing low-cost, easily scalable, and locally produced feeding solutions that can be implemented using available raw materials, traditional techniques, and female-led production systems (Fernandes et al., 2023; Haro-Vicente et al., 2017; Wati et al., 2024). In this context, it is critical to explore community-based food innovations that combine nutritional adequacy, cultural acceptance, and economic

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feasibility. Such approaches ensure that production and preparation costs remain minimal, enabling local households and small-scale processors to reproduce and sustain these products without external dependency.

In response to this need, sorghum emerges as a valuable local resource for improving infant nutrition, particularly when processed through germination and fermentation. These methods enhance the quality of protein, the amount of nutrients, and the ease of digestion, making sorghum-based formulas better for weaning (Oloyede et al., 2019; Tizazu et al., 2010). Fermentation, especially when combined with other local staples, further boosts the nutritional value of sorghum, making it a key tool for addressing childhood malnutrition in resource-limited settings (Adejuwon et al., 2021; Asma et al., 2006). Moreover, sorghum is drought-tolerant, widely cultivated across Sudan, and requires minimal inputs, positioning it as a practical and scalable base for nutritious food products during crises.

Nasha, a traditional sorghum-based porridge widely prepared by Sudanese women, is a promising and culturally accepted solution for childhood malnutrition in crisis-affected areas (Graham et al., 1986). Produced through fermentation, wet milling, and cooking, *Nasha* offers both nutritional benefits and a cost-effective approach to address infant malnutrition, particularly given its low input requirements and local acceptance (Dirar, 1994). The fermentation process involves both lactic acid and alcoholic fermentation, utilizing microorganisms such as *Streptococcus*, *Lactobacillus*, *Candida* spp., and *Saccharomyces cerevisiae*, which enhance its digestibility and flavor profile (Monawar and Badi, 1986). The sour taste, culturally accepted and preferred for its appetite-stimulating properties, further aligns with local practices, particularly for malnourished children (Monawar and Badi, 1986). This culturally embedded food system represents a resilient, low-cost alternative for emergency nutrition interventions and long-term food sovereignty (Dirar, 1993).

From a scalability perspective, *Nasha* requires neither sophisticated equipment nor imported ingredients. It can be prepared using traditional household utensils, locally grown grains, and simple fermentation steps, enabling community-level replication and commercial upscaling by women's cooperatives in the region. These features make *Nasha* production economically viable, environmentally sustainable, and socially inclusive, particularly under crisis conditions.

Traditional Nasha is widely accepted within local diets; however, fortification may alter its sensory attributes. Assessing the acceptability of these modified formulations is therefore critical for their integration into complementary feeding practices. Aligning weaning foods with local dietary practices and agricultural systems is crucial to enhancing nutritional outcomes. To optimize the promotion of sorghum-based weaning foods, it is essential to integrate sensory evaluations involving both children and their caregivers, given their roles in feeding infants. Responsive feeding, in which caregivers recognize and respond appropriately to children's hunger, satiety, and emotional cues, plays a vital role in fostering children's ability to self-regulate their energy intake, especially when they encounter new foods (Black and Aboud, 2011; Larsen et al., 2015). As emotional reactions influence how children accept unfamiliar foods, caregivers' responses to these cues are vital in determining the success of new formulations (Fernandes et al., 2023; Frankel et al., 2012; Wati et al., 2024).

This study aimed to evaluate the sensory acceptability of various *Nasha* formulations prepared from different Sudanese sorghum cultivars, including the biofortified cultivar Dahab, developed to combat iron and zinc deficiencies in Sudanese children. Caregiver feedback and children's emotional responses were the primary indicators for assessing the feasibility of incorporating these formulations into complementary feeding programs. This study was conducted to inform the development of culturally appropriate and nutritionally enhanced feeding solutions, potentially contributing to the long-term resilience and scalability of community-based food systems in Sudan.

2. Materials and Methods

2.1. Plant materials and participants

Five sorghum cultivars, Dabar, Wad Ahmed, Arfaa Gadamak-8, Eheemer, and Dahab, were used to prepare *Nasha* formulations for sensory and emotional evaluation. Fifty-four caregivers (aged 20–42 years) with infants and children aged 1–5 years participated in this study. They were recruited through community sensitization sessions in Wad Dayied village, Al-Gadareif state, Sudan, and selected as regular *Nasha* consumers ($\geq$2 times per month). Participants with food allergies, illnesses, or sensory impairment were excluded.

Dabar (PI 569666, IS, 20579) is a non-tannin sorghum with white, round, and plump grains. At the same time, Wad Ahmed is a Feterita type II cultivar known for its dense, tannin-rich testa. Arfa gadamak-8 is a white-grained Feterita type II. Eheemer (locally known as Feterita Hemaira) is a traditional dura landrace used for infant feeding. Dahab is a biofortified sorghum cultivar released in Sudan in 2022, enriched with iron (45 ppm) and zinc (32 ppm) to combat micronutrient deficiencies with minimal impact on sensory acceptability (Gobara Hamid et al., 2025; Sayed Abdelhalim T et al., 2025). All grain samples were sourced from the Agricultural Research Corporation (ARC) at Al-Gadarif Research Station, Sudan. The samples were manually sorted, cleaned, and washed thoroughly with potable water to remove dust, debris, and other contaminants.

2.2. Nasha preparation

Nasha was prepared following a culturally grounded, standardized decantation-based protocol (Dirar, 1993), with slight modifications. The preparation steps were verified with local women from the Al-Wefag Women's Cooperation in Wad Dayief Village, Al-Gadarif, Sudan, to ensure cultural authenticity and replicability. Cleaned grains were soaked (1:1.5 (w/v) for 8 h at 25–30 °C, wet-milled twice using a traditional quern, and fermented for 6 h at ambient temperature.

After fermentation, the paste was diluted (1:15 (w/v)), filtered through a 0.5 mm mesh, and the supernatant was collected after 20 min of settling time. The filtrate was gently heated to 80–90 °C under constant stirring until starch gelatinization was observed (transition from opaque to translucent), and granulated sugar (3 g per 100 mL) was added to enhance palatability Fig. 1). Nine *Nasha* formulations were prepared: five single-cultivar types (Dabar, Wad Ahmed, Arfa Gadamek-8, Eheemer, and Dahab) and four 1:1 (w:w) blends of Dahab with each traditional cultivar (see Fig. 2).

2.3. Ethical considerations

All procedures were approved in accordance with the Emergency Field Ethics Guidelines. Verbal consent was obtained owing to the participants' low literacy levels, and parental consent was obtained for each child. Participation was voluntary, and withdrawal was permitted at any time, without penalty. Each participant received a small gift as a token of appreciation, and their responses were anonymized. Data confidentiality and ethical standards were in accordance with the Declaration of Helsinki.

2.4. Emotional reactions and behavioral response assessments

Before testing, caregivers received short training sessions on observing infant feeding cues and the principles of responsive feeding Black and Aboud (2011). They were instructed to document the children's facial expressions, gestures, vocalizations, and reactions using real-time observation sheets adapted from Fabes et al. (2002). Reactions were categorized as positive (e.g., eagerness to eat, smiling, and repeated requests), neutral (e.g., passive tasting or indifference), or negative (e.g., refusal, turning away, and signs of distress).

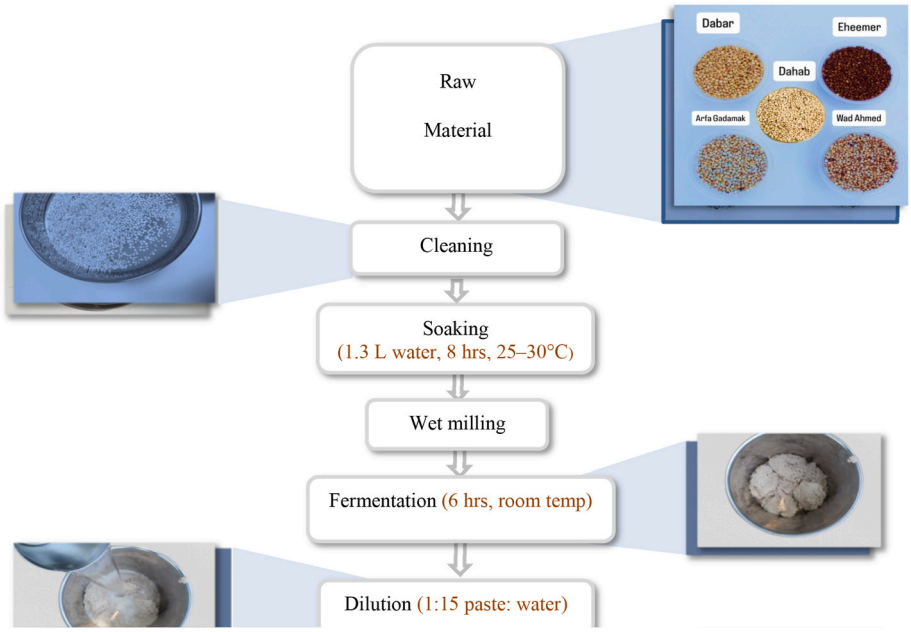

Fig. 1. Illustrates a flowchart detailing the preparation process for *Nasha*. The process involves cleaning, soaking, wet milling, fermentation, dilution, straining, cooking, sweetening, and cooling, followed by a sensory evaluation.

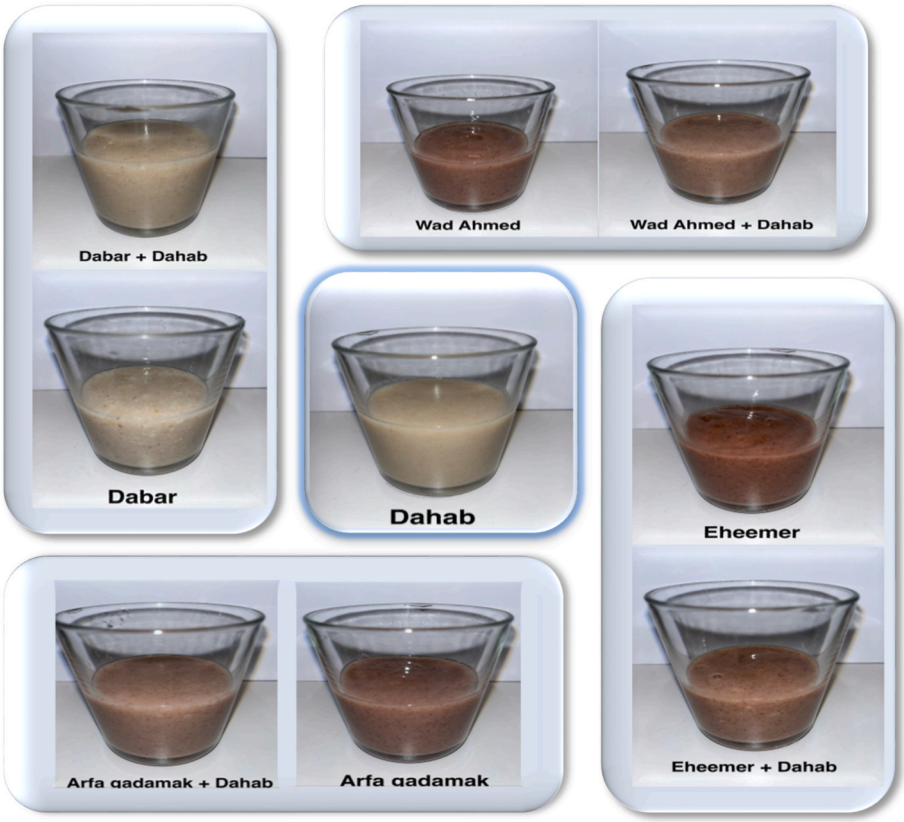

Fig. 2. Visual appearance of the nine *Nasha* formulations prepared from single or blended Sudanese sorghum cultivars: Dabar, Wad Ahmed, Arfaa Gadamak-8, Eheemer, and the biofortified Dahab. Blends were prepared at a 1:1 (w: w) ratio of Dahab to each traditional cultivar.

2.5. Descriptive sensory analysis methods

A rapid descriptive analysis (RDA) method, a validated rapid sensory descriptive technique that requires semi-trained panelists, was used to identify relevant sensory attributes without the extensive training needed in classical descriptive analysis (Nakitto et al., 2022). Each 100 mL sample was served warm in cups coded with three digits under standardized hygienic conditions to ensure consistent viscosity and fermentation levels. The samples were presented in a randomized Latin square design to minimize bias. Participants evaluated six sensory

attributes (appearance, color, aroma, taste, mouthfeel, and texture) using RDA to generate applicable descriptors (Table 1). Brief targeted training with reference examples was provided to ensure consistent terminology, as recommended for rapid descriptive sensory methods. Overall liking was evaluated using a nine-point hedonic scale (1 = extremely dislike, 9 = extremely like).

2.6. Familiarization and test sessions

Caregivers were instructed to feed their infants using standardized utensils (a bib and spoon) provided by the research team to ensure consistency and minimize external variation. A familiarization phase was conducted three days before the first testing session to help the children adapt to the feeding environment and procedures. All sessions were conducted in a clean, well-ventilated setting with consistent lighting and minimal distractions. The feeding protocol followed that of Mennella and Beauchamp (1997), comprising three sessions, each presenting three distinct Nasha formulations (a total of nine samples). The order of the presentations was randomized using a Latin square design to minimize the order and carryover effects. To minimize caregivers' influence on infant responses, participants wore face masks during the feeding sessions to reduce nonverbal cue bias (Gunnar and Stone (1984).

Caregivers were instructed to avoid offering new foods within 12 h before testing to prevent external dietary influences. Compliance was monitored using daily feeding logs and periodic follow-up (Gerrish and Mennella (2001). Infant reactions during each feeding were recorded by trained observers using standardized checklists documenting facial expressions, food acceptance or refusal, spitting, and eagerness to eat.

2.7. Emotional acceptability assessment

Emotional acceptability was assessed using a nine-point hedonic scale to quantify infants' reactions: 1–4 indicated negative responses (e.g., rejection and turning away), 5 indicated neutrality, and 6–9 indicated positive reactions (e.g., smiling and eagerness). The scale was adapted from validated infant sensory and feeding behavior protocols (Mennella et al., 2009, 2016; Schwartz et al., 2011), which are widely used to capture infants' nonverbal emotional responses during complementary food introduction. The scale was pilot-tested for clarity and relevance. This nonverbal assessment framework enabled consistent interpretation of infants' emotional and behavioral responses and provided additional insight into the sensory acceptability of *Nasha*-based formulations.

2.8. Statistical analysis

Hedonic scores for sensory evaluation were calculated using the Liking Analysis package in XLSTAT statistical software (Addinsoft, 2025; https://www.xlstat.com/en/) (Fliedel et al., 2022). Analysis of variance (ANOVA) was performed to assess the significant differences in the overall liking scores among the *Nasha* formulations. Mean separation was conducted using Tukey's HSD test at a significance level of 0.05. Internal preference mapping was performed using principal component analysis (PCA) to visualize the caregivers' preferences for the examined *Nasha* formulations. In contrast, cluster analysis has been used to identify groups of caregivers with similar sensory preferences (Fernández-Vázquez et al., 2018).

The Product Characterization package in XLSTAT generated a heatmap output summarizing the adjusted means of each sensory attribute across the nine *Nasha* formulations; these values are presented in Table 4 (Dijksterhuis, 1995). A sensory mapping profile was generated using a heat map, with gradient colors indicating positive and negative feedback from the assessors for each product and descriptor. This method provides a clear visualization of the sensory attributes that contribute to the most preferred formulations (Rios-Vega et al., 2024). To validate the most preferred *Nasha* formulation, partial least squares regression (PLSR) was conducted using XLSTAT software (Tenenhaus et al., 2005). Correlation plots and variable importance in projection (VIP) scores were generated to determine the strength of the relationships between the sensory descriptors and *Nasha* formulations.

Children's emotional feedback was captured using the classical sensory wheel package in XLSTAT, which categorizes responses as positive, neutral, or negative. A pivot table in Excel was used to summarize and describe the emotional responses of the children, and statistical analysis was used to assess patterns in their reactions (Berridge and Kringelbach, 2008). All statistical figures and analytical plots, including sensory mapping profiles and VIP analysis plots, were created using SigmaPlot software to enhance the clarity and interpretation of the sensory evaluation results.

Table 1
Sensory attributes, descriptions, and examples of anchor terms used in the caregiver questionnaire for evaluating the *Nasha* formulations.

Attribute	Description	Example anchor term
Appearance	The *Nasha* surface's visual appeal	Glossy, dull
Color	Lightness or darkness of *Nasha*	Creamy, brownish
Aroma	Smell intensity and pleasantness	Mild, fermented
Taste	Flavor acceptability	Sweet, sour
Mouthfeel	Texture perception during drinking	Smooth, coarse
Texture	Consistency after swallowing	Thick, watery

3. Results

3.1. Demographic profile of caregivers and their infants/young children

A total of 54 caregivers participated in the study, most of whom were aged 25–34 years (48.1 %) or 35–44 years (40.7 %). Educational attainment varied: 29.6 % had completed high school, 27.8 % primary school, 20.4 % had a bachelor's degree, and only 3.7 % were illiterate. The participants represented 10 ethnic groups, predominantly Tamaa (35.2 %) and Fur (25.9 %) (Table 2).

Nasha consumption was firmly rooted in local sorghum traditions: 88.9 % preferred formulations made from Feterita cultivars (Wad Ahmed, Wad Aker, Degias, and Arfa Gadamek-8). The consumption frequency was high, with one-third consuming *Nasha* twice weekly and more than half reporting daily intake (Table 2).

Among the 54 infants and young children, most were aged 3–4 years (61.1 %) with a balanced sex distribution (51.9 % male and 48.1 % female). *Nasha* was a staple food, with 46.3 % and 24.1 % of the participants consuming it twice and once daily, respectively. Complementary feeding was initiated at six months for nearly half of the children (46.3 %), while about one-third began earlier (4–5 months) or later (>12 months) (Table 3).

3.2. Hedonic profiles, internal preference mapping (IPM), and cluster analysis of caregivers

The liking scores were derived from caregivers' evaluations using a nine-point hedonic scale (1 = extremely disliked, 9 = extremely liked), as described in the Materials and Methods section under the rapid sensory descriptive method. Each caregiver rated all nine *Nasha* formulations for overall liking and six key sensory attributes: appearance, color, aroma, taste, mouthfeel, and texture. The scores were statistically analyzed using ANOVA, IPM, and cluster analyses.

One-way ANOVA indicated a significant difference ($P < 0.05$) in the overall liking scores among the nine *Nasha* formulations (Fig. 3A). The Dahab + Dabar blend achieved the highest mean score (8.1), followed by Dahab (7.6) and Wad Ahmed (7.3) blends. Intermediate acceptability was observed for Dahab + Arfagadamek-8 (6.9) and Dahab (6.8), whereas formulations such as Dahab + Wad Ahmed and Dahab + Eheemer scored 6.4 each, indicating moderate liking. The lowest rating was recorded for Eheemer-based *Nasha* (4.7), reflecting a low preference

Table 2
Demographic profiles of participating caregivers, including age group, education level, ethnic background, preferred *Nasha* formulations, and frequency of *Nasha* consumption (N = 54).

Category	Variable	Frequency	Percentage (%)
Age group	Youth (15–24)	6	11.1
	Young Adults (25–34)	26	48.1
	Middle-aged Adults (35–44)	22	40.7
Education levels	Bachelor	11	20.4
	High school	16	29.6
	Illiterate	2	3.7
	Intermediate	10	18.5
	Primary school	15	27.8
Ethnic background	Barte	5	9.3
	Brno	4	7.4
	Fur	14	25.9
	Goamr	1	1.9
	Maranen	1	1.9
	Maserriia	2	3.7
	Nuba	1	1.9
	Tamaa	19	35.2
	Tangr	2	3.7
	Zagawa	5	9.3
Preferred Nasha formulations	Dabar	1	1.9
	Feterita	48	88.9
	Feterita + Dabar	1	1.9
	Feterita + Rice	1	1.9
	Rice	2	3.7
	Wheat	1	1.9
Nasha Consumption Frequency	Twice a day	14	25.9
	Once a day	16	29.6
	3-6 times/week	5	9.3
	Twice a week	18	33.3
	Twice a month	1	1.9

Table 3
Demographic profiles of participating infants and young children, including age group, sex, frequency of *Nasha* consumption, and times of starting complementary feeding (N = 54).

Category	Variables	Frequency	%
Age (year)	Toddlers (1–2)	9	16.7
	Preschoolers (Early) (3)	15	27.8
	Preschoolers (Middle) (4)	18	33.3
	Preschoolers (Late) (5)	12	22.2
Sex	Female	26	48.1
	Male	28	51.9
Nasha consumption frequency	Twice a day	25	46.3
	Once a day	13	24.1
	3-6 times a week	1	1.9
	twice a week	12	22.2
	twice a month	3	5.6
Starting complementary feeding (months)	3	2	3.7
	4	11	20.4
	5	5	9.3
	6	25	46.3
	7	2	3.7
	8	1	1.9
	12	2	3.7
	24	6	11.1

(Fig. 3A).

Internal preference mapping (Fig. 3B), based on principal component analysis (PCA), explained 57.9 % of the total variance in the overall liking (F1 = 41.07 % and F2 = 16.83 %). Most caregivers' preferences

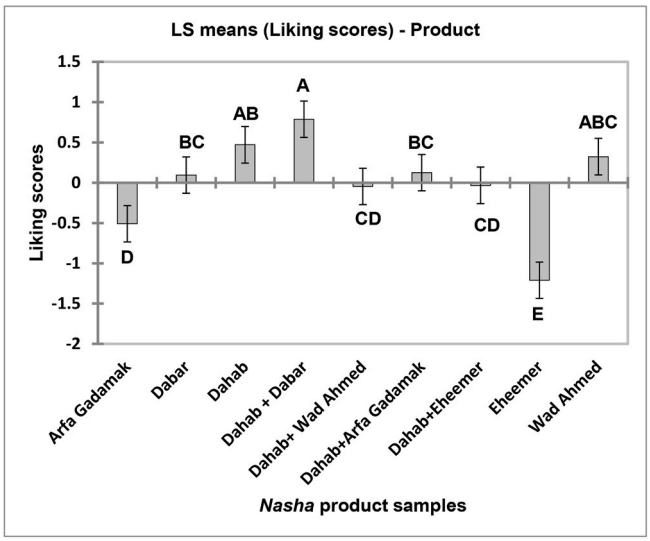

Fig. 3A. Least squares mean liking scores of the 54 participating caregivers for nine *Nasha* formulations (A). Means were separated using Tukey's HSD test. Column bars with different letters indicate statistically significant differences at $P < 0.05$.

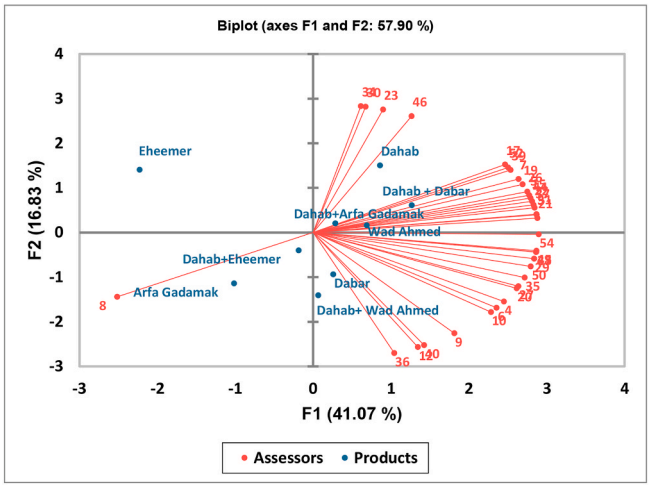

Fig. 3B. shows a biplot illustrating the internal preference mapping of the *Nasha* formulations and the assessors' preferences.

clustered in the upper right quadrant, corresponding to high ratings for the Dahab, Dabar, and Wad Ahmed formulations. Formulations such as Dahab + Arfagadamek and Dahab + Eheemer appeared near the origin, indicating mixed acceptability. In contrast, Arfagadamek and Eheemer were isolated on the negative F1 axis, reflecting their low preference. The distribution of caregivers (red dots) confirmed that most respondents were positioned near high-performing products on the right-hand side of the preference map, with very few showing a preference for Arfagadamek-8 or Eheemer (Fig. 3B).

Cluster analysis (Fig. 3C) grouped the 54 caregivers into two distinct clusters. Cluster 1 (37.0 %) expressed a strong preference for Dahab, Dahab + Dabar, and Wad Ahmed, aligning with the PCA distribution. Cluster 2 (63.0 %) showed moderate acceptance for Dahab + Arfagadamak, and Dahab + Eheemer, but consistently disliked Eheemer-based formulations (Fig. 3C).

3.3. Product characterization

The results revealed that all six sensory descriptors evaluated by the

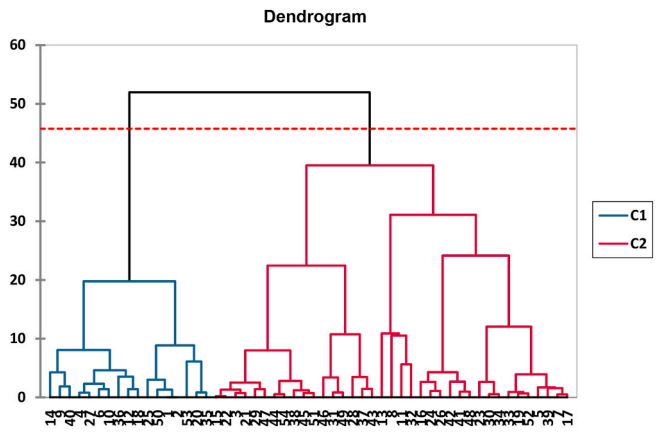

Fig. 3C. Cluster analysis of participating caregivers used Agglomerative Hierarchical Clustering (AHC) based on Euclidean distance, grouping caregivers into two distinct clusters according to their overall liking scores for *Nasha* formulations.

54 participating caregivers significantly contributed to differentiating the nine *Nasha* formulations ($p < 0.001$) (Fig. 4A). The most discriminating attributes were appearance (test value = 7.845) and color (test value = 5.191). Texture showed moderate discriminating power (4.602), followed by taste (3.393) and aroma (3.155). Mouthfeel exhibited the lowest discriminating power with a test value of 2.436.

The biplot with 95 % confidence ellipses (Fig. 4B) illustrates the distribution of nine Nasha formulations and six sensory descriptors, as evaluated by 54 caregivers, across the first two principal components, F1 and F2, which together explained 91.64 % of the total variance (F1 = 77.55 %; F2 = 14.10 %). Based on squared cosine values, the products Dahab + Dabar (0.964), Dahab (0.930), Arfa Gadamak (0.817), Eheemer (0.780), and Wad Ahmed (0.608) were strongly associated with F1. In contrast, Dahab + Wad Ahmed (cos^2 = 0.845), Dabar (0.648), and Dahab + Arfa Gadamak-8 (0.413) were strongly represented along the F2.

In the biplot, appearance, color, and aroma were heavily loaded on the positive side of F1 and closely aligned with Dahab and Dahab + Dabar, indicating that these Nasha samples exhibit favorable visual and aromatic attributes. In comparison, taste, texture, and mouthfeel were oriented toward the upper right quadrant, contributing to the profiles of Dahab + Arfagadamak-8 and Dahab + Wad Ahmed, but to a lesser extent. *Nasha* formulations, such as Eheemer and Dahab + Eheemer, clustered in the lower-left quadrant, indicating their association with less-preferred sensory traits (Fig. 4B).

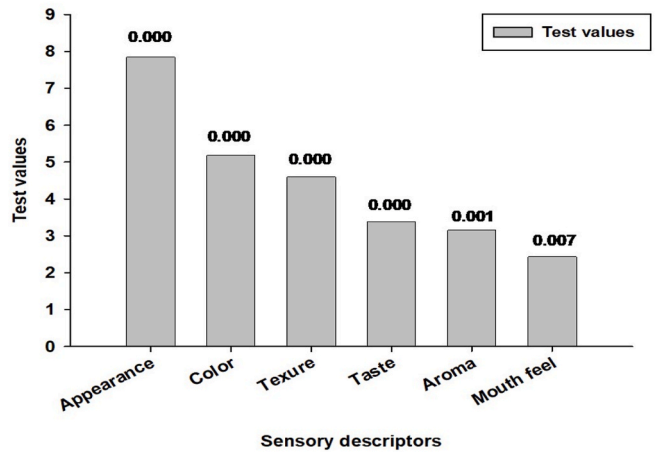

Fig. 4A. Discriminating power using descriptors derived from nine Nasha formulations.

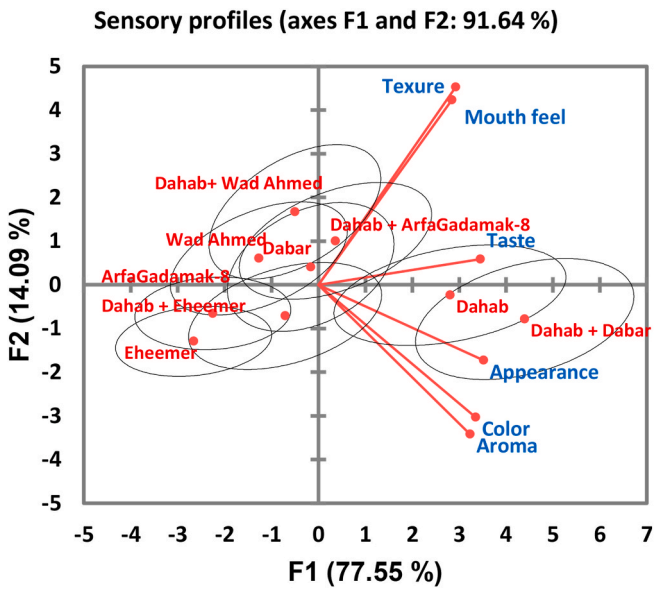

Fig. 4B. Biplot with 95 % confidence ellipses for the sensory profiles obtained by principal component analysis (PCA).

Table 4 presents the adjusted means for each sensory descriptor obtained from the XLSTAT Product Characterization heat-map output, highlighting the relative contributions of appearance, aroma, taste, and texture to overall liking. Among all *Nasha* samples, *Dahab* + *Dabar* blend consistently received the highest scores, particularly for appearance (7.13), color (6.25), taste (5.83), and aroma (5.57), indicating a strong consumer preference. *Dahab* formulation also performed well, particularly in terms of appearance (6.167) and texture (5.574).

Dabar alone exhibited moderate yet acceptable sensory performance in terms of taste (4.72), mouthfeel (4.91), and texture (4.72). In contrast, *Eheemer* received relatively lower scores, particularly for appearance, color, and texture (3.352), suggesting limited consumer appeal. Formulations combining *Dahab* with *ArfaGadamak-8* showed positive ratings, particularly for taste (5.167) and mouthfeel (5.370), indicating synergistic effects. *The Dahab* + *Wad Ahmed* blend received moderate scores, with notable improvements in mouthfeel (5.222) and texture (5.315) compared with *Wad Ahmed* alone, which scored positively only in texture (4.796) (Table 4).

3.4. Partial least squares regression and VIP analysis of Nasha Formulations

Partial Least Squares Regression (PLSR) analysis was performed to assess the relationship between the nine *Nasha* formulations and the six sensory attributes. The Dahab + Dabar formulation was positioned near appearance, color, aroma, and taste, indicating a strong positive association with these variables. The Dahab formulation was also aligned with appearance and aroma, while Dahab + ArfaGadamak-8 and Dahab + Eheemer were positioned near the texture and mouthfeel. In contrast, formulations such as Eheemer and ArfaGadamak-8 appeared farther from key sensory vectors. Based on the PLS model, the *Nasha* prepared from the Dahab + Dabar blend was proven to be the most valid and could be harnessed directly as a complementary weaning food for mainstream *Nasha* (Fig. 5A).

Variable importance in projection (VIP) scores supported these associations. Appearance recorded the highest significance in both components ($VIP_1 = 1.079$, $VIP_2 = 1.022$), followed by taste ($VIP_1 = 1.059$), color ($VIP_1 = 1.042$, $VIP_2 = 1.021$), and aroma ($VIP_1 = 1.000$, $VIP_2 = 1.004$). Mouthfeel and texture had lower scores in the first component (VIP_1 = 0.902 and 0.903, respectively), with slight increases in the second component ($VIP_2 = 1.012$ and 0.960, respectively) (Fig. 5B).

Table 4
Adjusted means for each formulation of the *Nasha* product sample characteristics.

	Appearance	Taste	Color	Aroma	Mouthfeel	Texture
ArfaGadamak-8	4.130	3.963	4.111	3.963	3.926	4.222
Dabar	4.500	4.722	4.333	4.370	4.907	4.722
Dahab	6.167	5.056	5.481	5.389	5.222	5.574
Dahab + ArfaGadamak-8	4.778	5.167	4.037	4.333	5.370	4.611
Dahab + Dabar	7.130	5.833	6.259	5.574	5.389	5.444
Dahab + Eheemer	4.463	4.352	4.630	4.537	4.741	3.907
Dahab + Wad Ahmed	3.926	4.407	3.981	4.093	5.222	5.315
Eheemer	3.648	4.000	3.852	4.370	4.019	3.352
Wad Ahmed	4.500	4.167	4.130	3.796	4.611	4.796

Blue corresponds to coefficients with significantly positive values, and red corresponds to coefficients with significantly negative values.

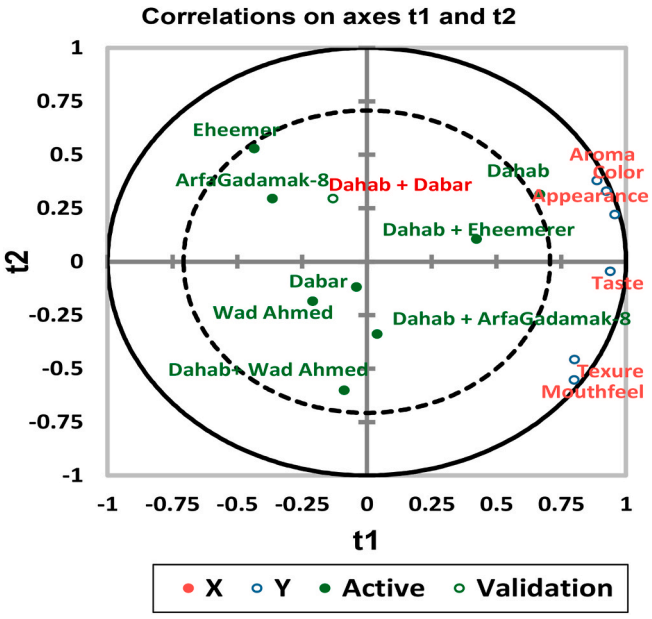

Fig. 5A. is a biplot representing the Partial Least Squares Regression (PLSR) derived from the contingency table of porridge products and sensory descriptors.

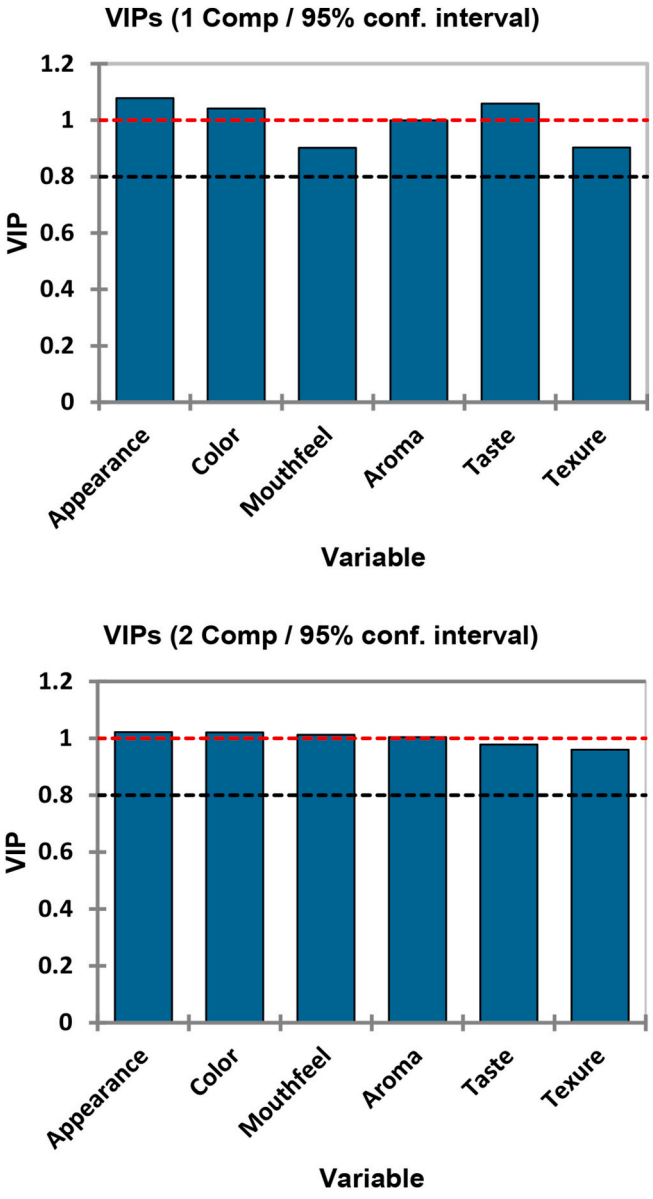

Fig. 5B. Variable importance in the projection (VIP) scores for sensory attributes contributing to partial least squares regression of *Nasha* formulations.

3.5. Sensory wheel and emotional response mapping

Fig. 6 presents the sensory wheel of infants' behavioral responses to *Nasha* formulations based on observational feeding data. Emotional reactions were classified into three primary valence domains: positive, neutral, and negative, each comprising distinct behavioral indicators. Positive reactions, located in the outer right segment, included being *eager*, *happy*, *accepting*, *curious*, *independent, joyful, demanding, satisfied,* and *hungry*, reflecting varying degrees of acceptance and engagement. Neutral responses, positioned clockwise, encompassed *thoughtful*, *distracted*, *pensive*, *playful*, and *cautious responses*, indicating uncertainty or exploratory behavior. Negative reactions grouped under rejection included *rejection*, *resistance*, *refusal, disgust, negativity, hostility, frustration, and being upset* (Fig. 6).

3.6. Behavioral indicators and emotional valence scores

In total, 1130 emotional responses were recorded from 54 infants and young children in response to the nine *Nasha* formulations. These were categorized as positive (n = 947, 83.8 %), neutral (n = 164, 14.5 %), or negative (n = 19, 1.7 %) reactions. Positive reactions were the most frequent in all formulations. "Eager" (252 responses; 51.9 %) and "Accepting" (190; 39.1 %) were the dominant indicators, followed by "Joyful" (100; 20.6 %), "Happy" (97; 20.0 %), and "Satisfied" (74; 15.2 %). The Dahab + ArfaGadamak blend elicited the highest number of positive responses (n = 121), followed by Dahab + Dabar (n = 116) and Dabar alone (n = 113), whereas Eheemer yielded the lowest number of positive responses (n = 84) (Table 5).

Neutral reactions accounted for 14.5 % of all the responses. The most prevalent neutral behavior was "Cautious" (n = 77; 15.8 %), followed by

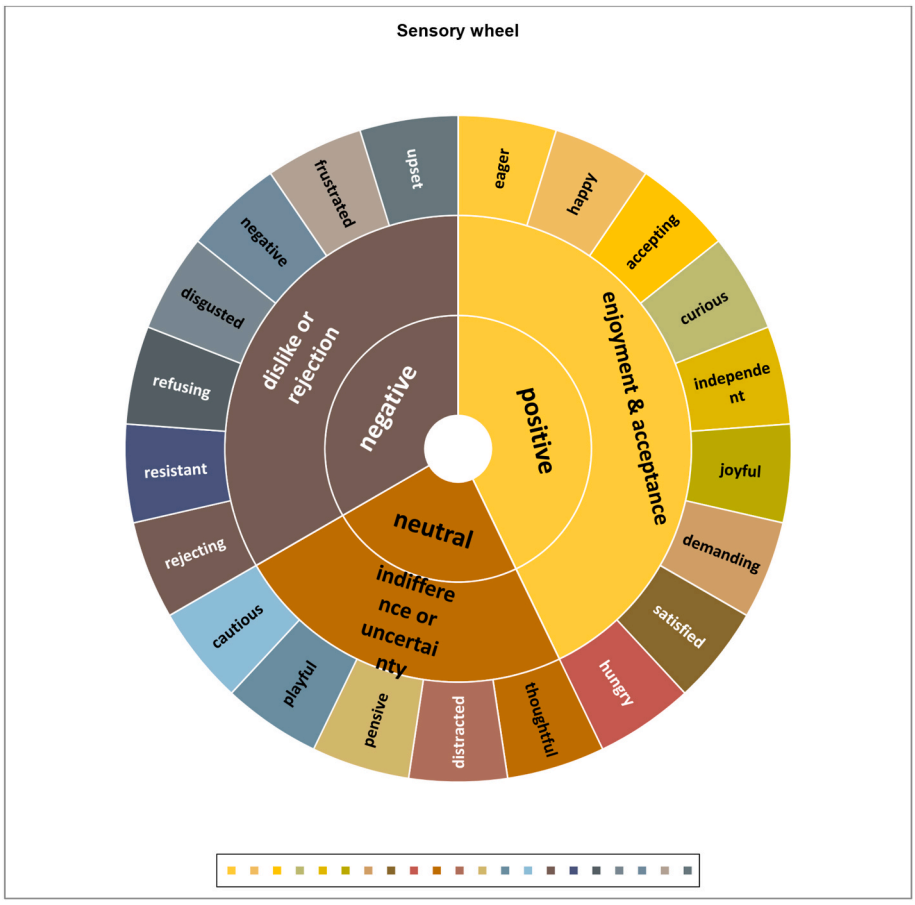

Fig. 6. The sensory wheel provides a structured visual framework for interpreting the behavioral responses of infants and children to *Nasha* formulations.

Table 5
Emotional reactions of infants and young children to nine Nasha formulations: Frequency and distribution of positive, neutral, and negative behaviors.

Reaction	AG	Dab	Dah	Dah + Dab	Dah + WA	Dah + AG	Dah + Ehe	Ehe	WA	Total	(%)
Eager	25	28	31	32	28	27	30	24	27	**252**	**51.9**
Happy	7	8	11	16	11	13	14	7	10	**97**	**20.0**
Accepting	20	21	21	17	20	29	22	19	21	**190**	**39.1**
Curious	15	16	11	14	13	18	11	8	11	**117**	**24.1**
Independent	3	4	3	2	3	4		1	3	**23**	**4.7**
Joyful	8	13	14	16	7	11	11	7	13	**100**	**20.6**
Demanding	10	8	4	9	11	8	9	6	8	**73**	**15.0**
Satisfied	8	9	11	7	5	11	8	9	6	**74**	**15.2**
Hungry	3	6	1	2	2	0	2	3	2	**21**	**4.3**
Total positive	**99**	**113**	**107**	**115**	**100**	**121**	**107**	**84**	**101**	**947**	
Thoughtful	0	1	0	0	0	0	0	0	2	**4**	**0.82**
Distracted	5	5	5	8	8	3	9	5	9	**57**	**11.73**
Pensive	1	0	0	1	0	0	0	1	4	**7**	**1.44**
Playful	1	1	3	2	3	2	2	3	2	**19**	**3.91**
Cautious	7	10	7	8	8	7	6	11	13	**77**	**15.84**
Total neutral	**14**	**17**	**15**	**19**	**19**	**12**	**17**	**20**	**30**	**164**	
Rejecting	1	0	1	0	0	0	0	3	0	**5**	**1.03**
Resistant	0	0	0	0	0	0	0	0	0	**0**	**0.00**
Refusing	0	0	0	0	0	0	1	1	0	**2**	**0.41**
Disgusted	1	0	1	0	0	0	0	4	0	**6**	**1.23**
Negative	1	0	0	0	1	0	0	2	0	**4**	**0.82**
Frustrated	0	0	0	0	0	0	0	0	0	**0**	**0.00**
Upset	0	0	0	0	0	0	0	2	0	**2**	**0.41**
Total negative	**3**	**0**	**2**	**0**	**1**	**0**	**1**	**12**	**0**	**19**	

"Distracted" (n = 57; 11.7 %). Wad Ahmed had the highest neutral response rate (n = 30), followed by Eheemer (n = 20). In contrast, negative reactions were rare (1.7 %), with "Disgusted" (n = 6; 1.23 %) and "Rejecting" (n = 5; 1.03 %) being the least frequently observed. Negative responses were predominantly linked to Eheemer (n = 12), whereas several formulations, including Dabar, Dahab + Dabar, Dahab

+ Arfa Gadamak, and Wad Ahmed, did not elicit negative reactions. Overall, blends containing Dahab tended to elicit higher positive and lower negative emotional responses than single local cultivars (Table 5).

4. Discussion

Sudan's deepening humanitarian crisis has critically disrupted food systems and healthcare services, intensifying inadequate weaning practices and accelerating the prevalence of malnutrition among children under five (Hemmeda, 2025). As the conflict continues to displace millions of Sudanese, families are forced into internally displaced persons (IDPs) and refugee camps, where access to diverse, safe, and nutritionally adequate food is constrained. Infants, young children, and pregnant and lactating women are the most nutritionally vulnerable populations in fragile environments (Noorallah et al., 2024). Therefore, there is an urgent need to develop cost-effective, nutrient-rich, and culturally acceptable complementary foods tailored to crisis settings (Dahab et al., 2020). Harnessing locally available and traditionally consumed ingredients, such as sorghum-based preparations like *Nasha*, offers a promising strategy for sustaining child nutrition and strengthening dietary resilience. To ensure both acceptance and nutritional adequacy, this effort must adopt a holistic framework that integrates sensory evaluation, maternal education, and consistent availability of suitable food products. Emphasizing the interplay among sensory appeal, cultural relevance, and practical feeding behaviors is essential for designing effective interventions to improve infant nutrition during this critical developmental window.

In this study, we developed a cost-effective, nutrient-enriched weaning food based on *Nasha*, a traditional Sudanese porridge made from sorghum, by blending adapted sorghum cultivars with the biofortified variety, Dahab. Sensory evaluation conducted with caregivers and their children revealed that formulations such as Dahab + Dabar received the highest hedonic scores, averaging 8.1 on a 9-point scale, significantly outperforming other blends. These results underscore the strong acceptability of Dahab-based formulations and support their potential to enhance complementary feeding practices in Sudan. These findings are consistent with those of Gunaratna et al. (2016), who reported a high acceptance of biofortified quality protein maize (QPM) among women and children in rural Ethiopia. In their study, QPM was preferred over conventional maize primarily because of its favorable sensory characteristics, including texture and aroma. Notably, both studies utilized culturally familiar food vehicles, such as *Nasha* in Sudan and maize porridge in Ethiopia, to assess the acceptability of biofortified crops in household feeding contexts. These parallels underscore the importance of culturally relevant formulations and participatory sensory assessments in fostering the consumer adoption of biofortified products.

Building on these findings, the preference for Dahab-based formulations was consistent with our previous study on *Aceda* (Hamid et al., 2025). In stiff sorghum porridge, blends such as Dahab and Wad Ahmed also received the highest overall liking scores. Although *Nasha* and *Aceda* differ in texture and use, the consistent appeal of Dahab-based blends across both products indicates that the sensory advantage of this biofortified cultivar is robust across the product matrices. However, variations in preferences linked to texture and consumption contexts indicate the need for further exploration. Understanding how porridge consistency affects sensory perception and acceptance could support the development of tailored formulations for different age groups, meals, and feeding practices.

Our investigation demonstrated the value of incorporating caregivers' perceptions into the sensory evaluation of complementary foods. This aligns with the work of Mabilia (1996), who demonstrated that caregivers' culturally embedded beliefs, such as non-coercive feeding practices and intuitive judgments about what constitutes "good" food, directly shape infant feeding behaviors and nutritional outcomes. By acknowledging these cultural logics, our sensory evaluation approach has ecological validity, ensuring that biofortified formulations, such as *Nasha,* are not only nutritionally adequate but also contextually and culturally acceptable. These insights are further supported by Pelto and Brown (2012), who emphasized that caregiver beliefs and practices are foundational in shaping feeding environments and in developing culturally appropriate interventions. International frameworks, such as the FAO/WHO guidelines, also reinforce this participatory approach, highlighting the essential role of household food preparers in sensory and dietary assessments because of their experiential knowledge and influence on feeding decisions.

Our findings align with those of Aboubacar et al. (1999), who studied the consumer acceptance of sorghum porridge in West Africa. They found that color significantly influenced consumer preference for lighter-colored variants. This supports the notion that visual attributes, such as color, are crucial for evaluating the acceptability of food products, as consumers frequently associate color with taste, texture, and overall quality. In our study, we found that the less favorable color (dark brownish to reddish) of *Nasha* made from Eheemer negatively affected its visual appeal and led to lower acceptance among both caregivers and children. Thus, to enhance the sensory acceptability of *Nasha* and similar products, it is crucial to consider the visual traits that align with consumer preferences, as they are closely tied to cultural norms and expectations regarding food.

The emotional responses of young children to the nine *Nasha* formulations revealed meaningful variations in affective engagement, thereby providing a complementary dimension to the traditional sensory evaluations. Blends involving the biofortified sorghum variety Dahab, particularly Dahab + Dabar and Dahab + Arfa Gadamak, elicited the highest rates of positive emotional reactions such as eagerness, smiling, and proactive feeding behaviors. These observations suggest that children not only found these formulations palatable but also emotionally rewarding, aligning with the concept of incentive salience, wherein certain foods evoke strong motivational responses independent of hedonic pleasure (Berridge and Kringelbach, 2008). Conversely, formulations such as Eheemer alone elicited a relatively higher proportion of negative, harmful, and adverse reactions compared with other samples, although these were infrequent overall, paralleling prior findings on texture aversion and food neophobia in early childhood (Chow et al., 2024; Mura Paroche et al., 2017). These behavioral patterns highlight the role of sensory congruence and familiarity in shaping early food experiences, suggesting that emotional responsiveness during feeding can serve as a reliable indicator of acceptance in complementary food development.

The findings of our study, which demonstrated the high sensory acceptability of Dahab-based *Nasha* formulations, particularly Dahab + Dabar, indicate the potential of biofortified sorghum as a culturally acceptable complementary food in crisis settings in Sudan. However, as with other biofortified crops such as quality protein maize (QPM), sensory appeal alone may not be sufficient to drive widespread adoption. As demonstrated by De Groote et al. (2014), providing rural Tanzanian consumers with information on the nutritional benefits of QPM significantly increased their willingness to pay from 19 % to 39 %, highlighting the decisive role of awareness in shaping consumer demand. Similarly, integrating tailored nutrition education and awareness campaigns into community-based programs could enhance both the understanding and uptake of nutrient-dense *Nash* formulations. This is particularly relevant in settings such as Sudan, where caregivers are not only the primary food preparers but also key influencers in household dietary decisions. Informing caregivers about the health benefits of biofortified ingredients, such as Dahab, may thus further reinforce their preferences and drive sustained use, ultimately enhancing the impact of biofortification initiatives in regions prone to malnutrition.

5. Conclusion

This study demonstrates that *Nasha*, a traditionally fermented

sorghum-based gruel, is a nutritionally promising and culturally rooted complementary food for Sudanese infants and children. When prepared with biofortified sorghum cultivars such as Dahab and its blends, *Nasha* demonstrated strong sensory and emotional acceptability, establishing it as a practical model for community-level complementary feeding in children. Among the evaluated formulations, the Dahab + Dabar blend achieved the highest overall liking, confirming its appeal to both caregivers and children and highlighting Dahab's sensory advantage across key attributes, namely, color, texture, aroma, and mouthfeel.

Despite these encouraging results, the study's modest sample size, short evaluation period, and reliance on observational and caregiver-reported data may limit its ability to capture the long-term nutritional impacts. Variations in fermentation time, temperature, and raw material quality may also have influenced the sensory outcomes, highlighting the need for standardized preparation protocols. Future research should integrate clinical and biochemical assessments to evaluate nutrient bioavailability and child growth outcomes associated with *Nasha*-based diets. Combining sensory science, food technology, and behavioral nutrition will be vital for optimizing product design, improving shelf-life stability, and strengthening fortification strategies. Promoting women-led cooperatives and public-private partnerships for large-scale production could transform *Nasha* from a household food into a sustainable, nutritionally enhanced complementary product. Linking traditional knowledge with modern food science offers a viable pathway to strengthen nutritional resilience, empower women economically, and advance food sovereignty in Sudan and other crisis-affected regions.

6. Implications for gastronomy

The findings of this study extend beyond nutrition and public health to highlight important implications for gastronomy. First, *Nasha* demonstrates how traditional fermentation and preparation techniques can be harnessed to create **culturally resonant, nutrient-dense foods** suitable for complementary feeding in resource-limited and crisis settings. By blending traditional sorghum cultivars with a recently biofortified variety, Dahab, this work shows that nutritional enhancement does not necessarily compromise the **sensory qualities**, appearance, taste, aroma, and texture, that drive acceptance.

Second, the integration of **sensory science with local food culture** underscores the role of gastronomy as a bridge between culinary heritage and modern food system challenges. The positive responses of both caregivers and children indicate that traditional foods, when thoughtfully adapted, can serve as vehicles for improving dietary resilience without eroding cultural identity.

Third, these results demonstrate the potential of gastronomy to inform **innovative food design in humanitarian contexts**. The ability to transform local crops into highly acceptable weaning foods provides a gastronomic pathway to address child malnutrition through **culinary creativity, cultural familiarity, and sensory appeal**. Such an approach aligns with the broader mission of gastronomy to integrate science, culture, and health in shaping sustainable diets.

This study highlights how gastronomy can contribute to tackling malnutrition by elevating traditional food knowledge, ensuring cultural acceptance, and combining it with modern scientific approaches to food design.

CRediT authorship contribution statement

Manhal Gobara Hamid: Writing – original draft, Methodology, Data curation, Conceptualization. **Khitma A. Sir Elkhatim:** Writing – review & editing, Methodology, Data curation. **Yousif M.A. Idris:** Writing – review & editing, Methodology. **Faraz Muneer:** Writing – review & editing, Methodology. **Mahbubjon Rahmatov:** Writing – review & editing, Methodology. **Mohammed Elsafy:** Writing – review & editing, Visualization, Validation, Resources, Methodology. **Eva Johansson:** Writing – review & editing, Methodology. **Tilal Abdelhalim:** Writing – review & editing, Visualization, Validation, Resources, Methodology, Formal analysis, Conceptualization.

Declaration of competing interest

Hereby, we declare that no conflict of interest for the study titled '**Nasha: A Culturally Embedded Sorghum-Based Weaning Food for Infants in Humanitarian Settings'**. Additionally, we state that this manuscript has not been published previously and is not under consideration for publication elsewhere in English or in any other language.

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Data availability

Data will be made available on request.

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