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Substitution of maize with sorghum and millets in traditional processing of *Mahewu*, a non-alcoholic fermented cereal beverage

Sakile Kudita,[1,2,3,4]* **Sijmen Schoustra,**[1,5] **Juliet Mubaiwa,**[6] **Eddy J. Smid**[2] **& Anita R. Linnemann**[3]

1 Laboratory of Genetics, Wageningen University & Research, P.O. Box 16, Wageningen, 6700 AA Gelderland, The Netherlands
2 Food Microbiology, Wageningen University & Research, P.O. Box 17, Wageningen, 6700 AA Gelderland, The Netherlands
3 Food Quality & Design, Wageningen University & Research, P.O. Box 17, Wageningen, 6700 AA Gelderland, The Netherlands
4 HarvestPlus – Zimbabwe, C/O International Food policy Research Institute (IFPRI), P.O. Box MP 228, Mt Pleasant, Harare, Zimbabwe
5 Department of Food Science and Nutrition, University of Zambia, PO Box 50516, Lusaka, Zambia
6 Department of Food Science and Technology, Chinhoyi University of Technology, Private Bag 7724, Chinhoyi, Zimbabwe

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Summary There is growing interest in Sub-Saharan Africa for substituting maize with climate-smart crops like sorghum and millets in local food processing. We conducted a survey to explore current variations in processing and consumption practices for *Mahewu*, a traditionally fermented cereal beverage from Zimbabwe. Processing involved cooking a cereal porridge, adding cereal flour or malt as a starter ingredient, and fermenting for 12–48 h. Ingredient availability was the main driver for porridge ingredient choice (42% of respondents) with the most preferred being maize (55% of respondents), pearl millet (22%) and sorghum (9%). Final product taste had the most influence on starter ingredient choice, with most respondents preferring pearl millet flour (23%), finger millet malt (22%), wheat flour (17%), and sorghum malt (13%). Our study proves that maize can be replaced with sorghum and millet in *Mahewu* processing, thus increasing the climate-resilience of future food systems, and demonstrates that traditional practices harbour clues for adapting current practices.

Keywords Cereal fermentation, climate change, Lactic acid fermentation, *Mahewu*, non-alcoholic fermented cereal beverage, spontaneously fermented cereal beverage, traditional processing, weaning food.

Introduction

The long-term sustainability of maize-based food systems in sub-Saharan Africa is uncertain. Models analysing the effects of climate change on maize production have predicted a sharp decrease in maize (*Zea mays* L.) productivity over the next few decades (Chemura *et al.*, 2022; Li *et al.*, 2022). This has resulted in growing interest in the search for maize alternatives in food processing with a special interest in climate resilient crops such as sorghum (*Sorghum bicolor*), pearl millet (*Pennisetum glaucum*) and finger millet (*Eleusine coracana*). Moreover, these traditional small grains are nutritionally superior to maize and their consumption has been associated with a reduced risk of non-communicable diseases such as hyperglycaemia and hypertension in humans (Saleh *et al.*, 2013; de Morais Cardoso *et al.*, 2017; Ogunremi *et al.*, 2017; Dias-Martins *et al.*, 2018; Yankah *et al.*, 2020; Satyavathi *et al.*, 2021; Hossain *et al.*, 2022). The re-integration of these cereals in the food-system will require processing technologies that enhance their organoleptic acceptance by modern day consumers whose palates are accustomed to maize.

In many countries, maize is traditionally processed by fermentation, a technology that relies on microbial activity to drive physical and biochemical changes in foods, making them safer and more attractive to consumers (Assohoun *et al.*, 2013; Sharma *et al.*, 2020; Meena *et al.*, 2022). The technology has its origins in antiquity but has attracted much interest in recent years as a sustainable low-cost technology for improving the organoleptic, nutritional and functional properties of cereals (Fend *et al.*, 2018; Phiri *et al.*, 2019; Materia *et al.*, 2021). A widely consumed product of traditional cereal fermentation in Zimbabwe is *Mahewu*, a non-alcoholic beverage produced through the spontaneous lactic acid fermentation of cereal porridge into a thick beverage with a sweet–sour taste. The beverage is popular with rural and urban consumers of all ages for its refreshing and

*Correspondent: E-mail: sakile.kudita@wur.nl

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hunger-quenching properties, and is often used as a weaning food for infants, a supplementary food for school feeding programs, and is also served to guests during social gatherings (Simango, 2002; Awobusuyi *et al.*, 2021; Daji *et al.*, 2022).

Mahewu processing, as described by Pswarayi & Gänzlea (2019) in (Fig. 1) involves (i) stirring maize flour into water and cooking the mixture into a thin gelatinized porridge, (ii) cooling the porridge and adding water to make it thin enough to be a drink, and finally (iii) adding uncooked sorghum or finger millet malt to start the fermentation. The mixture is then allowed to ferment at room temperature for 24–48 h. This process closely resembles the production process for *Togwa* in Tanzania (Kitabatake *et al.*, 2003; Mugula *et al.*, 2003) *Munkoyo* and *Chibwantu* in Zambia (Schoustra *et al.*, 2013; Phiri *et al.*, 2019), *Mageu* and *Amahewu* in South Africa (Awobusuyi *et al.*, 2016; Maakelo *et al.*, 2021), *Motsena* in Botswana (Maakelo *et al.*, 2021), *Emahewu* in Swaziland (Maakelo *et al.*, 2021) and *Maxau* in Namibia (Maakelo *et al.*, 2021).

Zimbabwe is divided into five agro-ecological zones on the basis of temperature and rainfall regime, and the agricultural practices they can support (Zimfact, 2020). The agricultural productivity of the regions decreases as one moves from agro-ecological zone I to V with zone I typified by high rainfall (>1000 mm annually) and intensive crop production while zone V receives less than 450 mm of rain annually and is considered too dry for crop production (Zimfact, 2020). Seventy seven (77%) of the total farming land in Zimbabwe falls under agro-ecological zones III–V, and although most households in these zones produce and consume maize, they may be forced by climate change to grow less maize and more of the traditional small grains for their drought tolerance, and use them more in producing local foods such as *Mahewu* (FAO, 2006; Muzerengi & Tirivangasi, 2019). The practicality of using traditional small grains to produce *Mahewu* depends on the cultural appropriateness of the practice, the accessibility of the ingredients and the sensorial acceptance of the final product. To effectively improve *Mahewu* and upgrade its processing, it is important to understand indigenous knowledge, attitudes and practices surrounding its processing and consumption. In view of this, this study will investigate current trends in *Mahewu* processing and consumption across varying ethnic groups in Zimbabwe,

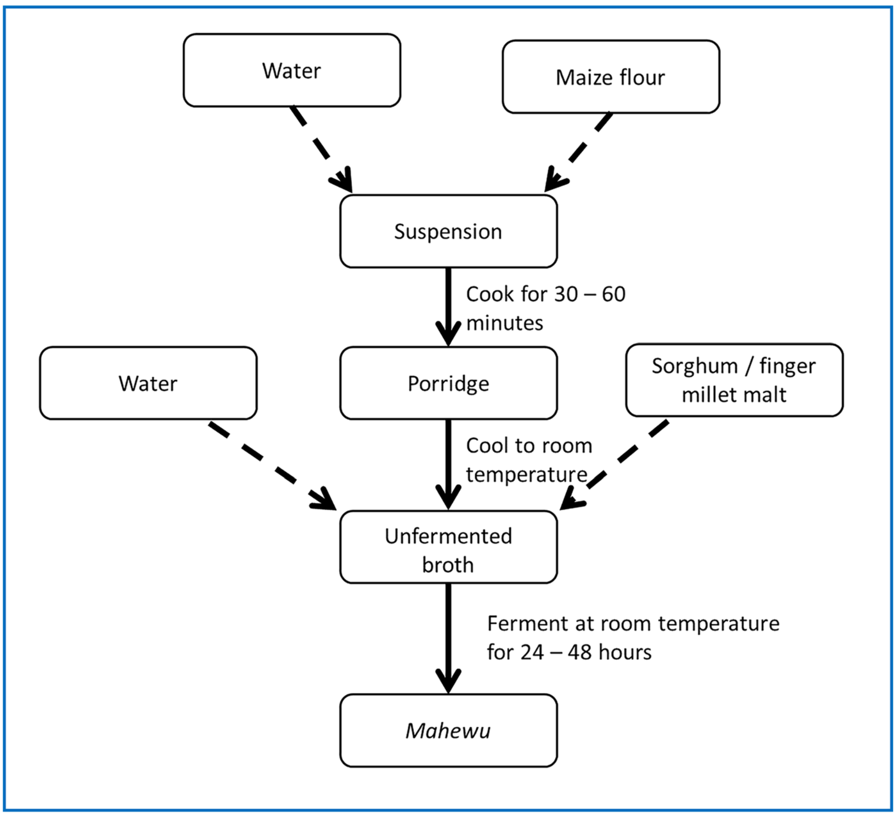

Figure 1 *Mahewu* production process as described by Pswarayi & Gänzlea (2019) The dotted arrows represents the addition of an ingredient while the solid arrow represents progression from one processing state to another.

the range of ingredients used, the factors affecting their choice, frequency of consumption and by whom.

Materials and methods

Sampling

The study was conducted from September to October 2021 through a cross-sectional survey covering five districts in agro-ecological zones III–V (Fig. 2). The sampling frame consisted of eight rural provinces which were grouped into five clusters based on the majority ethnicity in each province. From each cluster, all districts that fall under agro-ecological zones III–V and grow sorghum, pearl millet and finger millet on more than 10% of their total cereal area were sampled using data from the Zimbabwe 2021 annual crop and livestock survey (Ministry of Agriculture–Zimbabwe, 2021). From these, one district was randomly selected from each cluster and targeted for this study (Table 1). From each sampled district, one ward and at least 30 households per ward were selected for the study, giving a sample size of 150. This sample size was higher than the calculated minimum sample size of 96 attained through the use of the Cochran formulae (Cochran, 1977); based on a 95% confidence interval, 50% expected variability and a desired precision of 10%.

Data collection

During the survey, information on *Mahewu* processing and consumption was collected from sampled households using focus group discussions (FGDs) and personal interviews using a structured questionnaire

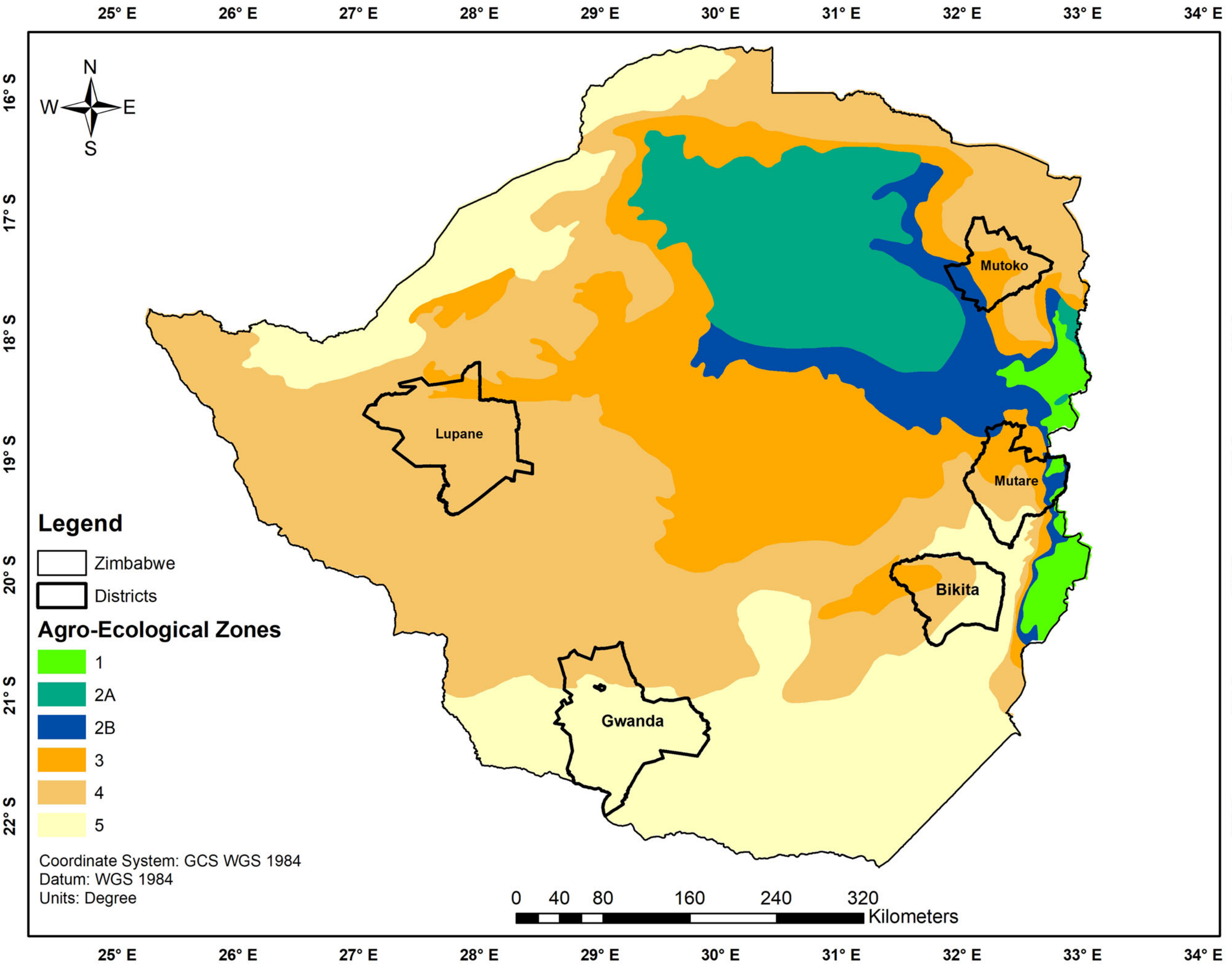

Figure 2 Map showing Zimbabwe's five agro-ecological zones and the sampled districts, Mutoko, Mutare, Bikita, Gwanda and Lupane (Zimfact, 2020).

Table 1 Sampled districts and their main characteristics

District	Province cluster	Majority Ethnic group	Natural farming region	% cereal area under each cereal			
				Maize	Sorghum	Pearl millet	Finger millet
Mutoko	Mashonaland east, Mashonaland west, Mashonaland central	Zezuru	III & IV	87	11	10	1
Mutare	Manicaland	Manyika	III, IV & V	75	14	10	1
Bikita	Masvingo, Midlands	Karanga	III, IV & V	70	18	8	5
Gwanda	Matabeleland south	Ndebele	IV & V	62	26	11	0
Lupane	Matabeleland north	Ndebele	III & IV	65	14	21	0

Table 2 Information collected during the household survey

Type of information	Details
Geographic information	District, ward, village, GPS coordinates
Demographic information	Age, gender, household size, ethnic group
Mahewu consumption information	Consumption days per week, type of the meal, who consumes *Mahewu*, its importance in infant and young child feeding, frequency of consumption by children aged 6–24 months
Mahewu production information	Ingredient used in cooking porridge for making *Mahewu*, ingredient used to start the fermentation, reasons for the choice of ingredients, religious restrictions on ingredient choice, containers used for fermentation, fermentation time

(Table 2; Data S1). The FGDs focused on indigenous knowledge of *Mahewu* production, when and how it is consumed, its perceived health benefits and the malt production process (Table 2).

Data analysis

All collected data were analysed using Microsoft® Excel® for Microsoft Office 365 Version 2202, Build 16.0.14931.20648, 32-bit (Redmond, Washington, United States of America) and IBM SPSS Statistics version 28.0.0.0 (Armonk, New York, United States of America) to obtain frequency tables and cross tabs.

Results

Demographics of surveyed households and the crops they grow

A total of 124 respondents participated in the survey of which 99% were women aged 22–82 years. The average size of surveyed households was six persons. Eighty-five percent of households grew maize, 74% sorghum, 60% pearl millet and 24% finger millet.

Mahewu consumption patterns

Respondents consumed *Mahewu* 4–6 days a week on average in summer (September–April) and only once a week in winter (May–August). Focus group participants attributed the low consumption in winter to the long time it takes for the beverage to ferment during this period. Most households consumed the drink as a snack (52%), 23% for lunch, 14% for breakfast, 10% for dessert and only 1% for dinner.

Mahewu use in feeding infants and young children.

Ninety-six per cent of respondents mentioned *Mahewu* as an important supplementary/weaning food for children from 6 to 24 months, and serve it to them 2–5 times a day in summer. Focus group participants explained the importance of *Mahewu* for infant and young-child feeding as it helps babies to grow faster, prevents malnutrition, and increases their appetite. They also described *Mahewu* as healthier for children than plain porridge because feeding children *Mahewu* is thought to prevent kwashiorkor, unlike plain porridge.

Mahewu preparation

The various processes for producing *Mahewu* as determined through the survey are summarised in Fig. 3.

Step 1—making a cereal porridge

According to the survey, the preparation of *Mahewu* starts with a cereal porridge as main raw material. Eighty-nine per cent of respondents always used freshly cooked porridge, 5% always used left-over thick porridge (sadza) from a previous meal, and 6%

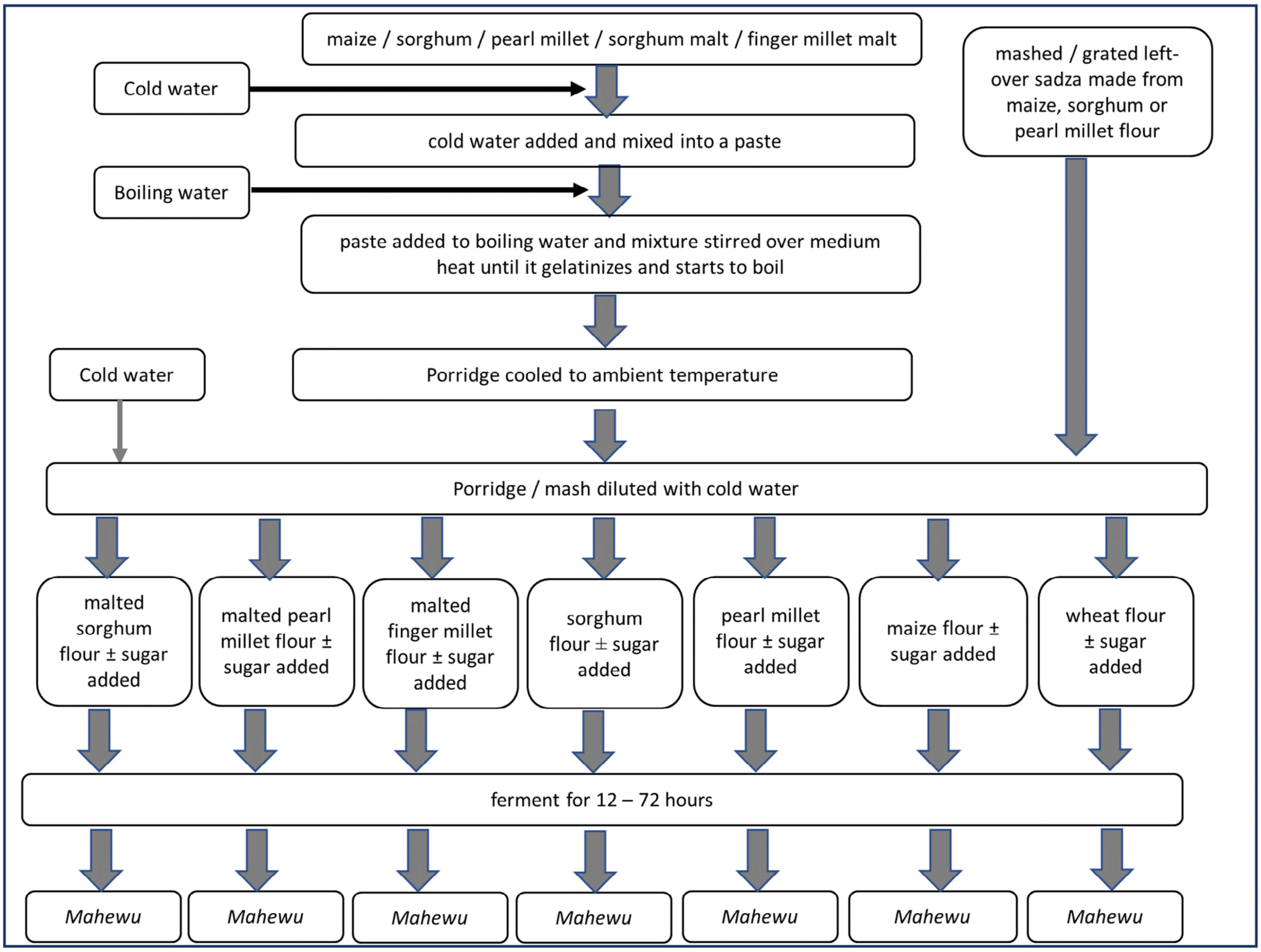

Figure 3 Overview of processes for making in *Mahewu* in Zimbabwe.

alternated between the two. Freshly cooked porridge was prepared the same way in all districts, namely by mixing cereal flour with cold water, transferring the paste into a pot of boiling water and stirring the mixture until it gelatinizes and then allowing it to boil for 30–60 min. After cooking, the porridge is removed from the fire and allowed to cool down to ambient temperature.

The most commonly used ingredients for producing porridge were maize (75% of respondents), pearl millet (33%) and sorghum (20%). Six percent of respondents used finger millet or sorghum malt. There was an association between district and the most preferred porridge flour. Maize flour was the most preferred in Gwanda, Lupane, Mutare and Mutoko and pearl millet in Bikita (Table 3).

The main factors for ingredient preference were availability (42%), familiarity (19%), taste (36%) and nutritional quality (14%). Most respondents who preferred maize in cooking porridge for making *Mahewu*, liked it because it was readily available, while preference for sorghum and pearl millet was because of their taste (Table 4). Finger millet was mostly preferred for its nutritional qualities while sorghum malt and finger millet malt were preferred for their taste, nutritional quality and reducing *Mahewu* fermentation time (Table 4).

Step 2—adding an ingredient to start the fermentation

The second stage in the preparation of *Mahewu* was, diluting the cooled porridge with water followed by mixing in another ingredient to start the fermentation. The most frequently used ingredients for starting the fermentation were finger millet malt (34% of respondents), pearl millet flour (29%), sorghum malt (23%), self-raising wheat flour (21%), pearl millet malt (19%)

Table 3 Most preferred cereal flour for making *Mahewu* porridge as a percentage of total respondents per district

District	Maize (%)	Pearl millet (%)	Sorghum (%)	Finger millet malt (%)	Finger millet (%)	Sorghum malt (%)	Others (%)	Total (%)
Bikita	13	63	0	9	9	0	6	100
Gwanda	90	0	10	0	0	0	0	100
Lupane	50	6	28	0	0	17	0	100
Mutare	71	21	0	4	0	0	4	100
Mutoko	65	0	15	4	4	0	12	100
Average	55	22	9	4	3	2	5	100

Table 4 Reasons for preference for specific porridge flour as a percentage of total respondents preferring a particular flour

Preferred flour	Availability (%)	Taste (%)	Habit (%)	Nutrition (%)	Nast fermentation (%)	Other (%)	Total (%)
Maize	44	19	22	6	2	6	100
Pearl millet	24	38	9	15	9	6	100
Sorghum	13	75	–	–	–	13	100
Finger millet	20	20	–	60	–	–	100
Finger millet malt	–	33	–	33	33	–	100
Sorghum malt	–	40	–	20	40	–	100
Other	–	100	–	–	–	–	100
Average	34	28	15	11	6	2	100

and maize flour (12%). Twenty-seven per cent of respondents also added a tablespoon of sugar to speed up the fermentation process.

There was clear association between district and the most preferred ingredient for starting fermentation. In Bikita, the most preferred ingredient for starting fermentation was pearl millet, in Mutare – finger millet malt, in Mutoko—sorghum malt, in Gwanda and Lupani—wheat flour (Table 5).

Respondents had more than one reason to prefer a particular starter ingredient, the most common of which were taste, availability and fermentation time (Fig. 4).

Ninety-one per cent of those who used malt, produced it themselves in batches of 2–20 kg, with all of it for making *Mahewu* for home consumption. Focus group discussions revealed that malt use was becoming less popular because it was time consuming to produce and many churches preach against it, claiming that it produces alcoholic *Mahewu*, which is considered undesirable. Religion was also an important factor with 29% of respondents discouraged from using malt by their churches and 12% from using yeast.

According to the focus group respondents, malt is produced by steeping grain in water in a bucket for 12–16 h overnight, sprouting it in a sack for 2–3 days, and then spreading it out to dry. Next, the dried grain is pounded lightly in a wooden pestle and mortar to remove rootlets and sprouts followed by grinding into flour on a stone grinder (Fig. 5). Producers described the malting process as a craft that one had to master to produce the best-tasting *Mahewu*. During sprouting, some producers would keep the sack in an upright position while others would lay it flat on the ground and spread the grain thinly inside the sack. Proponents of the latter process argued that it prevented the malt from contamination with moulds and produced better-tasting *Mahewu* with a longer shelf-life. Focus group respondents also explained that sprouted malt had to be dried under cool conditions, away from direct sunshine as sun-dried malt produced *Mahewu* with a sharp undesirable taste and short shelf life.

Step 3—fermentation

According to the respondents, the final stage in *Mahewu* production is the fermentation of the cereal broth for 12–72 h in plastic buckets (70% of respondents), clay vessels (25%), calabashes (2%) or metal buckets (3%) until it starts to froth and reaches the preferred sourness. Reportedly, fermentation was quicker at higher temperatures and when the same vessel was used before to produce *Mahewu*, even if it was washed after each batch. Sugar is added to taste before drinking. Respondents concurred that clay pots

Table 5 Ingredients used to start the fermentation of *Mahewu* as a percentage of respondents per district

District	Pearl millet (%)	Finger millet malt (%)	Wheat flour (%)	Sorghum malt (%)	Pearl millet malt (%)	Maize flour (%)	Other (%)	Grand total (%)
Bikita	66	13	0	0	9	0	12	100
Gwanda	0	10	55	0	0	25	10	100
Lupane	0	0	56	17	0	17	11	100
Mutare	29	32	0	0	25	0	14	100
Mutoko	0	46	0	50	0	0	4	100
Average	23	22	17	13	8	6	10	100

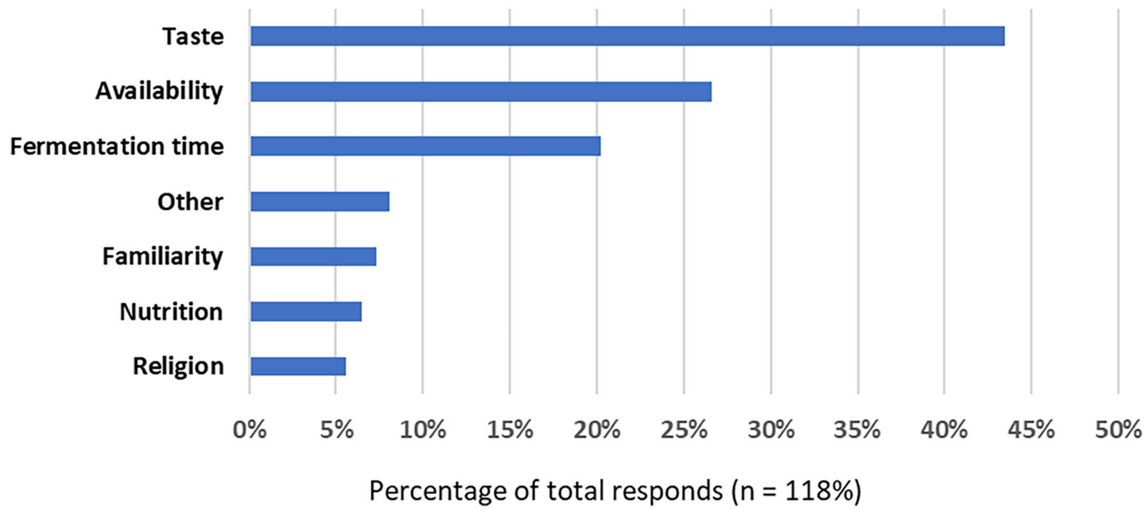

Figure 4 Reasons for preference for specific starter for the production of *Mahewu*.

produced the tastiest *Mahewu* with a long shelf life but most still used plastic buckets because they are cheap, durable and easier to find than clay pots.

Discussion and conclusion

Variation in *Mahewu* production

A key motivation for the present study was to evaluate traditional processing practices for variation in processing steps and the cereal used as a base substrate in *Mahewu* fermentation. We found that *Mahewu* is a diverse beverage produced from different combinations of cereal ingredients; all of which impact the organoleptic and physicochemical properties of the final product. The choice of ingredient used in processing step 1 (making the cereal porridge that is later fermented into *Mahewu*) mainly depends on availability, and maize, the country's staple cereal, is the most used. Though less common, other cereals, namely pearl millet, sorghum and finger millet are also used for their taste. This shows potential to promote the use of these alternative cereals that are less dependent on predictable rainfall patterns, for improved food and nutrition security in the wake of a changing climate.

We also found producers to be selective on the uncooked cereal ingredient they use to start the fermentation process (step 2), as they consider this an important factor in determining the taste of *Mahewu*. This concurs with the general knowledge that the flavour of fermented beverages depends on the raw materials used and the microbial community involved (Awobusuyi *et al.*, 2016, 2021; Awobusuyi & Siwela, 2019). The ingredient used to start fermentation has a double contribution to flavour, that is through its chemical composition and as a source of fermentation microbes (Pswarayi & Gänzlea, 2019). However, due to microbial species sorting and community evolution during fermentation, the microbial community structure at the start of fermentation is often different from that observed during and after fermentation, resulting in taste and flavour variations throughout the fermentation process (Schoustra *et al.*, 2013; Groenenboom *et al.*, 2020).

One other important factor in selecting an ingredient to start fermentation is religion. Some Christian

Figure 5 Wooden pestle and mortar, grinding stone (used for grinding cereal grains and malts), and clay pot (used as a fermentation vessel).

churches forbid the use of yeast and malt in producing *Mahewu* as observed in this study and confirmed by Gadaga (1999). The prohibition is based on an assumption that *Mahewu* fermented with either yeast or malt has a high alcohol content, which violates the churches' prohibition of alcohol intake (Adventists, 2023; Encyclopædia Britannica, 2023). Malts are indeed used in the brewing of traditional beer, but the production process is different from that for *Mahewu* (Gadaga, 1999; Lyumugabe *et al.*, 2012; Mawonike *et al.*, 2018; Hlangwani *et al.*, 2020). *Mahewu* and other related beverages are however not absolutely alcohol free (Mugula *et al.*, 2003; Phiri *et al.*, 2019; Pswarayi & Gänzlea, 2019). Their microbial community composition includes yeasts and heterofermentative lactic acid bacteria (LAB) of the *Weissella*, *Leuconostoc* and *Companilactobacillus* genera, which are known to produce ethanol under anaerobic conditions (Schoustra *et al.*, 2013; Phiri *et al.*, 2019; Pswarayi & Gänzlea, 2019; Zheng *et al.*, 2020; Daji *et al.*, 2022). Although *Mahewu* is generally referred to as a non-alcoholic drink, studies confirming its actual alcohol content to be less than the 0.05% ABV threshold were not found. Given the importance of *Mahewu* as a weaning food, there is need for further research to determine its ethanol content and how that varies with fermentation time and the type of ingredients used to start fermentation.

The fermentation step in *Mahewu* production lasts 12–48 h with the actual time being more a matter of environmental conditions than preference. Producers ferment the beverage for as long as it takes to reach the desired sourness, and this time is shorter under warm conditions. The survey also revealed that fermentation time is shortened by the repeated use of the same vessel to produce *Mahewu*, which is suggestive of the formation of microbial biofilms on the surface of fermentation vessels, acting as fermentation starter.

Another factor that the survey revealed as important in determining the taste and flavour of *Mahewu* is the vessel used during fermentation. There was consensus among producers that *Mahewu* produced in clay vessels was tastier and had a longer shelf-life compared to that produced in plastic buckets. This is similar to findings by Groenenboom *et al.* (2020) on mabisi, a spontaneously fermented milk product from Zambia where consumers preferred the taste of mabisi fermented in calabashes to that made in plastic vessels, even though the same study found the product from both vessels similar in terms of its biological and physicochemical properties (Groenenboom *et al.*, 2020). Interestingly, in both studies, most producers prefer to use plastic vessels because they are cheaper, more durable and easier to find than clay vessels or calabashes (Groenenboom *et al.*, 2020). The vessel effect on the taste of fermented beverages has also been observed in wines, ales and lagers (Hoogan, 1977; Cortiella *et al.*, 2020).

There is need for further investigations into why consumers find the taste of traditionally fermented beverages better when produced in clay pots and calabashes than plastic buckets. One possible explanation could be the formation of different biofilms on the different fermentation vessels since the characteristics and composition of biofilms varies with the properties of the surface they attach to (Donlan, 2002). The role of microbial biofilms in food fermentation is well documented by Yao *et al.* (2022) and includes optimising fermentation, controlling spoilage and contributing to the quality of the final product.

Dietary importance of *Mahewu*

This study confirmed the importance of *Mahewu* as a meal substitute, refreshment, and a weaning food for children aged 6–24 months. This is consistent with findings on similar beverages such as *Munkoyo* in Zambia (Phiri *et al.*, 2019) and *Amahewu* in South Africa (Chelule *et al.*, 2020). Consumers believe *Mahewu* to be nutritionally superior to unfermented porridge, which is consistent with research findings that fermented cereals are high in free amino acids, low in phytic acid and have high iron, zinc and calcium bioaccessibility when compared to unfermented ones (Ali *et al.*, 2003; Cui *et al.*, 2012; Pranoto *et al.*, 2013; Adebiyi *et al.*, 2017; Daji *et al.*, 2023). Adebo *et al.* (2022) and Nkhata *et al.* (2018) ascribe the increased free amino acid content to the release by fermentation microbes of proteases that catalyse the hydrolysis of proteins into their constituent peptides and amino acids. Fermentation is also known to activate phytases that catalyse the hydrolysis of phytic acid into a form that has low affinity for proteins and minerals, thus increasing protein digestibility and mineral bioaccessibility (Gupta *et al.*, 2015). Potential therefore exists to upgrade *Mahewu* into a beverage with superior health promoting qualities, using a carefully optimised combination of raw materials and processing practices. The upgraded product would ideally be rich in anti-oxidants, low in phytic acid, high in essential amino acids, high in micronutrients, have a low glycaemic index and contain climate smart cereal ingredients. We therefore propose further research into the specifics of how different ingredients influence the physicochemical, organoleptic and microbial properties of *Mahewu* and its acceptance by consumers.

Conclusion

Our study has unveiled traditional variations in the ingredients used in *Mahewu* processing, thus presenting an opportunity to capitalise on this diversity for targeted research to enhance product quality. While maize is the most used ingredient in the porridge step of *Mahewu* processing, our results show that sorghum and pearl millet can also be utilised, which is an important finding given their growing importance as potential substitutes for maize in climate change adaptation strategies. The acceptance of sorghum or pearl millet *Mahewu* by maize *Mahewu* consumers will however still need to be researched. The primary determinant of *Mahewu* taste is the choice of starter ingredient used to initiate fermentation. We recommend that any research aimed at improving the taste and aroma profile of *Mahewu* should scrutinise the role of sorghum malt, sorghum flour, pearl millet malt, pearl millet flour, finger millet malt and wheat flour in determining final product characteristics and the microbial community involved in *Mahewu* fermentation. Our study has also shown the importance of *Mahewu* for infant and young-child feeding and the positive perception that consumers have of its nutritional qualities, which warrants the need for further research on its current nutritional profile and how it can be improved.

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Author contributions

Sakile Kudita: Conceptualization; investigation; writing – original draft; methodology; validation; visualization; writing – review and editing; formal analysis; data curation; project administration. **Sijmen Schoustra:** Conceptualization; funding acquisition; methodology; validation; writing – review and editing; project administration; supervision; resources; visualization. **Juliet Mubaiwa:** Conceptualization; methodology; validation; writing – review and editing; funding acquisition; visualization; supervision; resources. **Eddy J. Smid:** Conceptualization; funding acquisition; methodology; validation; visualization; writing – review and editing; supervision; resources. **Anita R. Linnemann:** Conceptualization; funding acquisition; methodology; validation; visualization; writing – review and editing; supervision; resources.

Conflict of interest

The authors declare that they have no conflict of interest.

Ethics approval

Ethics approval for this research was granted by the Research Ethics Committee at Chinhoyi University of Technology in Zimbabwe.

Peer review

The peer review history for this article is available at https://www.webofscience.com/api/gateway/wos/peer-review/10.1111/ijfs.16887.

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Data S1. Mahewu processing and consumption survey questioner.