



## Consumer acceptance of foods derived from blended wheat flour in Nairobi, Kenya

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### ABSTRACT

Governments across Africa have shown enthusiasm for wheat flour blending to reduce food security risks and pull demand for traditional but underutilized crops. However, research has sidestepped the question of whether consumers will accept foods derived from blended wheat flour. We used sensory evaluation and contingent valuation techniques with a sample of 1871 consumers in Nairobi, Kenya to measure the acceptance of two commonly consumed foods (chapati and bread) made from wheat flours blended with up to 20% sorghum, millet, or cassava flour. In blind tasting, bread made of blended flour was slightly less preferred than conventional bread, while chapati products made of wheat and sorghum (10%) or millet (5%) blends were equally valued as chapati made of 100% wheat flour, suggesting the potential to replace up to 10% of wheat flour in chapati without compromising sensory characteristics and consumer acceptance. When informed about the flour composition before tasting, consumers showed a stronger preference for the products made from blended flour and expressed a higher willingness to pay for blend-based products than conventional products. We discuss the policy implications of how consumer interest in such foods can be harnessed to advance food security and economic development goals.

### 1. Introduction

Consumer preferences for starchy staples in Africa have evolved, and are influenced by factors such as increased incomes, urbanization, and the opportunity costs of women's time (Kennedy & Reardon, 1994; Mason et al., 2015; Onyango & Onyango, 2018; Orr et al., 2020). In particular, wheat consumption across Africa has increased dramatically, while the per capita consumption of traditional crops, such as sorghum, millets, and cassava, has stagnated or declined (Mason et al., 2015; Morris & Byerlee, 1993). The growth in wheat demand has been fueled, in part, by persistently low international prices. High demand, combined with relatively low and stagnant levels of local wheat production, has created an import dependency across Africa which was sharply brought into focus with conflict-induced wheat trade disruptions in 2022 (Bentley et al., 2022; Bertassello et al., 2023; Rahimiet al., 2023). The

dependence on wheat imports poses further potential risks to food security from future trade disruptions and climate change (Hedlund et al., 2022).

Substituting a portion of wheat flour with flour from traditional crops (e.g., millets, sorghum, and tubers) in wheat-based foods provides a strategic opportunity to increase food self-sufficiency, enhance food security, and support economic growth (Poole et al., 2024). Traditional crops are well-suited to Africa's evolving rainfed production environments, as they are more resilient to climate-related shocks and demonstrate stable performance in poor soil and drought conditions (Noort et al., 2022). Nonetheless, the lack of a commercial market for these crops has hindered investments in primary production and processing, leading to lower national yields, higher relative prices, and decreased competitiveness compared with other staple crops (Orr et al., 2016). Creating demand for traditional crops as inputs for the wheat flour

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processing industry would provide economic incentives for the private sector, farmers, and other stakeholders in the value chains to increase production, marketing, and processing activities for these crops. Blending wheat flour with these crops can also enhance the nutritional value of wheat-based foods (Ayele et al., 2017; Giami et al., 2003).

The incorporation of flour from other crops into wheat flour changes the physicochemical properties of wheat-based foods. This is particularly true when the alternative crops lack gluten, a protein in wheat responsible for the dough's ability to rise, and the final quality of wheat-based foods. Research has confirmed the technical feasibility of blending wheat flour at levels of 20–30% (see a recent review of technical studies on wheat flour blending by Poole et al. (2024)). However, we know relatively little about consumers' acceptability of wheat-based products made from blended flour (Gomez et al., 1992; Melesse et al., 2023). The feasibility of wheat flour blending depends on consumer acceptance of the resulting products. Does combining wheat flour with other flour types alter the sensory qualities of wheat-based foods in a way that dissuades consumers from consuming or purchasing them? How do consumers perceive the value of foods made of blended wheat flour? To what extent do consumers prefer foods derived from blended wheat flour? The current study sought to provide answers to these questions.

Specifically, we conducted sensory evaluations and contingent valuation with consumers in Nairobi, Kenya, to evaluate their interest in bread and chapati<sup>1</sup> made from wheat flour blended with up to 20% sorghum, millet, or cassava flour. Sensory evaluation was used to assess consumers' sensory responses to these novel food products, while contingent valuation<sup>2</sup> was used to determine consumers' willingness to pay (WTP) for the blend-based products. The sensory and contingent valuation assessments were conducted in two ways: blind tasting, where consumers were unaware of the flour composition before evaluating the products, and informed tasting, where consumers were informed of the flour composition before assessing the products. Information such as product composition, nutritional benefits, production processes, or country of origin may affect consumer expectations and perceptions of new products which may influence their sensory and economic evaluations (Banerji et al., 2016; Deliza et al., 2003; Di Monaco et al., 2004; Hirokawa & Yamazawa, 2008; Johansson et al., 1999; Lee et al., 2013; Torjusen et al., 2001). Disclosure of flour composition is particularly relevant in our context since regulations require millers to indicate this on labels.

Our results showed that for the blind-tasting group, bread with blended flour was slightly less preferred than conventional bread for all crops, whereas chapati made with wheat-sorghum (10%) or millet (5%) blends was valued on par with 100% wheat chapati, indicating that up to 10% of wheat flour in chapati could be replaced without affecting sensory qualities and consumer acceptance. Informing consumers of the flour composition led to a stronger preference and a higher WTP for the products made from blended flour across both products and all three alternate crops. This outcome appeared to be driven by consumers perceiving wheat-based products incorporating blended flour as healthier than conventional wheat products. Overall, our study shows that consumers in this context are interested in products made of blended flour and are willing to trade off any adverse effects of blending on the sensory characteristics for the perceived health benefits.

The finding that consumers value wheat-based products made from blended wheat flour contributes to the broader discussion about the feasibility of flour blending policies in developing countries. Several

governments in the global South have mandated wheat flour blending or are considering doing so. Inspired by the FAO Composite Flour Program, national wheat flour blending policies in Bolivia, Sudan, Colombia, Senegal, and Brazil were enacted in the 1960s and the 1970s (Fellers & Bean, 1988; Noort et al., 2022). From 1982 to 2012, Nigeria implemented policies that required millers to combine locally grown cassava with imported wheat flour. In the short term, these measures reduced foreign exchange, increased substitute crop production, and led some bakers to commercialize composite breads (Fellers & Bean, 1988; Ohimain, 2014). However, their long-term sustainability and effectiveness were undermined by poor compliance by the millers, limited policy incentives, unreliable supply of good quality substitute crops, lower prices of wheat relative to the other crops, and limited consumer awareness of blended products' benefits (Fellers & Bean, 1988; Ohimain, 2014).

Since 2018, the Kenyan government has expressed interest in a flour blending policy requiring millers to blend wheat<sup>3</sup> flour with at least 10% of flour derived from traditional crops like sorghum, millet, amaranth, and cassava.<sup>4</sup> The proposed policy in Kenya is likely to face some of the political-economy challenges faced in Nigeria and elsewhere. Kenyan-based millers have expressed disapproval in the local press towards the proposed policy due, in part, to the uncertainties in consumer demand for blended products, despite the government's commitment to provide subsidies and incentives to support restructuring and equipment upgrading.<sup>5</sup>

Emerging evidence, including in the current study, provides reason for optimism. Perceptions and preferences among urban consumers in Africa for food attributes such as nutrition, country of origin, ease of preparation (instant), and gluten-free products are evolving (Costa & Johnson, 2019; De Groote et al., 2020). While traditionally, sorghum, millet, and cassava have been perceived as foods for the rural poor (Gierend & Orr, 2015), these foods have gained attention among health-conscious consumers (Orr et al., 2022; Schipmann-Schwarze et al., 2013). The evolving consumer landscape provides incentives for private sector involvement in discussions on flour blending policies and their eventual implementation. Indeed, the private sector, driven by reputational mechanisms and a desire to expand its product lines, has already shown an interest in blended flours, as seen by a recently launched maize millet flour blend in the Kenyan market.<sup>6</sup>

The rest of the paper is organized as follows. Section 2 provides a brief review of the existing literature on the feasibility of wheat flour blending; Section 3 describes the study methods, followed by the results in Section 3. Section 4 concludes.

## 2. Literature review on the feasibility of wheat flour blending

Blended flour and food products present technological challenges for the food industry while raising questions about their profitability and consumer acceptance. The sensory attributes, or organoleptic characteristics, of the final product are critical determinants of consumer acceptance. Additionally, blending wheat flour with other flour types can alter the nutritional value of wheat-based products, depending on

<sup>3</sup> The blending policy first targets maize flour but is expected to extend to wheat flour.

<sup>4</sup> Unlike previous cases such as Nigeria, where the main objective of the blending policy was to reduce wheat imports, the proposed policy in Kenya has wider objectives and seeks to diversify the sources of flour to ensure food and nutritional security while also fostering economic growth by incentivizing the production and processing of traditional crops.

<sup>5</sup> Another concern expressed by millers is the lack of access to sufficient volumes of affordable raw materials for blending, as Kenya produces meager volumes of the proposed substitute crops.

<sup>6</sup> <https://toasterding.com/grocery-guide-the-10-popular-maize-flour-brands-in-kenya/>.

<sup>1</sup> Chapati is a round flat unleavened bread usually made of wheat flour and cooked on a griddle.

<sup>2</sup> Contingent valuation is a standard method for estimating the demand for goods or services not yet available on the market or for non-market goods, see Bateman et al. (1994) and Mitchell & Carson (2013) for an introduction, and Girma et al. (2021), Matuschke & Qaim (2006) and Michelson et al. (2021) for recent applications.

the nutritional profile of the substitute crop and the level of blending. Both the sensory and nutritional properties of the resulting products are crucial factors influencing their consumer appeal and the commercial feasibility of the blending process.

Numerous laboratory experiments have evaluated the nutritional, functional, chemical, physical, and sensory properties of blended wheat flour and wheat-based products made from blended flour. Many of these studies focus on flours derived from minor crops valued for their nutritional benefits, resilience, and local availability, such as Bambara groundnut (Kobue-Lekalake et al., 2022; Tan et al., 2020), Prosopis spp. (González-Montemayor et al., 2019), carob bean (Brassesso et al., 2021), and various fruit and vegetable by-products (Santos et al., 2022). While these minor crops hold potential for niche product innovations of local interest, they are often unsuitable for large-scale commercial production. Challenges to their broader use include supply constraints, limited knowledge of their agrifood potential, social stigma, and a lack of supportive policy incentives (Tan et al., 2020).

Efforts to reduce reliance on imported wheat and promote economic growth by commercializing locally adapted crops have driven interest from researchers and policymakers in partial substitutes for wheat flour in commercial production. Several laboratory experiments<sup>7</sup> have evaluated the effects of incorporating cereals such as sorghum and millet and root crops like cassava and sweet potatoes into wheat-based products. Studies on cassava-based substitutes reveal promising results. Eddy et al. (2007) found that bread with 10% or 20% cassava flour was comparable to 100% wheat bread in sensory attributes, acceptability, and purchase preference, though a 30% cassava substitution resulted in lower scores. Jensen et al. (2015) concluded that up to 30% of wheat flour could be replaced with certain types of cassava flour without compromising bread quality. Aristizábal et al. (2017) reported that composite flours with up to 30% cassava substitution produced bread comparable to 100% wheat bread in sensory acceptability and processing, with higher substitution rates suitable for other baked goods. Analysis of Nigerian cassava cultivars indicated that all were functionally acceptable, though sensory evaluations showed a preference for a specific cultivar (Nzuta et al., 2022).

Sorghum and millet have also been evaluated for their potential as wheat flour substitutes. Biscuits made with sorghum-wheat flour at substitution rates up to 20% were found to be of acceptable quality, comparable to those made with 100% wheat flour (Adebawale et al., 2012). In Zimbabwe, Sibanda et al. (2015) demonstrated that a 10% inclusion of sorghum flour produced bread of acceptable sensory quality, though higher substitution rates diminished sensory qualities in other contexts (Gadallah & Elsheshetawy, 2017; Ognean, 2015). For millet, Aprodu and Banu (2015) found that blends with up to 30% millet flour yielded acceptable loaves, but substitution rates of 40% or higher negatively impacted loaf volume, texture, and taste. Sharma et al. (2017) observed that wheat dough blended with 25% finger millet produced acceptable chapatis, while Sharma and Gujral (2019) highlighted the potential of millet-blended flatbreads for glucose-intolerant and diabetic consumers. Choudhary and Jood (2013) investigated ragi (finger millet)-wheat blends, finding that bread with up to 10% ragi flour retained acceptable sensory qualities while offering enhanced protein and dietary fiber content.

Studies involving consumers are relatively scarce compared to laboratory-based experiments that rely on trained or semi-trained panelists for product evaluation. However, research involving consumers outside the lab setting is crucial, as the acceptability of new products depends on more than just sensory characteristics. Factors such as consumer attitudes, perceptions, affordability, health benefits, and

perceived value also play a significant role in influencing consumer choices (Lusk & Briggeman, 2009).

A few studies have explored consumer acceptance and market potential of cassava-wheat composite bread in Nigeria and Ghana. Owusu et al. (2017), using data from 350 consumers in Ghana and a hedonic pricing model, found that bread made from 15-40% cassava flour blended with wheat flour was perceived as more nutritious than wheat-only bread. Approximately 40% of consumers were familiar with cassava-wheat bread, favored its taste and texture, and were willing to pay a premium compared to those unaware of the product. Similarly, Adepoju and Oyewole (2013) revealed that households were willing to pay a premium for bread with cassava flour blends, with the highest WTP observed for bread containing 30% cassava flour, though WTP slightly decreased at 40% inclusion. Factors such as taste, packaging, size, color, and price significantly influenced purchasing decisions. Komlaga et al. (2012) found that wheat: cassava composite bread, prepared using a 1:4 cassava-to-wheat flour ratio, was well-received by senior high school students in Ghana, who rated its attributes—including appearance, taste, texture, and mouthfeel—positively on a nine-point hedonic scale.

The current study builds on these existing studies and makes specific contributions to this literature. First, we examine consumer acceptability in a different context, which is crucial for the SSA region due to the presence of fragmented consumer markets marked by diverse consumer segments and an extensive variety of local products (Noort et al., 2022). Second, we focus on two of the most consumed wheat-based products in Kenya, bread and chapati. Unlike previous research, which focused on niche product innovations, our study targets products that are regularly consumed by a broad range of consumers. Third, our experimental design allows us to assess the impact of information about flour composition on consumer acceptability of blended products. This is complemented by an analysis of consumer perceptions and their influence on willingness to pay for these products, thus providing useful insights into consumer attitudes towards products derived from blended wheat flour. Lastly, we expand the range of substitute crops beyond cassava to include millet and sorghum. These crops are particularly relevant to the region due to their climate resilience, potential to enhance local production and economic growth, nutritional benefits, and relatively easier access to raw materials and processing compared to cassava, which is bulkier and more perishable.

### 3. Methods

#### 3.1. Data collection sites and sampling

The study targeted consumers in *peri*-urban Nairobi, specifically the Juja, Thika, Ruiru, and Kasarani sub-counties. These sites are located close to the Jomo Kenyatta University of Agriculture and Technology, JKUAT, where the products were prepared, thus facilitating ease of transport between the lab and the testing locations. Supermarkets provided benefits for data collection because of the ease of setting up food booths and the steady stream of consumers flowing into (out of) the store. Supermarkets have become common in Kenya in recent years and serve consumers from all income groups (Neven et al., 2006; Neven & Reardon, 2004). We established evaluation booths in ten supermarkets. The enumerators intercepted consumers as they left supermarkets and invited them to participate in the study. Our sample size was 1871 consumers. We targeted consumers aged 18 years and above. Additionally, we excluded consumers who reported being allergic to wheat, sorghum, cassava, or millet-based foods.

#### 3.2. Selection of products and substitute crops

Discussions with millers identified refined all-purpose flour for chapati and bread flour for baking as their most commercially important products. Therefore, we selected bread and chapati made from refined

<sup>7</sup> These studies typically rely on trained or semi-trained panelists, usually consisting of 10 to 20 individuals, for sensory evaluations. This approach contrasts with studies like ours, which involve evaluations by regular consumers, as discussed below.

wheat flour as the food products for evaluation. We selected pearl millet, white sorghum, and cassava as the crop flours for blending. Millers preferred flour from these crops as blending materials because of their white or nearly white colors, since ensuring a white-colored composite flour was deemed by millers as important for consumer acceptance of wheat-based foods derived from blended flour. These three crops have been proposed as substitute crops in the flour blending policy put forward by the Kenyan government. Moreover, laboratory experiments have shown that it is technically feasible<sup>8</sup> to incorporate these crops into wheat-based foods (Adebawale et al., 2012; Aprodu & Banu, 2015; Eddy et al., 2007). Lastly, millets and sorghum have attracted consumer interest as healthy and gluten-free foods (Ari Akin et al., 2022; Orr et al., 2017), making them desirable from a consumer perspective.

Based on available evidence in the literature, it is possible to replace up to 20–30 percent of wheat with flour derived from other crops to obtain a product with acceptable end-use quality (Poole et al., 2024). We aimed to find the highest possible substitution of non-wheat flours without jeopardizing sensory qualities. We opted for a maximum substitution level of 20%, thus replacing wheat flour with 5%, 10%, and 20% of either pearl millet, white sorghum, or cassava flour.

With three different crop substitutes (pearl millet, white sorghum, and cassava), three levels of substitution (5%, 10%, and 20%), and two types of products (chapati and bread), we initially had 18 potential products plus the control. To reduce the number of products to a manageable number for consumer testing, we performed physical, functional (such as baking performance), and preliminary sensory tests on these flour mixes and products to narrow down the selection (as described in a companion paper, Muoria et al., forthcoming). The aim was to maximize the substitution level without causing undue changes in the physical, functional, and sensory properties of the products. These tests showed that substitution levels of 5% and 10% with pearl millet flour and white sorghum flour were generally acceptable for use in making bread and chapati. The addition of cassava flour above 5% had a negative impact on bread production, whereas higher levels of cassava flour (above 10%) resulted in generally acceptable chapati products. Based on these assessments, the following flour composition was selected for chapati products: i) 10% sorghum: 90% wheat; ii) 5% millet: 95% wheat and iii) 20% cassava: 90% wheat and for bread products: i) 10% sorghum: 90% wheat; ii) 10% millet: 90% wheat and iii) 5% cassava: 95% wheat.

### 3.3. Flour and food product preparation

The blending of flours and the preparation of sample products took place in the Food Science Lab at the Department of Food Science and Technology of JKUAT University. Whole pearl millet flour, whole white sorghum flour, and whole cassava flour were sourced from Kirinyaga Flour Millers. Capwell Industries Limited supplied refined all-purpose wheat flour, and Bakex Millers Limited provided baker's flour. Additional ingredients (see Appendix 1) used to prepare bread and chapati were purchased from local supermarkets. The flour blends were created by substituting a portion of the wheat flour with pearl millet, white sorghum, and cassava flour according to the specified substitution rates. Bread and chapati samples were made following standardized methods to maintain consistency in the final products (see Appendix 1 for details).

The bread samples were sliced, and the crust of each slice was removed. Each slice of the various types of bread was separately sealed in cling film to maintain freshness and softness and avoid contamination. These slices were then stored in sealed plastic containers for

transport to testing locations. The chapati samples were divided into eighths, with each piece individually wrapped in a serviette to prevent contamination and allow each consumer to open their sample by themselves. In addition, these chapati pieces were wrapped in aluminum foil and placed in a thermal hotpot to keep them warm and fresh during transport to the research sites. The chapatis were made in two separate batches, one early in the day and another in the afternoon, to ensure that they remained warm when they reached consumers. The order in which different products were prepared was randomized to eliminate first-order bias. The dough kneading, rolling the dough into flat sheets, and frying the chapati were each handled by three separate personnel throughout the study to ensure consistency in all samples.

### 3.4. Sensory evaluation tests and contingent valuation

#### 3.4.1. Triangle test

We employed a discriminatory sensory test, or 'triangle test', to evaluate consumers' ability to distinguish between wheat-based food products made from blended wheat flour and those made from non-blended wheat flour, see Lawless & Heymann (2010) for an overview and Andoyo et al. (2023), Lim et al. (2022), Pinarli et al. (2004), and Rasco et al. (1989) for applications. This method evaluates whether alterations in the ingredients or processing techniques of a product significantly affect its sensory attributes. This test provided insights into whether blending changed the sensory attributes of wheat-based foods in a way that is noticeable to consumers. During the test, a panelist, in this case, a consumer, is presented with three samples, among which two are identical and one is different. The panelist tastes the three samples and identifies the one that differs. The option to abstain from choosing is not allowed (Sinkinson, 2017).

#### 3.4.2. Affective test

The affective test method was used to assess consumers' acceptability of products derived from blended wheat flour. Generally, researchers use affective tests to assess consumer preferences, perceptions, and emotional responses to products by measuring their liking or disliking of attributes such as taste, texture, and appearance, with the goal of gathering subjective data to inform product development, quality improvement, and market analysis (Lawless & Heymann, 2010). The literature provides various examples of recent applications (De Groote et al., 2016; Maroini et al., 2024; Nukabadi et al., 2022; Nyamayi et al., 2022; Ouma et al., 2012; Turuk & Banerjee, 2023). Consumers in our study rated the products using a five-point scale (ranging from 'dislike very much' to 'like very much') across various attributes. The five-point scale provided a simpler option for non-trained consumers than the seven- or nine-point scales that are typically used by trained or semi-trained panelists. We conducted focus group discussions at the beginning of the research to identify the specific attributes used by consumers in their evaluations.

We conducted the affective tests in two ways. In the first test, a subset of consumers, referred to as the 'blind tasting' group in this study, evaluated the products without information on the flour used to produce them. In the second test, the flour composition was disclosed before the consumers evaluated the products. This group is called the 'informed tasting' group in the rest of the paper.

#### 3.4.3. Contingent valuation of products derived from blended wheat flour

We used the contingent valuation method to determine the WTP of consumers for food products made from blended wheat flour. Contingent valuation is a well-established method for estimating the demand for goods or services not yet available on the market or for non-market goods (Bateman et al., 1994; Mitchell & Carson, 2013). The literature contains various applications of contingent valuation (Girma et al., 2021; Matuschke & Qaim, 2006; Michelson et al., 2021). We employed an open-ended elicitation approach, similar to Michelson et al. (2021), asking each consumer to specify the maximum price they would pay for

<sup>8</sup> That is, studies assessing the functional properties of blended flour, as well as the physical and chemical properties of products made from it, have demonstrated that substituting wheat flour up to a certain ratio produces products of acceptable quality.

400 g<sup>9</sup> of bread identical to each of the four bread products included in the study. For chapati products, we inquired about WTP for a 2 kg packet of flour similar to the flour used to make each of the chapati products. We chose 400 g for bread and 2 kg for chapati flour since they represent the typical forms and units in which these products are purchased in our study context.

Participants were asked for their WTP for each product after the affective tests for that product and before moving on to sample the subsequent product. For the blind tasting group, the WTP value thus represents the value consumers attributed to each product based on its sensory characteristics. In contrast, for the group informed about the flour composition, the WTP value indicates the consumers' assessment of the sensory attributes, as well as their perception of the added or reduced value due to specific flour types in the products.

All scenarios were hypothetical, and consumers were not required to purchase bread or flour. This could have introduced hypothetical bias, where stated WTP values differ from actual behavior in real purchasing situations, as is common in contingent valuation studies (Cummings et al., 1995; Murphy et al., 2005). The contingent valuation method was chosen due to practical constraints in conducting interviews, sensory evaluations, and willingness-to-pay exercises with urban consumers in a supermarket setting. These constraints limited the feasibility of more time-intensive elicitation methods, such as experimental auctions or real choice experiments,<sup>10</sup> which involve actual choices and monetary transactions to help mitigate hypothetical bias. However, while the hypothetical nature of our questions could have influenced WTP values, we argue that the elicitation method used and the characteristics of the products studied helped minimize this potential bias.

Firstly, consumers in our study were familiar with the types of products evaluated, that is, 400 g of bread and 2 kg of chapati flour packet. Both of these products were readily available in Nairobi, Kenya, and purchased on a regular basis by over 90% of respondents in our sample. Previous work showed that familiarity with the products under evaluation was more likely to yield more accurate responses in hypothetical cases<sup>11</sup> (Schmidt and Bijmolt, 2020). Second, we opted for the open-ended elicitation method over the dichotomous method (where consumers are presented with specific values and asked if they would be willing to pay that amount for the products). The latter method tends to show an upward bias compared to open-ended elicitation in some contexts<sup>12</sup> (Balistreri et al., 2001). Lastly, since certain consumer characteristics such as perceptions of health benefits, gender, age, and education—can influence WTP estimates and the associated hypothetical bias (Hofstetter et al., 2013; Penn & Hu, 2018), we gathered data on consumer socio-demographics to include as controls in our regression analysis.<sup>13</sup> As highlighted later in the results section, the WTP estimates

<sup>9</sup> The enumerators clarified that this was the “normal” bread size available in the market.

<sup>10</sup> See Canavari et al. (2018) for a recent review on experimental auctions and Caputo & Scarpa (2022) for methodological advances in (food) choice experiments.

<sup>11</sup> In a similar vein, hypothetical bias was often found to be lower for private goods relative to public goods (List & Gallet, 2001; Penn & Hu, 2018), perhaps due to greater familiarity and valuation experience with the former. As asserted by List and Gallet “Since most subjects are more comfortable valuing goods they commonly purchase, they may make less errors in valuing these types of goods than valuing public goods, which they may have little valuation experience”.

<sup>12</sup> This may be attributed to the absence of anchoring effects and the increased cognitive effort required in open-ended responses, as highlighted by Balistreri et al. (2001). However, Penn and Hu (2018) did not find evidence to support this hypothesis in their meta-analysis.

<sup>13</sup> Specific variables added to the regressions include age of the consumer, asset ownership index, an indicator for consumers who consume whole grain products, an indicator for consumers who perceive products from the blended flour as healthier compared to wheat-only products, and an indicator for consumers who expected to like the products before tasting.

in our study closely aligned with the observed market prices for the 100% wheat products, suggesting that respondents in our study offered realistic valuations of the products.

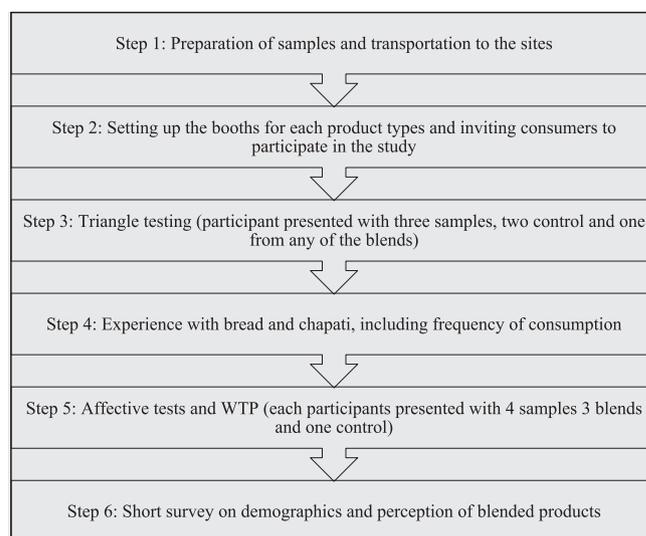
### 3.5. Field implementation

In this section, we outline the activities followed during the field implementation, as summarized in Fig. 1. Evaluation booths were positioned near the entrances (exits) of supermarkets. Participants were approached as they entered (exited) the supermarkets. Field teams alternated daily between handling bread or chapati and between blind tasting or informed tasting. This simplified logistics and minimized information spillovers.

The enumerators started by briefing participants on the voluntary nature of the study and screened for food allergies. The consumers were then invited to participate in the triangle test. Given that we had three blend-based products per product type, we randomly assigned participants to three groups, and each group evaluated each of the blended products against the wheat-only product. Each blended product was evaluated against the wheat-only sample by at least 300 consumers, giving us a sufficient sample size for the triangle test. We randomized the order in which the samples were served to each participant to minimize bias. Additionally, we presented all three samples together on a disposable plate, arranged in a triangle pattern, to ensure consistency in presentation and ease of comparison during the triangle test.

This was followed by the affective tests section. A participant was presented with four samples, three blends, and a control (100 percent wheat). We randomized the order in which the samples were presented across participants to minimize the first sample bias. Each sample was served in a disposable cup labeled with a three-digit code for the blind tasting group or information on the composition of the flour used to make each sample for the informed tasting group. Participants rated their overall liking and the specific attributes of each sample on a five-point hedonic scale. Sensory attributes assessed for bread and chapati included color, aroma, and taste, with additional evaluations of texture (in hand and mouthfeel) for bread, and tear ability and chewiness for chapati.

Finally, for each sample, participants were asked the highest price they would pay for 400 g of a comparable bread product or a 2 kg bag of flour for the chapati samples they evaluated. Palate cleansing with water



**Fig. 1.** Field implementation. Note: Each participant took part in triangle tests, during which they tasted three samples. Following this, participants completed affective tests, where they tasted and evaluated four samples of either bread or chapatti (not both), with or without information about the flour composition (not both).

occurred between samples. After the affective tests, consumers in the information category were asked about their perception of products made from a blend of wheat and each of the three crops, cassava, sorghum, or millet. This was followed by a short section where consumer demographic characteristics were collected for all the study participants.

## 4. Results

### 4.1. Sociodemographic characteristics of the sample

Table 1 summarizes the demographic characteristics of the consumers in our sample. The consumers were relatively young, about 30 years old on average. There was a balance in terms of the gender of the respondents. Slightly more than 60% of the respondents had university or college-level degrees. Almost half of the sampled households owned a car, over sixty percent had access to an internet connection, and nearly everyone owned a smartphone.

The study sample differs from national averages (generated from the Kenya Population and Housing Census 2019) in several key demographics. Participants were younger, with an average age of 30.5 years compared to the national average of 37 years. The sample was more educated, with 64% having tertiary education, exceeding the national average of 21%, and only 4% having primary education or below, compared to 42% nationally. Asset ownership was notably higher among the study participants, including cars (47% vs. 6%), refrigerators (65% vs. 9%), and internet access (65% vs. 4%). While only 23% of the sample resided in their own house, compared to 78% nationally, a larger proportion had piped water inside their homes (81% vs. 24%). We attributed these differences to the study setting (i.e., supermarkets in Nairobi where consumers were entering to purchase groceries or returning home having finished grocery shopping).

Table A1 presents the results of equivalence tests for the means of consumer characteristics listed in Table 1, comparing the informed and blind tasting groups. The two groups were generally comparable, with significant differences observed in only four of the 16 variables tested using a t-test. These differences were relatively small in magnitude. Specifically, the differences included: Age (a one-year difference between the groups), the proportion of individuals with primary school education (0.03 in the blind tasting group versus 0.06 in the informed tasting group), and the proportion of households owning a bicycle (0.45 versus 0.51) or a motorbike (0.29 versus 0.23). These variables are included as controls in the regression analysis to account for these differences

### 4.2. Experience with and perceptions of foods made from blended flour

Bread and chapati were popular foods, with approximately 90% of individuals reporting consumption of either product at least weekly, and 45% consuming bread daily, see Table 2. Nearly three-quarters of the sample reported regularly eating chapati and bread prepared from refined wheat flour.

The familiarity with bread or chapati made from blended wheat flour was low, with about 90% of consumers having reported no previous experience with either product. Notably, more than 90% of consumers believed that products made from blended flour (across all three substitute crops) were healthier and more expensive compared to conventional products made from refined wheat flour. Nearly half of the consumers considered that products made from blended wheat flour were not as tasty as those made solely from wheat flour.

### 4.3. Results of the discriminatory tests

Table 3 presents the proportion of consumers who correctly identified the blend-based products during the triangle tests. The proportion of those who correctly identified the distinct samples (products made from

blended flour) in the case of bread was slightly higher (around 60%), except for the bread samples containing 5% cassava blend, where less than 50% of consumers correctly identified the distinct sample. For chapati products, slightly more than half of the consumers correctly identified the distinct sample, which, in this case, was made from blended flour. However, the p-values<sup>14</sup> from the chi-squared test were significant across all products, suggesting that the proportion of consumers who correctly identified the distinct samples was significantly greater than the 33% expected by random chance, leading to the conclusion that consumers could differentiate between products made solely from wheat flour and those containing a blend of flour.

### 4.4. Sensory evaluation of the products made from blended wheat flour

#### 4.4.1. Descriptive statistics of the ratings of the products in the sensory evaluation

Fig. 2 shows the overall consumer preference for the different types of bread. The results are shown for both the blind and informed tasting groups. Preference results associated with the specific attributes are presented in Appendix Fig. A1.

The results of the blind tasting group showed a general appreciation for the four bread products, with more than 60% of the respondents at least liking the products. The percentage that reported to at least like the millet and sorghum-based products was slightly lower by around six percentage points than that of the bread products made from wheat-only flour. The products derived from wheat only flour and wheat-cassava blended flour were almost equally liked, with a difference of only two percentage points. The bread attribute with the most significant difference was the color of the products, with over a ten-percentage point difference between the millet and sorghum-based products and the wheat-only and cassava-based products. The color in the sorghum and millet-based products was liked less. The level of liking was generally comparable across the products for the other attributes, although more consumers along all the attributes generally liked the 100% wheat and cassava-based products.

Disclosing the composition of the flour before inviting consumers to taste the products led to a higher percentage of consumers reporting that they liked the products made from blended flour more than the products derived from only wheat flour. Compared to the blind tasting group, the wheat-only products were liked less by the informed tasting group, while the blend-based bread samples were liked more than in the blind tasting group.

Next, we present the results for the chapati products, see Fig. 3. Unlike bread products, where millet and sorghum products were the least liked by the blind tasting group, their chapati equivalents were the most appreciated. The products obtained from wheat-sorghum and wheat-millet blends, were at least liked by 73 and 71% of the consumers in the blind tasting group, respectively. The 100% wheat-based products were liked by a slightly lower percentage (69%). The cassava-based products were the least liked (liked by 55% of consumers), probably due to the high substitution rate (20%). The wheat-cassava products were the least liked for all attributes except for the color

<sup>14</sup> Data from the triangle test is analyzed by computing the proportion of participants who identified the correct different product among the three products presented to them. The null hypothesis tested is that there is no difference between the two products, in our case, products made from blended flour versus wheat only. Since participants in a triangle test are expected to pick one different product, even if he/she has to guess, there is thus a 33% chance of any of the products, including the different ones, being selected by chance. To test whether there is any actual perceptible difference, a test is done to determine how far the percentage of customers who identified the correct product is from the 33% that would result from chance. A chi-squared test is used to test whether the observed percentage that can identify the correct sample is significantly higher than the 33% that may result from chance.

**Table 1**  
Consumer demographics.

Variable	Study sample			National averages from the 2019 census data					
	1 N	2 Mean	3 SD	4 Mean	5 SD	–	–	–	–
Age of the consumer in years	1863	30.47	10.41	37.00	15.73				
Respondent is male	1871	0.49		0.48					
<i>The education level of the respondent</i>									
Primary school level and below	1868	0.04		0.42					
High school level	1868	0.32		0.37					
Tertiary level	1868	0.64		0.21					
<i>Assets ownership by the household</i>									
Owens a car	1871	0.47		0.06					
Owens a bicycle	1871	0.48		0.15					
Owens a motorbike	1871	0.25		0.09					
Owens a refrigerator	1871	0.65		0.09					
Owens a gas cylinder	1871	0.96		0.24					
Owens a cooker with an oven compartment	1871	0.56							
Has access to an internet connection	1871	0.65		0.04					
Has piped water inside the house	1871	0.81		0.24					
Owens a smartphone**	1871	0.95		0.61					
Resides in own house	1871	0.23		0.78					

The census data on age and education is based on the population aged 18 years and above.

\*\*In the census data, this reflects the percentage of individuals who own a phone, while in the study sample, it represents the percentage who own a smartphone.

**Table 2**  
Consumption and consumer perception of various types of bread and chapati.

Variable	1		2	
	Bread		Chapati	
	N	Proportion of consumers	N	Proportion of consumers
<i>Frequency of consumption</i>				
Every day	964	0.45	907	0.12
Every other day (2–3 times a week)	964	0.37	907	0.40
Once per week	964	0.09	907	0.34
Once in two weeks	964	0.02	907	0.07
Once per month	964	0.02	907	0.04
Rarely (Less than once per month)	964	0.04	907	0.03
<i>Main type of bread /chapati consumed</i>				
Made using whole-grain flour	964	0.25	907	0.11
Made using refined flour	964	0.70	907	0.72
Other types	964	0.16	907	0.16
<i>Ever tasted chapati or bread from blended flour<sup>+</sup></i>				
Millet and wheat blend	147	0.12	115	0.06
Cassava and wheat blend	146	0.06	130	0.11
Sorghum and wheat blend	135	0.10	123	0.09
<i>Perception of blends<sup>+</sup></i>				
<i>Blends are perceived to be healthier</i>				
Millet and wheat blends	147	0.90	115	0.95
Cassava and wheat blends	146	0.97	130	0.95
Sorghum and wheat blends	135	0.90	123	0.95
<i>Blends are perceived to be tastier</i>				
Millet and wheat blends	147	0.45	115	0.47
Cassava and wheat blends	146	0.46	130	0.35
Sorghum and wheat blends	135	0.52	123	0.60
<i>Blends are perceived to be more expensive</i>				
Millet and wheat blends	147	0.87	115	0.92
Cassava and wheat blends	146	0.88	130	0.88
Sorghum and wheat blends	135	0.88	123	0.93

<sup>+</sup> Only consumers in the informed tasting group were asked about their perceptions and experiences with blended products. Due to time constraints during exit interviews, consumers were randomly assigned to one of three groups, each corresponding to one of the three crops, to ensure that each consumer answered questions related to millet, sorghum, or cassava.

**Table 3**  
The proportion of consumers who correctly identified the blends-based products in discriminatory tests.

	Bread products			Chapati products		
	1 10% millet	2 5% cassava	3 10% sorghum	4 5% millet	5 20% cassava	6 10% sorghum
Consumer correctly identified the different sample	0.60	0.46	0.63	0.54	0.58	0.51
Number of observations	305	331	328	292	308	307
Pearson chi2	97.12	26.48	135.30	59.65	86.91	46.27
p-value	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

(Figure Appendix 2).

Disclosing the composition of the flour used to make chapati increased the percentage of consumers who at least liked the cassava and millet-based products. In contrast, chapati obtained from wheat-only and wheat-sorghum flour was liked by slightly fewer consumers. Interestingly, products from all three blends were liked or liked very much by more consumers than the 100% wheat-based products.

4.4.2. Evaluation of product ratings through ordinal regression analysis

Table 4 presents the results of the random effects ordered logistic model. The dependent variable is the score given to each product by consumers and ranges from 1 (dislike very much) to 5 (like very much). The independent variables were the indicators for each product: 100% wheat, sorghum-wheat, millet-wheat, or cassava-wheat products. The analysis was done at product level, with each product being an independent observation. We ran separate regressions for each product type (chapati and bread) and group (blinded tasting versus informed tasting groups). We present the coefficients from the models and the odds ratios are shown in square brackets. We also added to the regressions the following consumer demographics: age, asset ownership index, an indicator for consumers who consume whole grain products, an indicator for consumers who perceive products from the blended flour as healthier compared to wheat-only products, and an indicator for consumers who expected to like the products before tasting. Lastly, we added the

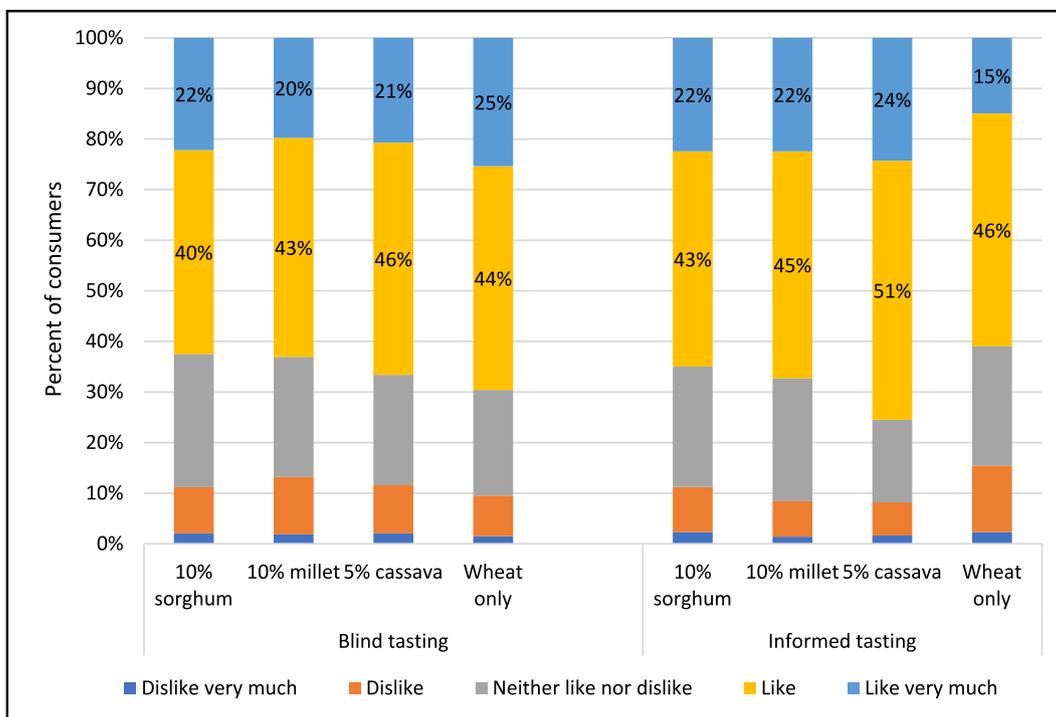


Fig. 2. Consumer evaluation of bread products by the different groups.

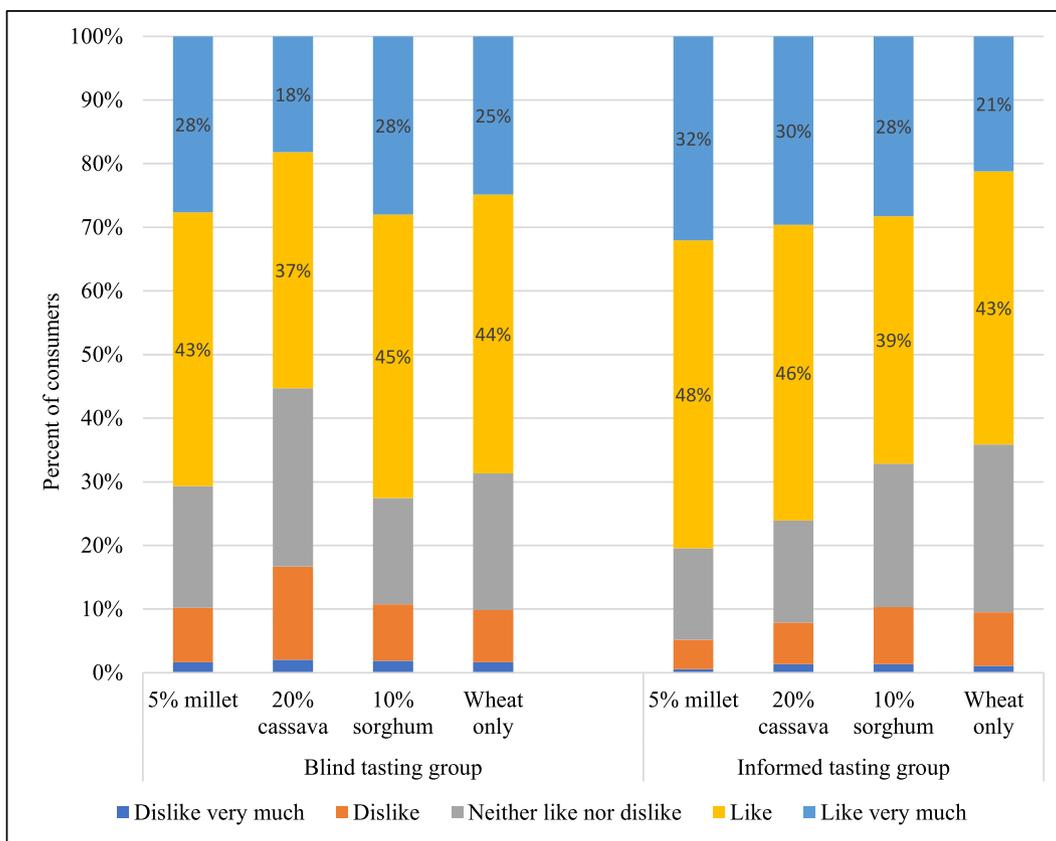


Fig. 3. Consumer evaluation of chapati products by the two groups.

enumerator and the order in the serving to control for any biases resulting from the study design.

The first column of Table 4 displays the scores for bread samples in

the blind tasting group. Bread products from blended flour scored significantly lower than those from 100% wheat. The likelihood of a consumer favoring a product derived from blended flour was less than

**Table 4**  
Ordered logit results for the scores for bread and chapati products.

	Bread		Chapati	
	1	2	3	4
	Blind tasting	Informed tasting	Blind tasting	Informed tasting
Wheat-Millet blend products	-0.341*** (0.117) [0.708]	0.442*** (0.128) [1.556]	0.108 (0.115) [1.114]	0.693*** (0.132) [1.999]
Wheat-Cassava blend products	-0.212* (0.110) [0.809]	0.671*** (0.120) [1.957]	-0.524*** (0.107) [0.592]	0.232 (0.149) [1.262]
Wheat-Sorghum blend products	-0.270** (0.115) [0.764]	0.331** (0.136) [1.392]	0.165 (0.110) [1.166]	0.510*** (0.147) [1.665]
Respondent is male	-0.050 (0.096) [0.951]	0.113 (0.095) [1.120]	-0.132 (0.088) [0.876]	0.249** (0.120) [1.282]
Age of the consumer in years	0.006 (0.005) [1.006]	0.000 (0.005) [1.000]	0.004 (0.004) [1.004]	0.004 (0.006) [1.004]
Asset ownership index	-0.065** (0.025) [0.938]	-0.045 (0.024) [0.956]	-0.002 (0.023) [1.002]	-0.049 (0.027) [0.952]
Consumes whole grain products (0/1)	-0.048 (0.109) [0.953]	-0.032 (0.128) [0.969]	-0.043 (0.148) [0.958]	-0.164 (0.198) [0.849]
Perceives blends as healthier (0/1)		0.484*** (0.145) [1.623]		0.272 (0.197) [1.312]
Expected to like the blends (0/1)		0.024 (0.110) [1.024]		0.069 (0.139) [1.071]
cut1	-4.661***	-3.401***	-4.205***	-3.847***
cut2	-2.706***	-1.549***	-2.187***	-1.721***
cut3	-1.209***	-0.105	-0.824***	-0.157
cut4	0.861***	2.017***	1.091***	1.908***
sigma2_u	0.393***	0.108	0.170**	0.335***
Observations	2136	1696	2156	1464
Wild chi 2	17.170	46.102	46.424	40.171

**Notes:**

The coefficients are logs of the odds ratio, estimated using the random effects ordered logit models. The odds ratios are presented in square brackets. Standard errors are shown in brackets, clustered at the consumer level. The dependent variable, consumer scores, ranges from 1 (dislike very much) to 5 (like very much). The independent variables are the indicators for each product type: 100% wheat, sorghum-wheat, millet-wheat, or cassava-wheat products. Millet substitution rate: 10% in bread and 5% in chapati; Cassava substitution rate: 5% in bread and 20% in chapati; Sorghum substitution rate: 10% in both bread and chapati. Separate regressions were conducted for each product type (chapati and bread) and group (blind vs. informed tasting groups). Added to the regressions were consumer demographics: age, asset ownership index constructed by adding all the positive responses to the question on whether the respondent owns specific assets, indicator for the consumption of whole grain products, indicator for perception of blended flour products as healthier and an indicator if the consume expected to like the products. The enumerator and serving order fixed effects were included to control for study design biases. \* $p < 0.10$ , \*\* $p < 0.05$  and \*\*\* $p < 0.01$ .

one, at 0.7–0.8 times the likelihood of favoring pure wheat flour products. However, this outcome was the opposite for the group informed about the flour types used; products made from the three blends (cassava, sorghum, and millet) were preferred, with an odds ratio of 1.5–1.9 compared to those made using 100% wheat flour.

For the chapati products, scores for those made with millet and

sorghum blends were comparable to those made with wheat-only products, whereas wheat-cassava blend products scored significantly lower than those made solely from wheat (see Table 4 column 3). Like the bread samples, revealing the flour types before tasting resulted in higher scores for the blended flour products compared to the 100% wheat products (see Table 4 column 4). Rerunning the regressions in Table 4 on a pooled sample, with interaction terms between the product indicators and the tasting condition, confirms that consumers in the informed tasting group consistently gave higher scores to blended products (for both bread and chapati product types) compared to those in the blind tasting group, see Appendix Table A2.

#### 4.5. WTP for blended flour and products derived from the blended flour

##### 4.5.1. Descriptive statistics of the WTP values

Table 5 presents the mean WTP values by product type (chapati or bread) and group (blind versus informed). In the blind tasting group, the average WTP for wheat bread (400 g) derived from non-blended flour was 63<sup>15</sup> KES, while bread derived from blended flour were valued 2–3 KES lower, reflecting their lower sensory test scores. In the informed tasting group, wheat-only bread fell to 59 KES, but the blends received a 2 KES premium, making their average WTP higher than wheat-only bread.

For chapati flour, the WTP of the blind tasting group was 203 KES for wheat and slightly higher for the millet and sorghum blends, indicating a preference for the sensory attributes of these blends. The cassava blend had the lowest WTP value at 194 KES due to poor sensory scores. In the informed tasting group, wheat only chapati dropped to 196 KES, while millet and sorghum blends increased by 4 KES, and cassava blend rose to 203 KES, showing that information improved the value of blends over conventional products.

##### 4.5.2. WTP for blended flour and products derived from the blended flour using a regression framework

Table 6 presents the results of the regression indicators for each flour type on the stated WTP using a random-effects model. In the case of bread derived from blended flour, we found that consumers in the blind tasting group discounted bread products made from sorghum and millet blends, reflecting the lower scoring in the sensory analysis, Table 6 column 1. Information on flour composition resulted in products from blends attracting a premium above wheat-only products, ranging from 3 KES in sorghum blends to 5 KES for cassava blends, or up to 9% above the WTP for wheat-only bread, see Table 6 column 2.

Column 3 of Table 6 shows the consumers' willingness to pay estimates for different types of blends for chapati flour in the blind tasting group. The cassava blend was significantly discounted by approximately 9 KES compared to the wheat-only flour, while the sorghum and millet blends were valued equally with the wheat-only flour. Consumers who received information on flour composition before tasting stated a higher WTP for the blends compared to wheat flour alone, placing a premium of 9 KES, 13 KES, and 14 KES for the cassava, millet, and sorghum blends, respectively. This is equivalent to up to 7% premium above the mean WTP for 100% wheat chapati flour.

#### 4.6. Heterogeneity in willingness to pay by consumer perceptions of the healthiness of foods derived from blended flour

Building on previous research showing that health and nutritional food attributes may command premiums (Alsubhi et al., 2023; Dolgoplova & Teuber, 2016), we hypothesize that the higher WTP observed

<sup>15</sup> The average market price for 400 g of wheat flour bread (used as a control) was 64 KES, whereas the price for refined wheat flour used in chapati was 194 KES during the study period, suggesting that respondents offered realistic valuations of the products.

**Table 5**  
Mean WTP for blended flour and products derived from the blended flour.

Product	Treatment group	N. of observations	Mean KES (Standard Deviation)				Mean difference <sup>b</sup>		
			Sorghum wheat blend	Millet wheat blend	Cassava wheat blend	Wheat Only	Sorghum Blend vs. Wheat Only	Millet Blend vs. Wheat Only	Cassava Blend vs. Wheat Only
Bread	Blind tasting	536	61.1 (22.5)	60.3 (20.5)	61.8 (22.7)	63.4 (23.0)	2.3*	3.0*	1.6
	Informed tasting Blind v.s Informed	428	61.9 (18.9)	62.7 (17.3)	63.7 (17.7)	58.7 (15.9)	-3.2*	-4.0***	-5.0***
Chapati	Blind tasting	539	203.6 (56.2)	203.5 (58.9)	194.0 (62.2)	202.6 (56.4)	-1.0	-0.9	8.6*
	Informed tasting Blind vs. Informed	368	207.8 (47.2)	207.3 (46.0)	203.2 (47.9)	194.5 (44.3)	-13.3***	-12.8***	-8.7*

The millet substitution rate is 10% in bread and 5% in chapati; the cassava substitution rate is 5% in bread and 20% in chapati; and the sorghum substitution rate is 10% in both bread and chapati. The standard deviation is in brackets.

<sup>b</sup> P-values from a t test for the equivalence of the means; \*p < 0.10, \*\*p < 0.05 and \*\*\*p < 0.01.

for products made from blended flours among the informed tasting group was driven by consumers perceiving these products as healthier compared to the 100% wheat-based products.<sup>16</sup> To test this hypothesis, we reanalyzed the willingness to pay among consumers in the informed tasting groups, dividing the sample based on their reported perceptions of the healthiness of foods made from blended wheat flour compared to those made exclusively from wheat flour (see Table 7). Columns one and three of Table 7 show the WTP values for consumers who perceived the 100% wheat-based products as healthier than the blends. In this category, we find no premium for the products obtained from the blended flours. On the other hand, we find a significant and positive WTP for the products made from the blended flours relative to the 100% wheat products among the consumers who perceive such products as healthier.

## 5. Discussions and policy implications

The current study examined consumer acceptance of chapati and bread products made from wheat flour blended with sorghum, millet, or cassava flour. We report four key findings. First, our analysis revealed that the partial substitution of wheat flour with these other crops induces noticeable alterations in the sensory characteristics of wheat-based food products. Second, consumers perceived foods derived from blended flours to have enhanced nutritional value. More than ninety percent of consumers perceived wheat-based foods derived from blended flour as healthier and more expensive than conventional foods. Third, bread made of blended flour was slightly less preferred than conventional bread. In contrast, chapati products made of wheat and sorghum (10%) or millet (5%) blends were equally valued as chapati made of 100% wheat flour, suggesting the potential to replace up to 10% of wheat flour in chapati without compromising sensory characteristics and consumer acceptance. Lastly, informing consumers about the flour composition before tasting resulted in a greater liking and willingness to pay for the blends relative to wheat-only products. This increased preference and willingness to pay were also observed in bread, suggesting that consumers were ready to accept the adverse sensory effects of blending in exchange for its perceived advantages. Consequently, consumers were willing to pay a modest premium, up to 9%, for the

blended products.

Our finding on consumer perceptions of blend-based wheat foods, which prompted them to accept a trade-off in sensory qualities for some of the products under study, is particularly interesting. Previous studies have shown similar results, that is, consumers are willing to sacrifice sensory qualities for other perceived benefits (De Groot et al., 2020; Papoutsi et al., 2019). Since this result was consistent across all our bread products, including bread made with 20% cassava flour—the highest substitution rate in our study—there is potential for substitution rates beyond 20%. A higher substitution rate could enhance the nutritional value of the products and create more demand for the substitute crops. However, further research is needed to determine the highest acceptable substitution rate, balancing the possible adverse effects on sensory qualities with the nutritional benefits and consumer willingness to pay for these attributes. Such research can also explore the use of food science innovations, like enzymes, to improve the sensory qualities of products with higher levels of substitute crops. Lastly, such work could extend to other wheat-based products with more nutritional benefits, such as foods derived from whole grains.

Our study contributes to the ongoing discussions on the feasibility of wheat flour blending policies in Kenya. It demonstrates that replacing at least 10% of wheat flour with flour from other crops is feasible from a consumer acceptability perspective. This evidence eliminates the uncertainties that private sector actors face and highlights existing opportunities for them to innovate new products. The study thus provides an important input into the ongoing deliberations about the feasibility of blending policies in Kenya and elsewhere.

An important factor for private sector engagement in blending is the profitability of the resulting products. While profitability analysis of wheat flour blending has received limited attention in the literature (Gomez et al., 1992; Poole et al., 2024), we provide some estimates based on our understanding of the context and our results. The main costs for a miller include fixed costs for milling and blending equipment and variable costs for the raw materials. In 2024, the factory gate prices in Nairobi were roughly KES 80/kg for white sorghum and pearl millet, KES 90/kg for cassava flour, and KES 53/kg for wheat flour. Replacing 10% of wheat with any of these crops would increase the raw material costs for a miller by an additional KES 2.7–3.7. This additional cost is comparable to the premium consumers in our study were willing to pay for blended products over conventional ones (4–7 KES per kg of chapati flour, with information). Although the additional variable cost aligns with the extra price consumers were willing to pay for blended products, the miller still faces substantial initial fixed costs as well as risks associated with the constant supply of quality raw materials.

Given Kenya's annual wheat consumption of around two million metric tons, substituting up to 10% of wheat flour translates to roughly

<sup>16</sup> It is also possible that the higher WTP values observed among consumers who perceive the new products as healthier may have resulted from overstating their WTP in hypothetical scenarios rather than reflecting their actual demand. As demonstrated by Hofstetter et al. (2013) such consumers might inflate their WTP values in hypothetical survey designs due to emotional enthusiasm or strategic behavior aimed at encouraging product development and market introduction.

**Table 6**  
Willingness to pay for blended chapati flour and bread derived from blended flour.

	WTP for 400 gm loaf of bread, KES		WTP for a 2 kg packet of chapati flour, KES	
	1	2	3	4
	Blinded tasting	Informed tasting	Blinded tasting	Informed tasting
Millet-Wheat blend	-3.016*** (1.045)	4.120*** (0.984)	0.678 (2.560)	12.807*** (2.496)
Cassava-Wheat blend	-1.446 (1.003)	5.308*** (0.880)	-8.779*** (2.620)	8.855*** (2.760)
Sorghum-Wheat blend	-2.170** (0.995)	3.357*** (1.023)	1.229 (2.404)	13.522*** (2.550)
Respondent is male	-4.076*** (1.574)	0.134 (1.290)	3.067 (3.885)	-0.224 (3.966)
Age of the consumer in years	-0.073 (0.058)	-0.098 (0.063)	-0.806*** (0.199)	-0.655*** (0.200)
Asset ownership index	-1.160*** (0.425)	-0.271 (0.345)	0.062 (0.995)	-0.668 (1.059)
Consumes whole grain products (0/1)	-0.751 (1.574)	-2.517 (1.646)	0.152 (7.589)	1.700 (9.643)
Perceives blends as healthier (0/1)		2.757 (2.350)		11.511 (7.371)
Expected to like the blends (0/1)		-0.529 (1.456)		3.934 (4.505)
Mean WTP for wheat only	63.4	58.7	202.6	194.5
Observations	2136	1696	2156	1464

**Notes.** Random effects models were used. The dependent variable is the stated willingness to pay, measured in KES. The independent variables are the indicators for each product type: 100% wheat, sorghum-wheat, millet-wheat, or cassava-wheat products. Millet substitution rate: 10% in bread and 5% in chapati; Cassava substitution rate: 5% in bread and 20% in chapati; Sorghum substitution rate: 10% in both bread and chapati. Separate regressions were conducted for each product type (chapati and bread) and group (blind vs. informed tasting groups). Added to the regressions were consumer demographics: age, asset ownership index constructed by adding all the positive responses to the question on whether the respondent owns specific assets, indicator for the consumption of whole grain products, an indicator for perception of blended flour products as healthier and an indicator if the consume expected to like the products. The enumerator and serving order fixed effects were included to control for study design biases. Standard errors are shown in brackets, clustered at the consumer level. \*p < 0.10, \*\*p < 0.05 and \*\*\*p < 0.01.

200,000 metric tons (FAOSTAT, 2024). This amount is nearly double the annual millet production in Kenya and matches the yearly production of sorghum and cassava flour (FAOSTAT, 2024). The national yields of these crops are below their potential (Handschuh & Wollni, 2016; Kazungu et al., 2023), leading to low price competitiveness compared to other staples like maize and wheat. As a result, the local production of these crops does not satisfy the existing demand, leading to occasional small imports from Uganda and Tanzania. Therefore, ensuring the availability of raw materials in sufficient quantities to leverage the demand induced by the flour blending policies remains a pertinent issue. A short-term approach could involve increasing imports from neighboring East African countries. Sorghum production in Tanzania has notably increased over the past decade (Akpo et al., 2022), with most of it being exported to Kenya and other countries.

In the long term, investments are needed to boost local production of these traditional crops. Given the public benefits associated with wheat flour blending policies, such as reduced foreign exchange expenditures,

**Table 7**  
WTP for different products based on the consumer's perceptions.

	WTP for 400 g loaf of bread (KES)		WTP for a 2 kg packet of chapati flour (KES)	
	1	2	3	4
	Perceives wheat only as healthier than blends	Perceives blends as healthier than wheat only	Perceives wheat only as healthier than blends	Perceives blends as healthier than wheat only
Sorghum-Wheat blend	-2.134 (3.889)	3.801*** (1.068)	-3.630 (9.815)	14.336*** (2.653)
Cassava-Wheat blend	3.476 (3.219)	5.423*** (0.921)	1.194 (9.022)	9.520*** (2.877)
Millet-Wheat blend	-0.657 (2.561)	4.515*** (1.045)	-5.701 (13.217)	13.912*** (2.517)
Mean WTP for wheat only	60.0	58.6	197.9	194.3
Observations	128	1568	72	1392

**Notes:** The sample was restricted to the informed tasting group only. The dependent variable is the stated willingness to pay, measured in KES. The independent variables are the indicators for each product type: 100% wheat, sorghum-wheat, millet-wheat, or cassava-wheat products. Millet substitution rate: 10% in bread and 5% in chapati; Cassava substitution rate: 5% in bread and 20% in chapati; Sorghum substitution rate: 10% in both bread and chapati. Separate regressions were conducted for each product type (chapati and bread) and for each consumer type based on their perception of the healthiness of blended flour and associated products. Added to the regressions were consumer demographics: age, asset ownership index constructed by adding all the positive responses to the question on whether the respondent owns specific assets, an indicator for the consumption of whole grain products, and an indicator if the consumer expected to like the products. The enumerator and serving order fixed effects were included to control for study design biases. Standard errors are shown in brackets, clustered at the consumer level. \*p < 0.10, \*\*p < 0.05 and \*\*\*p < 0.01.

increased food security, and economic growth, public sector investment may be justified. Investments are needed in advancing improved production technologies, such as improved varieties and agronomic practices, extension services to encourage farmers to adopt these technologies, and advancing input markets to provide access to improved varieties. In addition, there is a need to create market linkages between producers and wheat millers. The government could use fiscal tools such as subsidies or tax incentives to encourage private-sector investments in blending.

Public investments in consumer education and promotional campaigns highlighting blended products' benefits should form an important element of supporting wheat flour blending. The information treatment in the current study, in which consumers were informed about the composition of the flour, showed a modest increase in the willingness to pay for blend-based over conventional products. Stronger messages emphasizing nutritional benefits and support for locally produced crops could lead to a higher willingness to pay, incentivizing the private sector to invest in these products. More work should be done on the nutritional profiles of these crops and ways of enhancing the nutritional value of wheat-based products (e.g., whole grain foods, whole grains blend-based foods, etc.) to inform such campaigns.

Lastly, we highlight additional areas that warrant future research. First, our study sample is confined to an urban area, given the higher consumption of wheat among urban areas relative to rural areas (Mason et al., 2015). Our sample also comprises middle- and high-income consumers in urban areas. However, wheat consumption is increasing in rural areas and among low-income consumers, and these populations may have unique preferences for wheat blend products. Second, we

acknowledge the limitations of the contingent valuation method used to assess consumer WTP for blended products, particularly the potential for hypothetical bias (Cummings et al., 1995; Murphy et al., 2005). While this method has been applied in previous studies (Ha et al., 2019; Magnus et al., 1997; Michelson et al., 2021; Romano et al., 2016), future research should prioritize approaches that minimize this bias. Research designs and settings that facilitate the use of more incentive-compatible methods, such as experimental auctions and real choice experiments, should be considered, such as conducting household surveys or central location testing instead of consumer intercepts. Emerging evidence suggests that real choice experiments are particularly promising in such contexts (Caputo et al., 2023). Lastly, more research is required on the quality requirements of the substitute crop flours needed in wheat flour blending and on the effect of blending on the shelf-life of the resulting products. The role of varietal characteristics for alternative crops and the impact of additives such as enzymes in improving the sensory properties of blended products. Genomic, environmental, and agricultural factors are likely to influence the composition and functional properties of cereal flour (Banu et al., 2014).

## Appendix 1. Bread samples preparation

### Ingredients:

- Bakers flour 2 kg
- Salt 20 g
- Instant yeast 20 g
- Sugar 100 g
- Fat 80 g
- Water 1.1lts

### Procedure

All the ingredients were weighed, and the flour was sieved for aeration and removal of contaminants. All the ingredients except fat were put in a mixing bowl and mixed for 3 min at low speed. Fat was added to the mixture and mixed further for three minutes at low speed. Mixing continued for a further 3 min at medium speed, after which the dough was placed on the table, covered with a proofing cloth and allowed to proof at 20–25 °C for 1 h for the first proofing phase to allow the yeast to produce gas within the dough mass. Once the dough had been proofed for 1 h, the dough was scaled into 460 g pieces, which were moulded and put into greased baking pans. The dough pieces were placed in a humid proofing cabinet at 30–40 °C for 60 min for the second proofing phase, for the dough to rise to the rims of the baking pans. The doughs were removed from the proofing cabinet and baked in the oven at 220 °C for 30–40 min until a golden-brown crust was formed. The baked loaves were removed from the oven, depanned, and placed on a cooling rack for 60 min before slicing. The bread samples were sliced, and the crust of each slice was cut off. The slices from each bread sample were individually wrapped in cling film to maintain freshness and softness (texture) and to protect the samples from external contamination. The wrapped bread samples were kept in airtight plastic containers for transportation to the street testing sites.

## Appendix 2: Chapati samples preparation

### Ingredients:

- 1 kg of all-purpose flour
- 40 ml cooking oil
- 30 g sugar
- 4 g salt
- 600 ml warm water

### Procedure

All the ingredients were put in a mixing bowl and kneaded until the dough was smooth and tender. The dough was covered with a plastic wrap and allowed to rest for 1 h. The dough was rolled into a large sheet using a rolling pin, and some cooking oil was smeared onto the dough. The large dough sheet was cut into strips, rolled and scaled into 120 g spherical dough balls. A non-stick frying pan was placed on medium heat, and some oil was added. The dough balls were rolled into flat, round shapes, one at a time, and put on the frying pan. The rolled chapati was allowed to cook until golden brown before turning over the other side. Oil was added as needed to achieve the desired outcome. The cooked chapatis were removed from the

## CRediT authorship contribution statement

**Sarah W. Kariuki:** Writing – original draft, Project administration, Methodology, Investigation, Formal analysis, Conceptualization. **Jason Donovan:** Writing – original draft, Supervision, Funding acquisition, Conceptualization. **Francisca N. Muteti:** Writing – original draft, Project administration, Methodology, Investigation, Formal analysis, Conceptualization. **Maria Itria Ibba:** Writing – review & editing, Investigation, Conceptualization. **John Muoria:** Writing – review & editing, Methodology, Investigation. **Alex Mahugu:** Writing – review & editing, Project administration. **Daniel Sila:** Methodology, Conceptualization. **Alison Bentley:** Writing – review & editing, Funding acquisition, Conceptualization.

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heat and placed in a hotpot to maintain freshness and warmth.

The samples were cut into 1/8th pieces, and a serviette wrapped each piece to avoid external contamination and allow each consumer to unwrap the sample independently. The chapati pieces were wrapped further in aluminum foil and kept in a hotpot to maintain freshness and warmth during transportation to the street testing sites. The chapati samples were cooked in two batches, one in the morning and the second in the afternoon, to ensure that the samples got to the consumers (respondents) while being as warm as possible. The different blends of chapati samples were cooked randomly to eliminate bias between the blends cooked first and last. Three distinct stages of cooking the chapati were denoted as critical control points for maintaining the consistency and uniformity of the final chapati samples. The critical control points of the chapati-making process, (1) kneading of the dough, (2) rolling of the dough into flat sheets, and (3) actual cooking of the chapati, were handled by three separate personnel throughout the entirety of the study to disregard product inconsistencies.

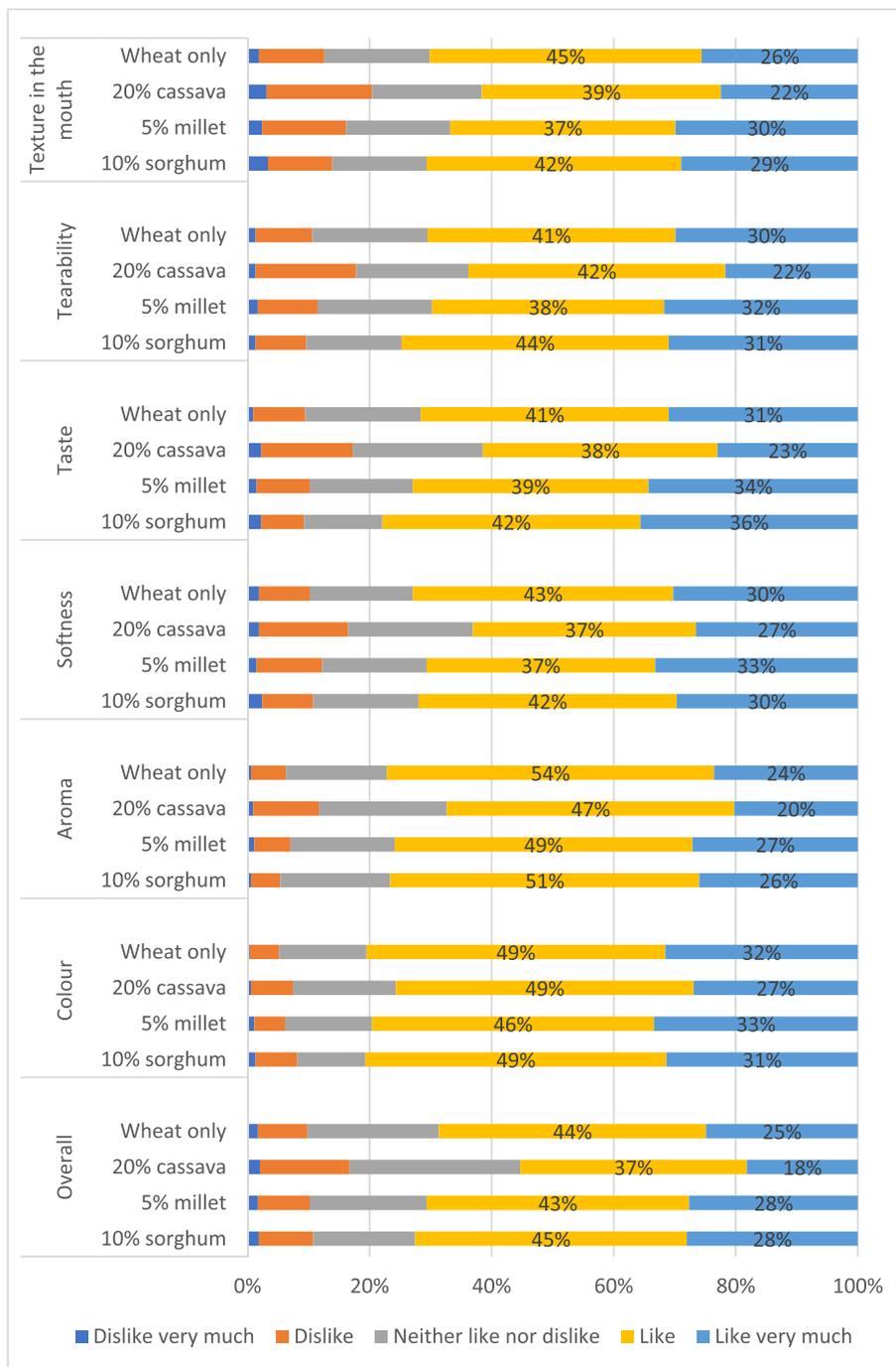


Fig. A1. Evaluation of chapati products along different attributes by the blind-tasting group

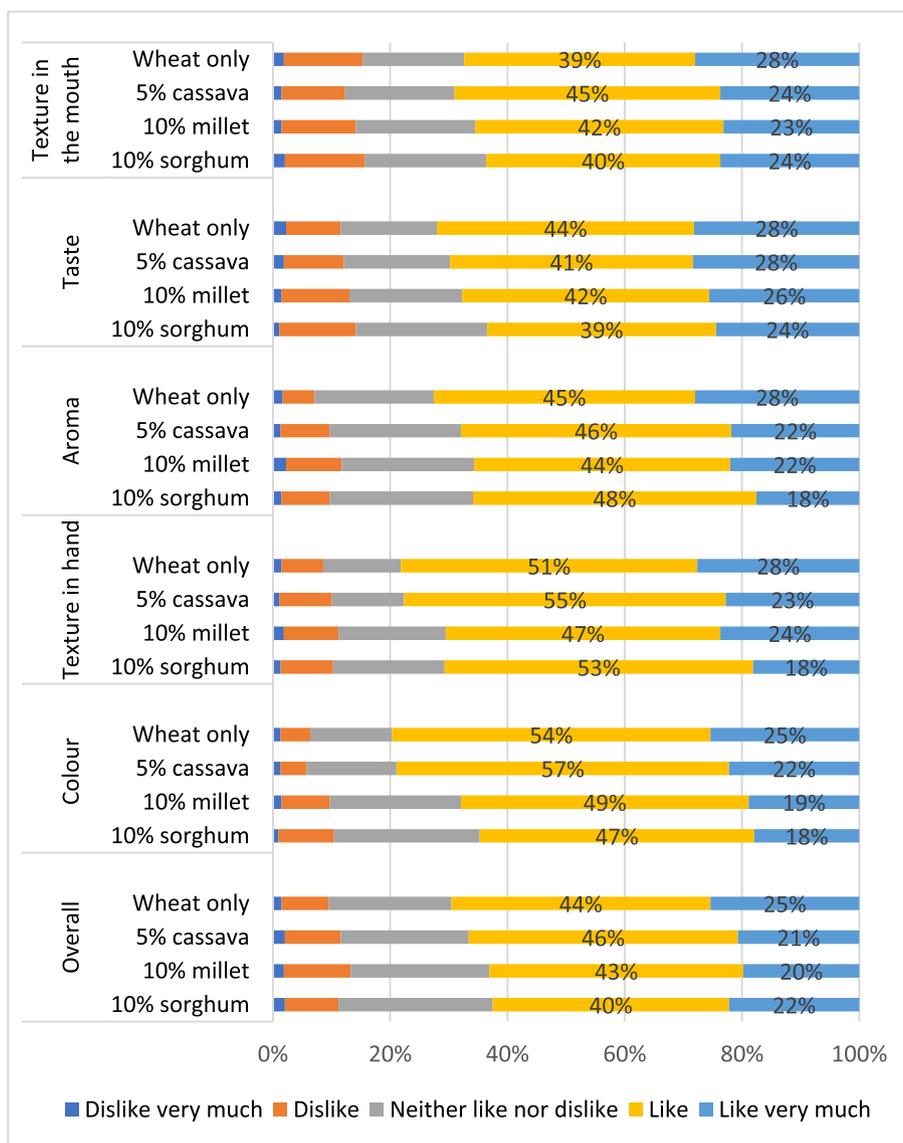


Fig. A2. Evaluation of bread products along different attributes by the blind-tasting group

Table A1

Tests for balance between the blind and informed tasting groups

Variable	Blind tasting group			Informed tasting group			pvalue
	N	Mean	SD	N	Mean	SD	
Age of the consumer in years	1073	30.87	10.67	790	29.92	10.03	<b>0.052</b>
Respondent is male	1075	0.50	0.50	796	0.48	0.50	0.305
<i>The education level of the respondent</i>							
Primary school level and below	1073	0.03	0.18	795	0.06	0.23	<b>0.015</b>
High school level	1073	0.31	0.46	795	0.32	0.47	0.684
Tertiary level	1073	0.65	0.48	795	0.62	0.49	0.152
<i>Assets ownership</i>							
Owns a car	1075	0.47	0.50	796	0.47	0.50	0.923
Owns a bicycle	1075	0.45	0.50	796	0.51	0.50	<b>0.012</b>
Owns a motorbike	1075	0.23	0.42	796	0.29	0.45	<b>0.003</b>
Owns a refrigerator	1075	0.65	0.48	796	0.65	0.48	0.798
Owns a gas cylinder	1075	0.96	0.19	796	0.95	0.23	0.101
Owns a cooker with an oven compartment	1075	0.56	0.50	796	0.55	0.50	0.450
Has access to an internet connection	1075	0.64	0.48	796	0.65	0.48	0.962
Has piped water inside the house	1075	0.82	0.38	796	0.80	0.40	0.307
Owns a smartphone	1075	0.94	0.23	796	0.95	0.22	0.539

(continued on next page)

Table A1 (continued)

Variable	Blind tasting group			Informed tasting group			pvalue
	N	Mean	SD	N	Mean	SD	
Asset ownership index	1075	5.74	2.07	796	5.81	2.18	0.479
Resides in own house	1075	0.24	0.42	796	0.22	0.42	0.595

Table A2

Tests for equivalence of regression coefficients between the blind and informed tasting groups

	Bread	Chapati
10% millet (bread)	-0.344*** (0.116)	0.110 (0.119)
5% cassava (bread)	-0.209* (0.111)	-0.538*** (0.111)
10% sorghum (bread)	-0.265** (0.115)	0.168 (0.113)
Information disclosed	-0.553*** (0.126)	-0.155 (0.127)
Wheat-Millet*Information	0.787*** (0.173)	0.550*** (0.172)
Wheat-Cassava*Information	0.595*** (0.178)	0.763*** (0.180)
Wheat-Sorghum*Information	0.881*** (0.164)	0.317* (0.177)
Respondent is male	0.028 (0.069)	0.017 (0.071)
Age of the consumer in years	0.003 (0.003)	0.004 (0.003)
Asset ownership index	-0.049*** (0.017)	-0.015 (0.018)
Consumes Whole Grain Products (0/1)	-0.056 (0.081)	-0.110 (0.121)
cut1	-4.794***	-4.437***
cut2	-2.882***	-2.385***
cut3	-1.405***	-0.950***
cut4	0.702***	1.022***
sigma2_u	0.255***	0.198***
Observations	3832	3620
Wald chi2	306.242	10439.829

## Note

The coefficients are logs of the odds ratio, estimated using the random effects ordered logit models. Standard errors are shown in brackets, clustered at the consumer level. The dependent variable, consumer scores, ranges from 1 (dislike very much) to 5 (like very much). The independent variables are the indicators for each product type: 100% wheat, sorghum-wheat, millet-wheat, or cassava-wheat products. Millet substitution rate: 10% in bread and 5% in chapati; Cassava substitution rate: 5% in bread and 20% in chapati; Sorghum substitution rate: 10% in both bread and chapati, an indicator for tasting condition (blind vs. informed tasting groups) and interaction terms for the product indicators and the tasting condition. Separate regressions were conducted for each product type (chapati and bread). Added to the regressions were consumer demographics: age, asset ownership index constructed by adding all the positive responses to the question on whether the respondent owns specific assets, indicator for the consumption of whole grain products. The enumerator and serving order fixed effects were included to control for study design biases. \* $p < 0.10$ , \*\* $p < 0.05$  and \*\*\* $p < 0.01$ .

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