African cereal fermentations: A review on fermentation processes and microbial composition of non-alcoholic fermented cereal foods and beverages

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Abstract

Africa has a rich tradition of cereal fermentations to produce diverse products including baked goods, porridges, non-alcoholic beverages and alcoholic beverages. Diversity also relates to the choice of the fermentation substrates, which include wheat, maize, teff, sorghum and millet, and the fermentation processes that are used in food production. For fermentation processes that are used in baking and brewing, it is well established that the composition of fermentation microbiota and thus the impact of fermentation on product quality is determined by the choice of fermentation conditions. This link has not been systematically explored for African cereal fermentations. This review therefore aims to provide an overview on the diversity of African fermented cereal products, and to interrogate currently available literature data with respect to the impact of fermentation substrate and fermentation processes on the assembly of fermentation microorganisms and product quality.

Keywords: non-alcoholic fermented cereal beverages, porridges, maize, millet, sorghum, malt, *Lactiplantibacillus plantarum, Limosilactobacillus fermentum, Lactobacillus*

Introduction

Africa has a rich tradition of fermenting cereals to obtain diverse products including non-alcoholic and alcoholic beverages, porridges and baked goods (Franz et al., 2014). With more than 2,000 distinct languages and cultures in Africa, it is conceivable that thousands of different fermented foods are produced with many variations in the production processes and ingredients. Most of this diversity is found in sub-Saharan Africa, the area south of the Sahara Desert (Anonymous, n.d.). Fermented cereal foods and beverages have been produced using traditional fermentation methods at the household level; this tradition continues in rural communities across Africa. The knowledge and skills to produce traditional fermented are referred to as indigenous knowledge systems and are specific to each community and region.

The assembly of microbiota in fermentations is limited by dispersal unless the fermentation is controlled by back-slopping (Gänzle and Ripari, 2016). Many traditional fermentation products rely on spontaneous fermentation by microorganisms that are associated with the raw materials (Pswarayi and Gänzle, 2019). Back-slopping eliminates dispersal limitation (Gänzle and Ripari, 2016), which often leads to dominance of host-adapted lactobacilli in cereal fermentations (Li and Gänzle, 2020). The types of fermentation containers used, the different cereals as well as the environmental conditions contribute to the selection of microorganisms and are responsible for the different flavor characteristics of the products. In Africa, calabashes, large fruits that have been dried and hollowed out, clay pots, and metal or plastic buckets are used as fermentation vessels. Clay pots and calabashes are continuously reused and are the preferred fermentation vessels for traditional fermented foods. Micropores in the container walls retain fermented product from the previous batch and transfer microorganisms from previous fermentations which act as inoculum (Pswarayi and Gänzle, 2019; Schoustra et al., 2013; Zvauya et al., 1997).

The process of spontaneous cereal fermentations leads to a succession of fermentation organisms that is comparable worldwide for comparable products and processes globally and has been termed “the usual suspects" (Gänzle, 2019). Fermentation is initiated by plant-associated *Enterobacteriaceae*, which are the most abundant facultative anaerobes in cereal grains, followed by growth of enterococci, lactococci, *Leuconostoc* and *Weissella* spp.. Lactobacilli, particularly *Lactiplantibacillus plantarum, Limosilactobacillus fermentum* or *Pediococcus* species are typically the last organisms in this succession, which is attributable to their high acid resistance when compared to earlier fermentation organisms. This sequence closely resembles the succession of microbiota in spontaneous vegetable fermentations (Lee et al., 2005; Wuyts et al., 2018).

The characterization of fermentation microbiota in fermented cereal foods requires culture-dependent methods that are often complemented by culture-independent methods (Comasio et al., 2020). Dominant microorganisms in cereal fermentations or plant fermentations can all be isolated with culture-dependent methods (Bessmeltseva et al., 2014; Meroth et al., 2003; Van der Meulen et al., 2007; Wuyts et al., 2018). Use of only sequence-based characterization is inadequate because culture independent data do not account for viability (Pswarayi and Gänzle, 2019; Wuyts et al., 2018). This shortcoming distorts the analysis of spontaneous fermentations, where different microbial communities occur in succession. The comparison of culture, rRNA quantification and rDNA quantification of bacteria in carrot juice fermentations demonstrated that DNA-based 16S rRNA gene sequencing also includes DNA from dead bacterial cells that originate from the raw material or earlier fermentation steps (Wuyts et al., 2018). The adhesion of bacterial cells to insoluble cereal proteins or starch granules, which are removed during DNA isolation, additionally distorts the composition of microbiota when analysed by DNA-based methodology (Meroth et al., 2003; Van der Meulen et al., 2007; Zheng et al., 2015). Moreover, analyses of only fragments of rRNA genes do not reliably inform on species level (Bessmeltseva et al., 2014; Scheirlinck et al., 2009; Van der Meulen et al., 2007; Vogel et al., 1999) although this shortcoming can be addressed by full shotgun metagenomics sequencing (Comasio et al., 2020).

The composition of fermentation organisms in food fermentations is strongly dependent on the fermentation conditions but irrespective of the region of where the fermentation is carried out (Gänzle and Zheng, 2019; Van Kerrebroeck et al., 2017). For example, fermented vegetables, back-slopped mesophilic fermented dairy products and sourdough fermentations for bread leavening are each produced with globally uniform fermentation organisms (Gänzle, 2019). Past reviews on African fermented food products provide an overview of African fermented foods and fermentation microbiota (Franz et al., 2014; Nout, 2009; Todorov and Holzapfel, 2015) but these communications did not differentiate the products by process, substrate or region. The aim of this review is to relate available data on the fermentation process to data on microbial composition of non-alcoholic fermented cereal foods and beverages in sub-Saharan Africa.

Publications were selected that (i) provide a description of the processes that are used to produce the fermented products, preferably also with reference to the social context of food production and consumption and (ii) provide a reliable quantification and characterization of fermentation organisms. In the following sections, fermented cereal foods of sub-Saharan Africa are grouped on the basis of comparable production processes. The term sub-Saharan Africa is not precisely defined; for the purpose of this communications, Sudan, which lies at the intersection of sub-Saharan Africa and North Africa, was included. Flow charts depicting the key processing steps of representative fermented cereal food products are matched to the corresponding fermentation microbiota of the fermented cereal food products.

Finger millet and sorghum malts

The fermented cereal products which use malted cereals in their production are listed in Table 1. The flow chart for the production of malted cereals is shown in Figure 1, with household, community, or country-specific variations in the length of the time of the various stages in the malting process. Germinated millet or sorghum grains are sometimes used without sun drying and are wet milled or are used as malted whole grains (Table 1). The malt acts as both a source of multiple hydrolytic enzymes and as source of starch, proteins and other nutrients. Malt is used in conjunction with cooked cereals as a source of amylases and proteases, and of fermentation organisms (Ogbonna, 2011; Pswarayi and Gänzle, 2019). Other products use malt as sole substrate as a source of amylases and proteases where it is typically cooked or heated above 60 °C prior to the fermentation step (Table 1). The choice of malt from sorghum or finger millet is mainly based on regional preferences (Nout and Davies, 1982). Malting generally improves the nutritional quality of the foods by making nutrients more bioavailable and reducing some antinutrients, and impacts phytochemicals (Taylor, 2017). The levels of α-amylase in sorghum malt are similar to those of barley malt, but the β-amylase content of sorghum malt is very low compared with that of barley malt (Beta et al., 1995). The low β-amylase levels corresponds to low maltose concentrations, which selects against lactobacilli that use maltose as the preferred carbon source (Sekwati-Monang et al., 2012).

Finger millet and sorghum malt microbiota consists mainly of plant-associated *Enterobacteriaceae*, *Enterococcaceae*, environmental lactic acid bacteria, bacilli and few yeasts which are likely source of fermentation microbiota of fermented cereal beverages (Mukisa et al., 2012; Noots et al., 1999; Pswarayi and Gänzle, 2019; Sawadogo-Lingani et al., 2010).

Non-alcoholic fermented cereal beverages prepared from cooked porridge

The flow charts and fermentation organisms for production of non-alcoholic fermented beverages that are produced from cooked porridge are shown in Figure 2 and the fermentation organisms are listed in Table 2. The fermented non-alcoholic cereal beverages are a common feature in the diet of rural communities in East, Central and Southern Africa (Table 2). These beverages are processed in a similar manner which involves cooking of a thin maize porridge but differ with respect to the adjunct material that is added after cooking. Most beverages in the different countries are produced from maize but the porridges can also be made from finger millet or sorghum meal or combinations of these cereals (Table 2). These fermented beverages contain viable lactobacilli and yeasts, are colloidal, coarse and gritty. Some beverages including *togwa* are opaque and reddish to brownish in color depending on the finger millet variety used and contain solid particles from the pericarp of finger millet and maize grains, which give a slightly floury flavor and a gritty mouth feel (Kitabatake et al., 2003). These beverages are a part of the staple diet and are refreshing drinks in the fields or at social gatherings and are also used as complementary food for infants and for the sick (Gadaga et al., 1999; Kitabatake et al., 2003; Pswarayi and Gänzle, 2019; Schoustra et al., 2013).

Since most LAB lack amylolytic enzymes, the malt is added to degrade starch and to release sugars, which impart a sweet taste and promote fermentation by lactic acid bacteria and rapid acidification of the porridge, resulting in lower viscosity beverage products (Steinkraus, 2004; Taylor and Duodu, 2019). In the Democratic Republic of Congo and Zambia, *Rhynchosia* roots are used in the production of *munkoyo* and *chimbwantu* beverages (Foma et al., 2012; Schoustra et al., 2013). *Rhynchosia* roots contain high levels of α- and β-amylases and rapidly liquefy the porridge (Mulkay et al., 1985 as cited by (Zulu et al., 1997). In a few products, e.g. *tobwa*, *emahewu* and *ekitiribita*, no adjunct is used in the fermentation process, which takes up to five days to ferment and is more susceptible to proliferation of harmful microorganisms (Gadaga et al., 1999; Mukisa et al., 2012; Simatende et al., 2015). In South Africa, wheat flour acts a source of bacteria and hydrolytic enzymes in the preparation of *mageu* which is also known as *amahewu* (Taylor, 2016).

Reliable data on the composition of fermentation microbiota is available for *ekitiribita*, *obuteire*, and *mahewu* that are produced in Uganda and Zimbabwe respectively (Mukisa et al., 2012; Pswarayi and Gänzle, 2019). The microbiota of *ekitiribita*, *obuteire* and *mahewu* samples consisted of 3 to 8 dominant strains of lactobacilli and 1 or 2 yeasts (Table 2). These organisms largely conform to the organisms that are expected in spontaneous cereal fermentations, i.e. *Lactococcus lactis, Leuconostoc lactis, Enterococcus* spp., *Weissella. confusa, P. pentosaceus, Lm. fermentum* and *Lp. plantarum* but *Lactobacillus delbrueckii* and *Streptococcus infantarius* or *Sc. lutetiensis* were additionally detected (Table 2). Data for other products *chimbwantu* and *munkoyo* are based on amplicon sequencing without culture (Schoustra et al., 2013) but confirm the assumption that fermentation microbiota largely overlap with the "usual suspects". Variation in sensory attributes is due to the different raw materials and adjuncts used, stage of fermentation and to the effect of different household or producers’ preferences (Foma et al., 2012; Gadaga et al., 1999; Mukisa et al., 2012; Phiri et al., 2020).

Non-alcoholic fermented malted cereal beverages

The process flow charts for the production of non-alcoholic beverages that are produced from malted grains as sole substrate are shown in Figure 3 and the fermentation microbiota are listed in Table 3. The preparation of beverages involves the spontaneous fermentation of the mash produced by heated or boiled malt (Table 3). The fermentations are predominantly spontaneous and not controlled with back slopping (Table 3). *Oshikundu* is colloidal because it is not filtered whereas *mangisi* and *leting* are light brown liquids because the production process involves a filtration step (Embashu, 2014; Gadaga et al., 2013; Zvauya et al., 1997).

Amylases may remain active in the initial stages of heating until a temperature of greater than 60 °C is reached. Therefore, a good part of the starch is converted to maltose or glucose prior to heat inactivates of amylases (Zvauya et al., 1997). Based on the combination of starch hydrolysis and lactic acid fermentation, these fermented cereal beverages are sweet and sour refreshing drinks for the whole household, for the sick and the elderly, as well as weaning foods for infants, and are consumed at social gatherings and important traditional functions (Embashu et al., 2013; Gadaga et al., 1999; Zvauya et al., 1997).

Several fermented cereal beverages are produced from malted cereals with two fermentation steps. The corresponding flow chart for the production of non-alcoholic fermented malted cereal beverages with two fermentation steps is shown in Figure 4 and the fermentation microbiota are listed in Table 4. *Gowé* is a non-alcoholic beverage produced in Benin and involves the primary fermentation of sorghum malt and a secondary fermentation after the addition of sorghum flour to form a paste that is cooked and further diluted with cold water or milk (Vieira-Dalodé et al., 2007) (Table 4). Maize meal can also be used instead of sorghum flour to prepare gowé. Unlike other African fermented cereal beverages, the malted cereal is the substrate for the primary fermentation and therefore *gowé* has a natural sweet taste and a soft texture loved by children and adults (Vieira-Dalodé et al., 2007). *Gowé* processing is characterized by a mixed fermentation microbiota consisting of several lactobacilli and yeasts (Table 4).

Non-alcoholic fermented cereal beverages prepared from baked fermented cereals.

The flow charts for the production of non-alcoholic cereal beverages that are produced from baked fermented cereals is shown in Figure 5 and the fermentation organisms are listed in Table 5. In Sudan, non-alcoholic beverages are made from fermented sorghum sourdoughs that are baked into thin sheets before being soaked in water. The baked thin transparent flakes are dissolved in water to make *abreh* (Table 5). The baked brown flat sheets are broken down into flakes and soaked in water for a few hours and the brownish supernatant becomes the beverage *hulu mur* (Table 5). Enzymes are derived from the malted sorghum which also provides fermentation microbiota (Table 1). Baking generates color and flavor from the Maillard reaction (Ames, 1990). *Hulu mur* and *abreh* are thirst quenching drinks, with *hulu mur* being especially popular during the Muslims' Ramadan month of fasting (Mahgoub et al., 1999).

Non-alcoholic fermented beverage prepared from fermented roasted sourdough.

The flow chart for the production of a non-alcoholic fermented beverage that is prepared from fermented and roasted sourdough which is fermented again is shown in Figure 6 and the product is listed in Table 6. *Kwete* is a traditional fermented beverage produced in Uganda whereby maize sourdough is fermented, roasted, and then fermented again with the addition of finger millet malt and water, and then strained (Figure 6 and Table 6). Roasting generates color and flavor in the Maillard reaction, and facilitates the gelatinization of starch which is crucial for the activity of amylases during the mashing process. *Kwete* is a thirst quenching beverage for the whole family (Namugumya and Muyanja, 2009). Finger millet malt is a source of hydrolytic enzymes and fermentation microbiota (Table 1).

Fermented sour porridges.

The flow chart for the production of fermented cereal slurries that are produced as intermediate products in the preparation of sour porridges is shown in Figure 7 and the fermentation microbiota are listed in Table 7. Traditional fermented slurries from maize, millet or sorghum meals, or a mixture thereof, are produced as intermediate products for the preparation of thin and thick porridges, which are an important staple of the African diet (Figure 7 and Table 7). The thin porridge is eaten at breakfast while the thick porridge forms the main part of the meal at lunch and dinner and is known by different names in different countries. Sour porridges are important weaning foods for infants and children (Graham et al., 1986; Madoroba et al., 2011; Masha et al., 1998; Simango, 1997). The porridges are produced with unmalted cereals. Fermentation improves the protein digestibility of cooked sorghum porridges like *ting* (Taylor and Taylor, 2002). As with other fermented cereal foods throughout Africa, the preparations are similar within the country and beyond but the differences in household preferences account for slight variations with respect to the level of souring and whether the cereals are mixed together or used singly.

Wet milled fermented cereal doughs and slurries.

The flow charts for the production of wet milled fermented cereal doughs and slurries that are produced as multi purpose intermediate products for the preparation of diverse foods are shown in Figure 8 and the fermentation microbiota are listed in Table 8. The variety of products obtained from either fermented cereal slurries or doughs can be categorized into the following groups: non-alcoholic beverages, thin and thick porridges (gruels), dumplings and baked flatbreads (Table 8). Steeping is essentially the first fermentation step and serves to facilitate milling. If the grains are steeped for more than 12 h, fermentation takes place and after 24 h the “usual suspects” are present. Maize is the most common cereal used in the southern parts of West Africa, while sorghum and pearl millet are mainly used in the drier northern parts of West Africa. These cereals doughs are cooked after the fermentation process and do not contain live microbiota. However, the beverage *kunun-zaki* contains live microbiota because a second fermentation step is included after cooking (Figure 8)(Efiuvwevwere and Akona, 1995). Unlike *mahewu* and *togwa*, *kunun-zaki* has a smooth milky and creamy appearance because a filtration step is included (Efiuvwevwere and Akona, 1995; Kitabatake et al., 2003). Another beverage that contains live microbiota is *koko* sour water, the top-layer of the fermenting *koko* slurry that is consumed uncooked as a treatment for up-set stomachs or as a refreshing drink (Lei and Jakobsen, 2004). These fermented cereal doughs are prepared at the household level in rural communities but are also produced by micro-enterprises for sale at the local markets in urban communities (Halm et al., 2004; Mouquet-Rivier et al., 2008). Some fermented foods of West Africa are part of the main course while others are beverages and porridges which are also used as weaning foods for infants (Table 8). *Lm. fermentum* is the predominant microorganism in many of the West African fermented cereal foods (Table 8).

Sourdough fermentation for breads and flat breads.

The flow chart for the production of fermented cereal sourdoughs used in the preparation of flatbreads is shown in Figure 9 and the fermentation microbiota are listed in Table 9. *Injera*, a flat-bread with a slightly spongy texture, traditionally made of fermented dough from teff flour is a staple in Ethiopia (Figure 9) (Tamene et al., 2019). At the household level, the process of making *injera* is continuous, as it is baked and consumed while the next batch of dough is being fermented (Abraha et al., 2013). *Injera* can also be made from wheat, barley, maize, sorghum, singly or as a mixture of the cereals but teff, a small millet-like grain is preferred due to its softer texture and taste (Yetneberk et al., 2005, 2004). *Injera* is central to dinner, like bread or rice elsewhere and is served with a variety of dishes made with vegetables, pulses, and / or meat (Abraha et al., 2013). *Injera* batter fermentation microbiota consisted of seven lactobacilli (Figure 9) (Fischer et al., 2014), In Sudan, *kisra* can be made from either sorghum or millet flour, and is produced at the household level from spontaneously fermented sourdough or from a back-slopped sourdough produced in households by consecutive re-inoculations (Hamad et al., 1997) (Table 9). *Kisra* is a popular flatbread with a very sour taste and constitutes a staple in the diet Sudanese (Mohammed et al., 1991; Odunfa and Oyewole, 1998). The main microorganisms depend on whether the sourdough was back slopped or not (Table 9).

Solid pit fermented products.

The flow charts for the production of solid pit fermented cereal sourdoughs that are produced as intermediate products in the preparation of non-alcoholic cereal beverages and a dough-like fermented food are shown in Figure 10 and the fermentation microbiota are listed in Table 10. Solid pit fermented food products include either the primary or secondary fermentation under the fire pit and are cooked before or after the solid pit fermentation (Table 10). *Hussuwa* is a semi-solid, sweet sour dough-like fermented food made in Sudan from malted or unmalted sorghum or millet and undergoes a secondary solid pit fermentation (Yousif et al., 2010). *Malwa* is a sweet and sour beverage that is consumed in Uganda with straws after dilution with hot water (Muyanja et al., 2010). Both lactic acid and ethanolic fermentations take place during the production of these products. The yeasts were not characterized and the bacterial microbiota of *hussuwa* is dominated by strains of *Lm. fermentum* and *P. acidilactici* but may also include enterococci (Yousif et al., 2010)(Table 10). As with other African cereal fermentations there are variations in production of *hussuwa,* with the solid pit fermentation as major part of the process (Yousif et al., 2005).

Synthesis: Do African fermented cereal foods differ from other regions of the world?

Traditions of sub-Saharan Africa include a world of knowledge on cereal fermentations that remains largely unexplored and undocumented. Moreover, the study of food fermentations and fermentation microbiota requires research resources which are not available in all countries of sub-Saharan Africa. Therefore, production processes and fermentation microorganisms of many fermented food products are not well represented in the scientific literature. This review does thus not reflect the entirety of the diversity of fermented cereal foods in sub-Saharan Africa. Current information suffices to outline differences between the major groups of products and between countries in East, West, Central and Southern Africa, and to compare African traditions with other regions in the world.

Most fermented foods are based on tradition and artisanal fermentation processes and are deeply rooted in the culture which is governed by climatic conditions that determine the availability of specific crops which require fermentation. For example, large areas of sub-Saharan Africa grow high-tannin sorghum varieties that are provide higher yield despite local herbivore threats (Wu et al., 2019) but also require fermentation to reduce bitterness (Kobue-Lekalake et al., 2007). In North East Africa including Ethiopia, flatbreads based on wheat, teff or sorghum are the major fermented cereal foods. In the remainder of sub-Saharan Africa fermented porridges and non-alcoholic beverages based on maize, millets or sorghum are the major fermented cereals (Gänzle, 2022). Although several products are produced in different African regions (examples in Tables 2, 3, 7, and 8), regional preferences within Africa with regards to the fermented food products can be discerned and are listed in Table 11.

African traditions differ from other areas of the world with respect to the diversity of non-alcoholic cereal beverages and the widespread use of fermented porridges. Only few non-alcoholic fermented cereal beverages are produced in Europe or Asia, namely *boza* produced in Bulgaria, Albania, Turkey, and Romania (Todorov and Dicks, 2006) and *kvass* produced in Eastern Europe (Dlusskaya et al., 2008). A second difference relates to the site of production. In rural communities, African traditional fermentations are predominantly carried out by women at the household level; this micro-scale of production adds to the diversity of fermented food products. In contrast, traditional production of bread and beer in Europe was carried out by trades and is now largely industrialized. In Africa but not in Europe, malt is widely used for non-alcoholic beverages. Whereas most fermented foods produced in Europe and North America depend on back-slopping or defined starter cultures, fermentations in sub-Saharan Africa predominantly rely on spontaneous fermentations; i.e. the fermentation is initiated with microorganisms from the raw materials. Several products, however, rely on back-slopping or fermentation vessels with porous walls that retain microorganisms from the previous batch and thus provide a microbial inoculum (Tamang et al., 2020).

Overall, the organisms identified in African fermented cereal foods conform to prior observations that spontaneous cereal fermentations are dominated by “the usual suspects”, a succession of fermentation organisms that begins with plant-associated *Enterobacteriaceae*, followed by the growth of enterococci, lactococci, *Leuconostoc* and *Weissella* spp., and finally by the growth of pediococci, *Lp. plantarum* and *Lm. fermentum*. However, back-slopping by re-use of fermentation vessels without sanitation generates somewhat of a hybrid of this succession of fermentation organisms and dominance of host-adapted lactobacilli that has not been described elsewhere (Table 2).

Many *Enterobacteriaceae* including *Cronobacter, Klebsiella* and *Enterobacter* are part of plant microbial communities and occur as seed endophytes in grains (Ko et al., 2002; Kucerova et al., 2010; Podschun and Ullmann, 1998) and were thus also identified as initial fermentation microbes in African spontaneous cereal fermentations. *Klebsiella* and *Enterobacter* are also notorious members of the "ESKAPE" pathogens that are leading causes of nosocomial infections with antibiotic resistant bacteria (Pendleton et al., 2013). The best example is *Enterococcus faecalis*, which is also a notorious opportunistic pathogen and member of the "ESKAPE" club (Franz et al., 2003) but also occurs in high cell counts in fermented dairy and meat products. These organism rarely cause disease upon ingestion but nevertheless may represent a risk in spontaneous fermentations (Hamad et al., 1997; Holzapfel, 2002; Mukisa et al., 2012; Pswarayi and Gänzle, 2019). Interestingly, consumers prefer sour *malwa* to the sweet one (1-2 days old), because the sweet *malwa* causes upset stomachs (Muyanja et al., 2010). This may relate to the cell counts of *Enterobacteriaceae* at the beginning of the spontaneous fermentations (Pswarayi and Gänzle, 2019; Wuyts et al., 2018). Similar findings were also reported for *bushera* (2-day old) (Muyanja et al., 2003). Likewise, *Ekitiribita,* a thin porridge prepared from un-malted finger millet is consumed within 1–2 days, the laboratory preparation however, revealed that it took four days for the pH to drop below 4.6 (Mukisa et al., 2012). Acidification of the fermentation substrate with lactic and acetic acids is the predominant factor that results in elimination of *Enterobacteriaceae* in cereal fermentations (Dinardo et al., 2019; Pswarayi and Gänzle, 2019).

African cereal fermentations include few organisms that unusual in cereal fermentations, namely staphylococci in *ogi* and *kunu-zaki* (Oguntoyinbo and Narbad, 2012) (Table 8) and *L. delbrueckii* in *ekitiribita, obuteire, obutoku, ogi, kunu-zaki* and *poto-poto* (Abriouel et al., 2006; Ampe and Miambi, 2000; Mukisa et al., 2012; Oguntoyinbo et al., 2011) (Tables 2, 3, 8). Staphylococci and *L. delbrueckii* have been rarely, if ever, reported in other cereal fermentations; the reasons for their repeated occurrence in African cereal fermentations remain to be elucidated.

In Africa the diversity of non-alcoholic fermented cereal beverages with live microbiota is much larger than elsewhere in the world, and several reviews emphasize the probiotic potential of these products (Franz et al., 2014; Waters et al., 2015). Specifically, *Lm. fermentum* and *Lp. plantarum* are two bacterial species that are abundant in many African fermented foods and also include strains with well-documented probiotic properties (Hill et al., 2014). Even though probiotic activity is not documented at the strain level, live dietary microbes are increasingly recognized as health beneficial (Marco et al., 2021; Wastyk et al., 2021). The characterization of traditional fermentation processes and microbiota allows for the improvement of the fermentation process to decrease hygienic risks and to increase the abundance of health-beneficial microbes. One of the health benefits that is provided by probiotics is the reduction of the severity and duration of childhood diarrhea (Allen et al., 2010; Guandalini, 2011; Niel et al., 2002). The estimated number of deaths due to diarrhea in children under 5 years globally are 525 000 per year, and mostly result from contaminated food or water sources (WHO, 2017). Thus, viable probiotic fermentation organisms and viable opportunistic pathogens may positively affect the health of consumers (Marco et al., 2017).

This review links the fermentation microbiota to the process, which is necessary to shift food fermentations from production at the household level to industrial production. In most of the sub-Saharan countries, there is a clear distinction between the urban population that consumes standardized, industrially produced fermented beverages, and the rural communities which produce traditional fermented foods at the household level. Traditional food fermentation represents an extremely valuable resource and harbors a huge potential of valuable but hitherto undiscovered probiotic strains. Looking at trends in Europe and North America there are two market opportunities where African traditional fermented cereal foods provide useful templates, the gluten-free market and the market for non-alcoholic cereal beverages. African traditional fermented cereal foods thus represent an untapped source for novel fermented cereal foods including functional food products with live probiotic bacteria that are produced based on African templates or strains.

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Figure Legends

Figure 1. Preparation of finger millet and sorghum malts. The grey shading indicates a fermentation step.

Figure 2. Preparation of non-alcoholic fermented cereal beverages from cooked porridge. Shown are the names of the non-alcoholic beverages produced from the fermentation of cooked porridges. The steps in the flow chart are colour-coded as follows: grey shading indicates fermentation; dashed double lines indicate optional back-slopping; red shading indicates a heating step that inactivates vegetative bacterial cells.

Figure 3. Preparation of non-alcoholic fermented malted cereal beverages. Shown are the names of the non-alcoholic beverages produced from fermented malted beverages. The steps in the flow chart are colour-coded as follows: grey shading indicates fermentation; dashed double lines indicate optional back-slopping; red shading indicates a heating step that inactivates vegetative bacterial cells.

Figure 4. Preparation of non-alcoholic fermented malted cereal beverages with two fermentation steps. Shown is the name of the intermediate product which is used for the preparation of *gowé*. The steps in the flow chart are colour-coded as follows: grey shading indicates fermentation; dashed double lines indicate optional back-slopping; red shading indicates a heating step that inactivates vegetative bacterial cells.

Figure 5. Preparation of non-alcoholic beverages from baked fermented cereals. Shown are the names of the products produced from baked fermented cereal products. The steps in the flow chart are colour-coded as follows: grey shading indicates fermentation; double lines indicate back-slopping; red shading indicates a heating step that inactivates vegetative bacterial cells.

Figure 6. Preparation of non-alcoholic beverage from fermented roasted sourdough. Shown is the non-alcoholic beverage produced from fermented roasted sourdough. The steps in the flow chart are colour-coded as follows: grey shading indicates fermentation; dashed double lines indicate optional back-slopping; red shading indicates a heating step that inactivates vegetative bacterial cells.

Figure 7. Preparation of fermented cereal slurries used to produce sour porridges.

Shown are the names of the intermediate products which are used for the preparation of sour porridges. The steps in the flow chart are colour-coded as follows: grey shading indicates fermentation; dashed double lines indicate optional back-slopping; red shading indicates a heating step that inactivates vegetative bacterial cells.

Figure 8. Preparation of wet milled fermented cereal doughs and slurries. Shown are the names of the intermediate products which are used for the preparation of a variety of fermented foods that are always cooked. The steps in the flow chart are colour-coded as follows: grey shading indicates fermentation; dashed double lines indicate optional back-slopping; red shading indicates a heating step that inactivates vegetative bacterial cells.

Figure 9. Preparation of fermented cereal flatbreads. Shown is the name of the intermediate product which is baked prior to consumption. The steps in the flow chart are colour-coded as follows: grey shading indicates fermentation; dashed double lines indicate optional back-slopping; red shading indicates a heating step that inactivates vegetative bacterial cells.

Figure 10. Preparation of solid pit fermented cereal doughs. Shown are the names of the intermediate products used for the preparation of a fermented food which is cooked and a non-alcoholic beverage which is not cooked. The steps in the flow chart are colour-coded as follows:

grey shading indicates fermentation; dashed double lines indicate optional back-slopping; red shading indicates a heating step that inactivates vegetative bacterial cells.

Table 1: Malted cereals used in the preparation of fermented cereal foods as a source of hydrolytic enzymes and, for most products, of fermentation organisms

Product (country)		**Malted Substrate**	**Malted Adjunct**	**References**
Mahewu	Zimbabwe		Finger millet/ Sorghum	(Pswarayi and Gänzle, 2019) (Gadaga et al., 1999)
Togwa	Tanzania		Finger millet/ Sorghum	(Kitabatake et al., 2003; Mugula et al., 2003)
Munkoyo	Zambia		Finger millet	(Phiri et al., 2019)
Obushera	Uganda		Finger millet/ Sorghum	(Mukisa et al., 2010)
Obutoko	Uganda	Sorghum	Sorghum	(Mukisa et al., 2012, 2010)
Obuteire	Uganda	Finger millet	Finger millet	(Mukisa et al., 2012, 2010)
Mangisi	Zimbabwe	Finger millet		(Zvauya et al., 1997), (Gadaga et al., 1999)
Leting	Lesotho	Sorghum		(Gadaga et al., 2013)
Obiolor	Nigeria	Sorghum + Millet		(Achi, 1990)
Oshikundu	Namibia	Sorghum	Sorghum	(Embashu et al., 2013)
Bushera	Uganda	Finger millet/Sorghum	Finger millet/ Sorghum	(Muyanja et al., 2003)
Gowé	Benin	Sorghum		(Vieira-Dalodé et al., 2007)
Kwete	Uganda		Finger millet	(Namugumya and Muyanja, 2009)
Malwa	Uganda	Finger millet	Finger millet	(Muyanja et al., 2010)
Hussuwa	Sudan	Sorghum	Sorghum	(Yousif et al., 2010)
Hulu mur	Sudan	Sorghum		(Mahgoub et al., 1999)
Sorghum malt	Burkina Faso	Sorghum	Sorghum	(Sawadogo-Lingani et al., 2010)

Table 2: Non-alcoholic fermented cereal beverages prepared from cooked porridge

Product	Country	Substrate	Adjunct	Microorganisms	Reference
Mahewu	Zimbabwe	Maize meal	Finger millet malt (Sorghum malt)	*Lm. fermentum, Lp. plantarum, P. pentosaceus, Ff. rossiae Candida glabrata, S. cerevisiae, W. cibaria, W. confusa, Weissella spp., Leuconostoc holzapfelii, Lactococcus lactis, Leuc. pseudomesenteroides, P. pentosaceus, Saccharomyces cerevisiae*	(Pswarayi and Gänzle, 2019)
Ekitiribita (Obushera)	Uganda	Finger millet meal		*Leuc. lactis, Streptococcus gallolyticus, Bacillus spp., Enterobacteriaceae, Sc. infantarius /Sc. equinus, Lc .lactis, Sc. thermophilus* (DGGE)	(Mukisa et al., 2012, 2010)
Obuteire (Obushera)	Uganda	Finger millet meal	Finger millet malt	*Sc. gallolyticus, L. delbrueckii, S. cerevisiae* (DGGE)	(Mukisa et al., 2012, 2010)
Related products for which information on fermentation microorganisms is unavailable					
Munkoyo	Zambia	Maize meal	*Rhynchosia* root, (finger millet/ sorghum)	*Lactobacillaceae*	(Schoustra et al., 2013)
Chimbwantu	Zambia	Maize meal	*Rhynchosia* root, (finger millet/ sorghum)	*Lactobacillaceae*	(Schoustra et al., 2013)
Munkoyo	Zambia (Choma)	Maize grits	*Rynchosia* root extract	*Streptococcaceae, Lactobacillaceae,*	(Phiri et al., 2020)
Munkoyo	Zambia (Nyimba)	Maize meal	*Rhynchosia* root	*Enterobacteriaceae, Streptococcaceae, Moraxellaceae, Lactobacillaceae*	(Phiri et al., 2020)
Munkoyo	Zambia (Kitwe)	Maize meal (caramelized porridge)	*Rhynchosia* root	Unknown *Lactobacillaceae*	(Phiri et al., 2020)

Product	Country	Substrate	Adjunct	Microorganisms	Reference
Munkoyo	Zambia	Maize meal	*Rynchosia* root (finger millet malt/ cowpea root/sweet potato peels)	*Streptococcaceae*, *Lactobacillaceae*, *Enterobacteriaceae*, *Bacillaceae* *Aeromonadaceae*	(Phiri et al., 2019)
Munkoyo	Democratic Republic of Congo	Maize meal	*Rynchosia* root	Unknown	(Foma et al., 2012)
Togwa	Tanzania	Maize+/finger millet+/ Sorghum+/meals	Sorghum/finger millet malt flour +/ back slopping	Unknown	(Mugula et al., 2003)
Togwa	Tanzania	Maize	Finger millet malt flour	Unknown	(Kitabatake et al., 2003)
Maxau	Namibia	Maize meal	Wheat flour + sugar + back slopping	Unknown	(Misihairabgwi and Cheikhyoussef, 2017)
Tobwa	Zimbabwe	Maize meal		Unknown	(Gadaga et al., 1999)
Amahewu	South Africa	Maize meal	Wheat flour	Unknown	(Chelule et al., 2010)
Emahewu	Swaziland	Maize meal	Maize bran, or potato or sugar, or sorghum malt grains/no adjunct	Unknown	(Simatende et al., 2015)

Table 3: Non-alcoholic fermented malted cereal beverages

Product	Country	Substrate	Adjunct	Microorganisms	Reference
Obutoko (Obushera)	Uganda	Sorghum malt flour		*Sc. gallolyticus, W. confusa/W. cibaria, Lm. fermentum, L. delbrueckii, Streptococcus* spp. *S. cerevisiae, Pichia spp.* (DGGE)	(Mukisa et al., 2012, 2010)
Bushera	Uganda	Finger millet/ Sorghum Malt flour	Finger millet +/ sorghum malt flours	*Lp. plantarum, Lb. paracasei, Lm. fermentum, Lv. brevis L. delbrueckii; S. thermophilus* (API)	(Muyanja et al., 2003)
Oshikundu	Namibia	Pearl millet (boiling water)/ Pearl millet flour + sorghum malt (warm water)	Sorghum malt flour Pearl millet bran + back slopping +	*Lp. plantarum, Lc. lactis, L. delbrueckii, Lm. fermentum, Lp. pentosus, Lt. curvatus, Ent. cloacae, C. sakazakii, P. luteola, P. aeruginosa, Serratia ficaria* (API)	(Embashu et al., 2013) (Embashu, 2014)
Related products for which information on fermentation microorganisms is unavailable					
Mangisi	Zimbabwe	Finger millet malt		Unknown	(Simango, 1997; Zvauya et al., 1997) (Gadaga et al., 1999)
Leting	Lesotho	Sorghum + sorghum malt		Unknown	(Gadaga et al., 2013)
Obiolor	Nigeria	Millet +Sorghum malt flours		Unknown Bacilli, lactobacilli, lactococci	(Achi, 1990)

Table 4: Non-alcoholic beverage prepared from fermented malted cereal with 2 fermentation steps

Product	**Country**	**Substrate**	**Adjunct**	**Microorganisms**	**Reference**
Gowé	Benin	Sorghum malt flour	Sorghum flour + hot sorghum slurry	*Lm. fermentum, Lm. mucosae, W. confusa, W. kimchii, P. acidilactici, P. pentosaceus, Kluyveromyces marxianus, Pichia anomala, C. krusei, C. tropicalis*	(Vieira-Dalodé et al., 2007)
Gowé	Benin	Maize + sorghum malt		*C. krusei, Cl. lusitaniae, C.tropicalis and K. marxianus.* (Culture independent: *Dekkera bruxellensis, Debaryomyces hansenii)*	(Greppi et al., 2013b)

Table 5: Non-alcoholic cereal beverages prepared from baked fermented cereals

Product	Country	Substrate	Adjunct	Microorganisms	Reference
Abreh	Sudan	Sorghum grains	Mother dough (from 1st fermentation)	Unknown	(Odunfa and Oyewole, 1998)
Hulumur	Sudan	Sorghum malt flour + sorghum grains	Fermented kisra dough	Unknown	(Mahgoub et al., 1999)

Table 6: Non-alcoholic beverage prepared from fermented roasted sourdough

Product	Country	Substrate	Adjunct	Microorganisms	Reference
Kwete	Uganda	Maize grits +/ finger millet grains	Finger millet malt flour +/back slop	Unknown	(Namugumya and Muyanja, 2009)

Table 7: Fermented cereal slurries used to produce sour porridges.

Product	Country	Substrate	Adjunct	Microorganisms	Reference
Ting	Botswana	Sorghum meal	Back-slop or not	*Lm. reuteri, Lm. fermentum, Schleiferilactobacillus harbinensis, Lp. plantarum, Ln. parabuchneri, Lb. casei, Lo. coryniformis*	(Sekwati-Monang and Gänzle, 2011)
Ting	South Africa	Sorghum meal Lab preparation		*Lc. lactis, Lm. fermentum, Lp. plantarum, Lc. rhamnosus, W. cibaria, E. faecalis, E. mundtii, Enterobacteriaceae* (DGGE)	(Madoroba et al., 2011)
Related products for which information on fermentation microorganisms is unavailable					
Motoho	Lesotho	Sorghum meal Back-slop	Tomoso (sorghum starter culture) +/ back slop	Unknown	(Gadaga et al., 2013)
Uji	Kenya	Maize + millet/ maize + sorghum meals		Unknown	(Masha et al., 1998)
Nasha	Sudan	Sorghum meal	Starter culture derived from wild yeasts	Unknown	(Graham et al., 1986)
Ilambazi lokubilisa	Zimbabwe	Maize meal		Unknown	(Simango, 1997)

Table 8: Fermented cereal doughs

Product	Country	Substrate (Adjunct)	Microorganisms	Reference
Akamu	Nigeria	Maize, millet or sorghum	*Lm. fermentum, Lp. plantarum, L. helveticus, Lc. lactis ssp. cremoris, L. acidophilus, Lb. casei, Lb. rhamnosus, C. tropicalis, C. albicans, Clavispora lusitaniae, Saccharomyces paradoxus*	(Obinna-Echem et al., 2014)
Mawè	Benin	Maize or (sorghum	*Lm. fermentum, Lp. plantarum, P. acidilactici, W. confusa, P. pentosaceus, Pichia kudriavzevii, Kluyveromyces marxianus, S. cerevisiae, Ogataea polymorpha, C. glabrata, Wickerhamomyces anomalus*	(Houngbédji et al., 2018)
Ogi	Nigeria	Maize	*Lm. fermentum, Lp. plantarum, Bacillus pumilus, B. cereus, B. subtilis, St. hominis*	(Oguntoyinbo and Narbad, 2012)
Kunu-zaki	Nigeria	Pearl millet	*Lm. fermentum, Lp. plantarum, Sc. gallolyticus, P. pentosaceus Bacillus pumilus, B. cereus, B. subtilis, St. hominis*	(Oguntoyinbo and Narbad, 2012)
			Sc. lutetiensis, Lm. fermentum, L. delbrueckii, W. confusa, Sc. gallolyticus, Sc. bovis, B. cereus, C. perfringens (16S rRNA gene clone libraries)	(Oguntoyinbo et al., 2011)
Ogi	Nigeria	Maize	*L. delbrueckii, L. helveticus, Lm. fermentum, Lp. plantarum, Lb. pantheris, Paucilactobacillus vaccinostercus,* *Lo. bifermentans, Companilactobacillus nantensis* (16S rRNA gene clone libraries)	(Oguntoyinbo et al., 2011)
Doklu	Cote d'Ivoire	Maize	*Lp. plantarum, Lm. fermentum, P. acidilactici, P. pentosaceus, W. cibaria* Yeasts not characterized	(Assohoun-Djeni et al., 2016)

Product	Country	Substrate (Adjunct)	Microorganisms	Reference
Koko sour water (KSW)	Ghana	Pearl millet, maize or sorghum	W. *confusa, Ligilactobacillus salivarius, P. pentosaceus, P. acidilactici, Lp. plantarum*	(Adimpong et al., 2012)
Koko	Ghana	Pearl millet, maize or Maize, sorghum	Koko & KSW: W. *confusa, Lm. fermentum* KSW: *Lg. salivarius, P. pentosaceus, P. acidilactici, Lp. paraplantarum* (API)	(Lei and Jakobsen, 2004)
Ben-saalga	Burkina Faso	Pearl millet	*Weissella, Pediococcus, Lactobacillus, Streptococcus, Lactococcus, Leuconostoc, Enterococcus, Enterobacteriaceae* (Pyrosequencing 16S rRNA Gene Amplicons)	(Humblot and Guyot, 2009)
Dèguè	Benin	Maize, pearl millet, sorghum (lab preparation)	*Lm. fermentum, Lp. plantarum, Lp. pentosus, Cyberlyndnera fabianii, K. marxianus* *Raw materials: Lm. fermentum, P. acidilactici, W. paramesenteroides, Ent. mundtii, Cyberlindnera fabianii, C. glabrata, Meyerozyma caribbica*	(Angelov et al., 2017)
Dèguè	Burkina Faso	Pearl millet	*Lm. fermentum L. gasseri, Lv. brevis, Lb. casei, Enterococcus sp., E. coli* (TTGE) Yeasts not characterized	(Abriouel et al., 2006)
Poto poto	The Republic of the Congo	Maize	*L. gasseri, Lp. plantarum/paraplantarum, L. acidophilus, L. delbrueckii, Lm. reuteri, Lc. casei, Bacillus sp., Enterococcus sp., E. coli* (TTGE) Yeasts not characterized	(Abriouel et al., 2006)
Poto poto	The Republic of the Congo	Maize	*L. delbrueckii* (DGGE) Yeasts not characterized	(Ampe and Miambi, 2000)
Fura	Ghana	Pearl millet	*Lm. fermentum, P. acidilactici, W. confusa, Lm. reuteri, Lg. salivarius, Lp. paraplantarum*	(Owusu-Kwarteng et al., 2012)
Mawè	Benin	Maize	*C. krusei, Cl. lusitaniae and S. cerevisiae.*	(Greppi et al., 2013b)

Product	Country	Substrate (Adjunct)	Microorganisms	Reference
			(Culture independent: Dekkera bruxellensis, Debaryomyces hansenii) *Bacteria not characterized*	
Mawe	Benin	Maize	*Saccharomyces cerevisiae, C. krusei, K. marxianus*	(Greppi et al., 2013a)
Ogi	Benin	Maize	*C. krusei, C. lusitaniae, S. cerevisiae*. (Culture independent: Dekkera bruxellensis, *Debaryomyces hansenii)* Bacteria not characterized	(Greppi et al., 2013b)
Ogi	Benin	Maize	*Lp. plantarum*, *L. delbrueckii*, *Lm. fermentum* (DGGE) Yeasts not characterized	(Ampe and Miambi, 2000)
Kenkey	Ghana	Maize	(Before fermentation) *Candida*, *Saccharomyces, Trichosporon, Kluyveromyces, Debaryomycesg* and early phases of fermentation. (After fermentation) *C. krusei and S. cerevisiae* (API)	(Halm et al., 1993) (Amoa-Awua et al., 2007)
Kunun-zaki	Nigeria	Pearl millet, maize or sorghum (uncooked flour)	lactobacilli, bacilli, *Enterobacteriaceae*	(Efiuvwevwere and Akona, 1995)
Mutwiwa/ mudzvurwa	Zimbabwe	Dehulled maize	Unknown	(Simango, 1997)
Kirario	Kenya	Green maize +millet or sorghum meals	Unknown	(Kunyanga et al., 2009)
Ben-saalga	Burkina Faso	Pearl millet	Unknown	(Tou et al., 2006)

Table 9: Fermented cereal flatbreads.

Product	**Country**	**Substrate**	**Fermentation**	**Microorganisms**	**Reference**
Kisra	Sudan	Sorghum (pearl millet)	Back-slopped	*E. faecalis, Lc. lactis, Lm. fermentum, Lm. reuteri; Lm. vaginalis, L. helveticus*	(Hamad et al., 1997)
Kisra	Sudan	Sorghum (pearl millet)	spontaneous	*P. pentosaceus, W. confusa, Lv. brevis, Lactobacillus sp., Erwinia ananas, K. pneumoniae, Ent. cloacae, yeasts (C. intermedia D. hansenii), molds (Aspergillus sp., Penicillium sp., Fusarium sp., and Rhizopus sp.)* API.	(Mohammed et al., 1991)
Injera	Ethiopia	Teff	*Ersho* (back slopped)	*Lp. plantarum, Lp. pentosus, Lm. fermentum, P. pentosaceus, Companilactobacillus crustorum, Lb. casei, Ln. buchneri, Lv. brevis/ Schleiferilactobacillus harbinensis*	(Fischer et al., 2014)

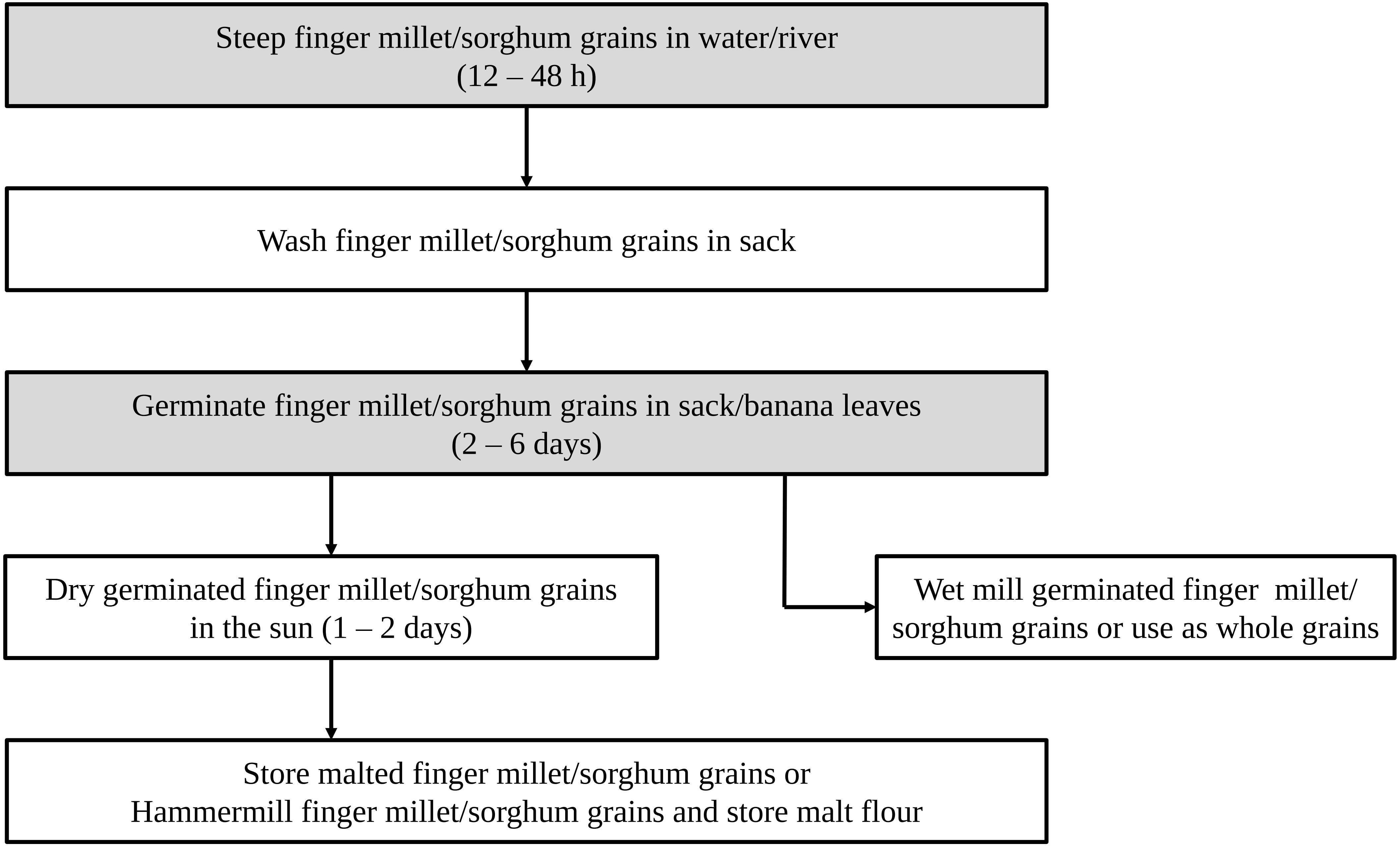
Table 10: Solid pit fermented cereal sourdoughs.

Product	Country	Substrate	Adjunct	Microorganisms	Reference
Hussuwa	Sudan	Sorghum	Sorghum malt	*Lm. fermentum, P. acidilactici, P. pentosaceus,* enterococci	(Yousif et al., 2010) (Yousif et al., 2005)
Related products for which information on fermentation microorganisms is unavailable					
Malwa	Uganda	Finger millet flour	Finger millet malt +/ back slopping	Unknown	(Muyanja et al., 2010)

Table 11: Comparison of fermented cereal beverages and porridges in Africa

East, Central and Southern Africa	**West Africa**
Porridges are coarse and gritty	Fine paste
Most beverages are coarse, gritty, colloidal	Smooth
Coarse maize particles	Fine pasty maize particles
Live microbiota in beverages	Few beverages have live microbiota (e.g. *Kunun-zaki*, KSW[a])
Cooked before fermentation	Cooked after fermentation
Initial wild fermentation by fungi, etc. is eliminated by boiling the maize meal	Initial wild fermentation by fungi, etc. is not eliminated as there is no initial cooking step
Nothing is discarded	Loss of nutrients and minerals during steeping and sieving
Few grains are wet milled	Wet milling of grains with spices is common
Finger millet used most	Pearl millet used most
Fermented without spices	Fermented with spices
Maize is the most commonly used cereal	Maize is the most commonly used cereal

[a] KSW is koko sour water



Steep finger millet/sorghum grains in water/river
(12 – 48 h)

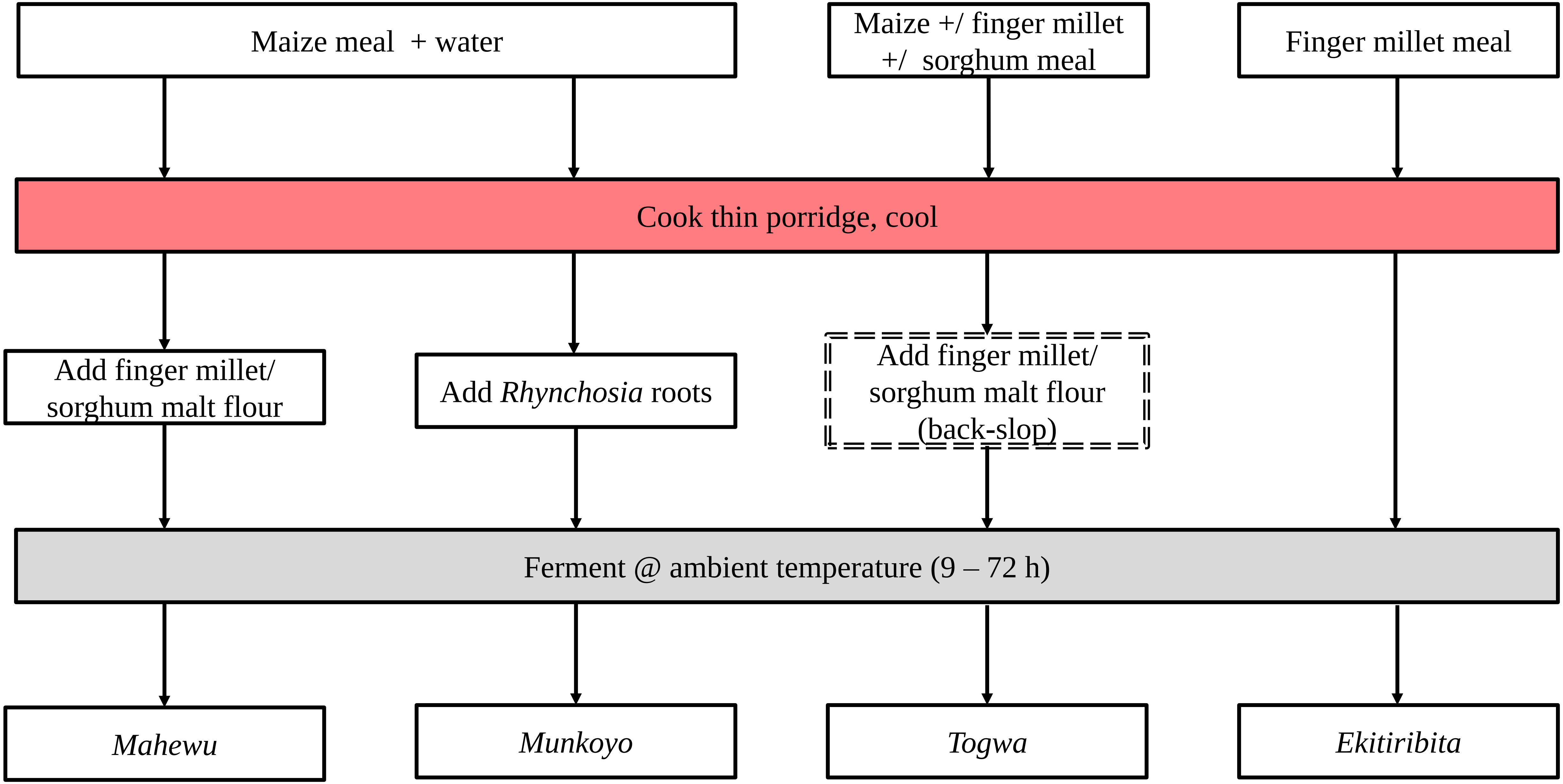
Wash finger millet/sorghum grains in sack

Germinate finger millet/sorghum grains in sack/banana leaves
(2 – 6 days)

Dry germinated finger millet/sorghum grains
in the sun (1 – 2 days)

Wet mill germinated finger millet/
sorghum grains or use as whole grains

Store malted finger millet/sorghum grains or
Hammermill finger millet/sorghum grains and store malt flour



Maize meal + water

Maize +/ finger millet +/ sorghum meal

Finger millet meal

Cook thin porridge, cool

Add finger millet/ sorghum malt flour

Add *Rhynchosia* roots

Add finger millet/ sorghum malt flour (back-slop)

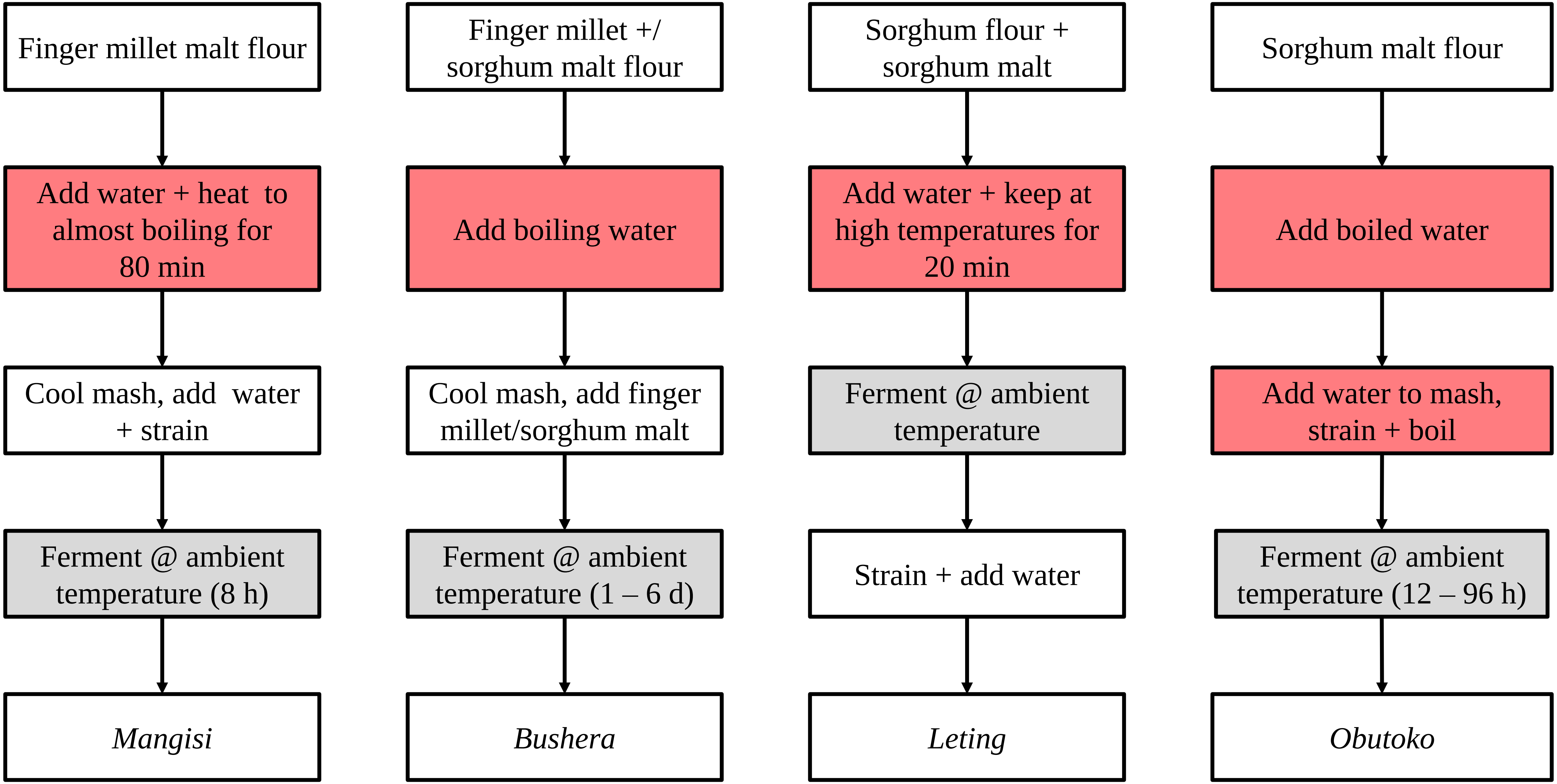
Ferment @ ambient temperature (9 – 72 h)

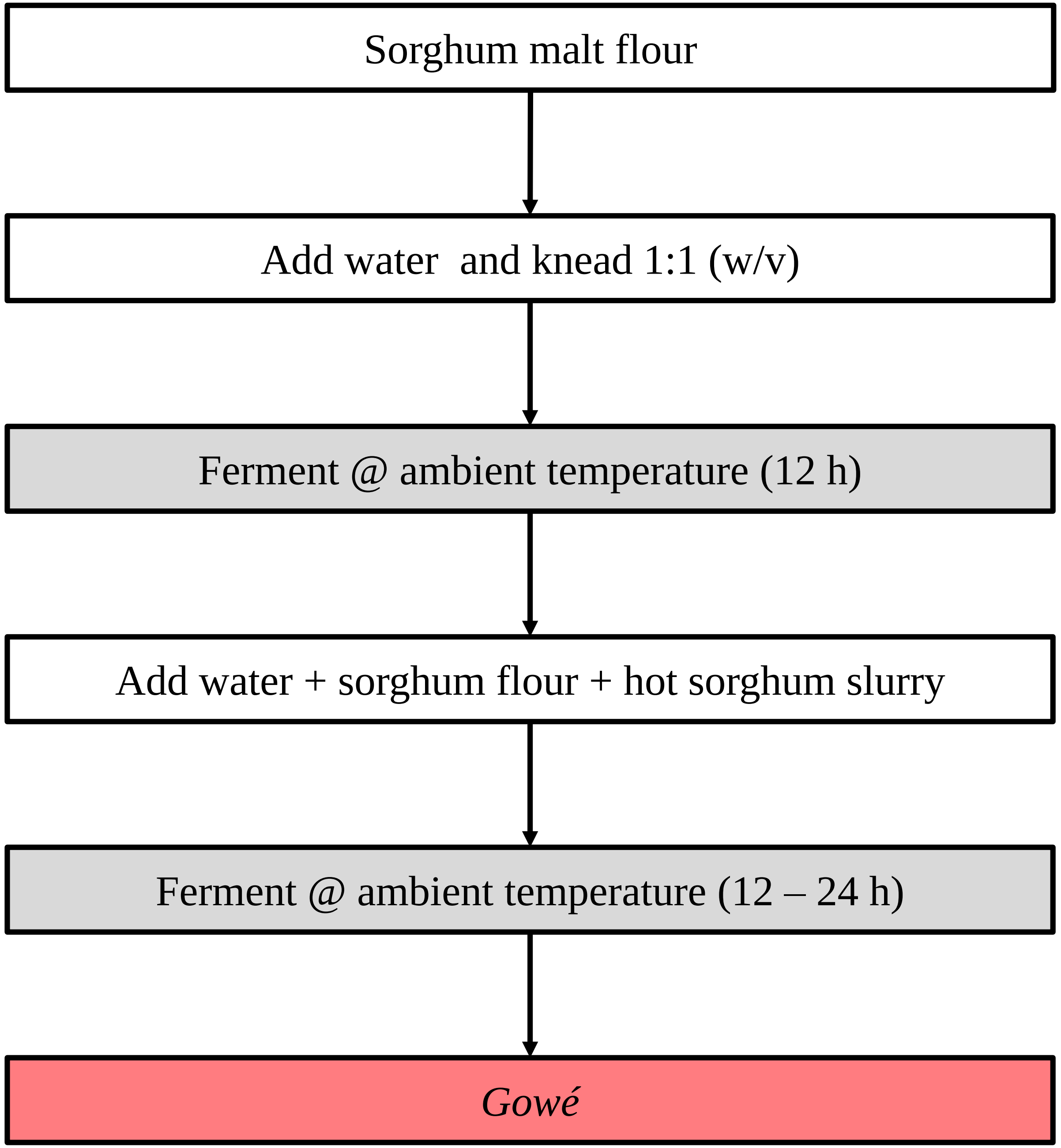
Mahewu

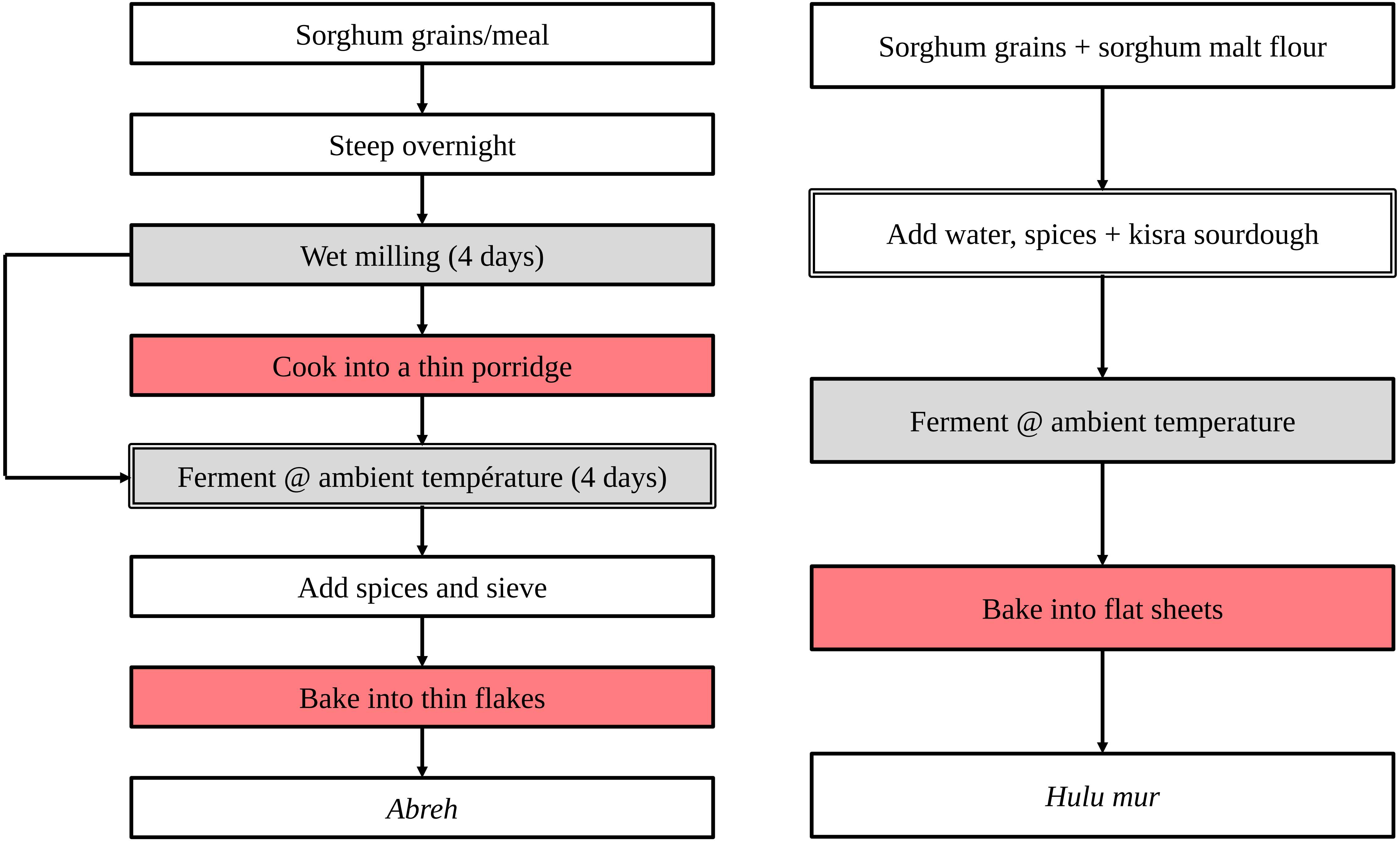
Munkoyo

Togwa

Ekitiribita


Finger millet malt flour
Add water + heat to almost boiling for 80 min
Cool mash, add water + strain
Ferment @ ambient temperature (8 h)
Mangisi
Finger millet +/ sorghum malt flour
Add boiling water
Cool mash, add finger millet/sorghum malt
Ferment @ ambient temperature (1 – 6 d)
Bushera
Sorghum flour + sorghum malt
Add water + keep at high temperatures for 20 min
Ferment @ ambient temperature
Strain + add water
Leting
Sorghum malt flour
Add boiled water
Add water to mash, strain + boil
Ferment @ ambient temperature (12 – 96 h)
Obutoko


Sorghum malt flour
Add water and knead 1:1 (w/v)
Ferment @ ambient temperature (12 h)
Add water + sorghum flour + hot sorghum slurry
Ferment @ ambient temperature (12 – 24 h)
Gowé



Sorghum grains/meal

Steep overnight

Wet milling (4 days)

Cook into a thin porridge

Ferment @ ambient température (4 days)

Add spices and sieve

Bake into thin flakes

Abreh

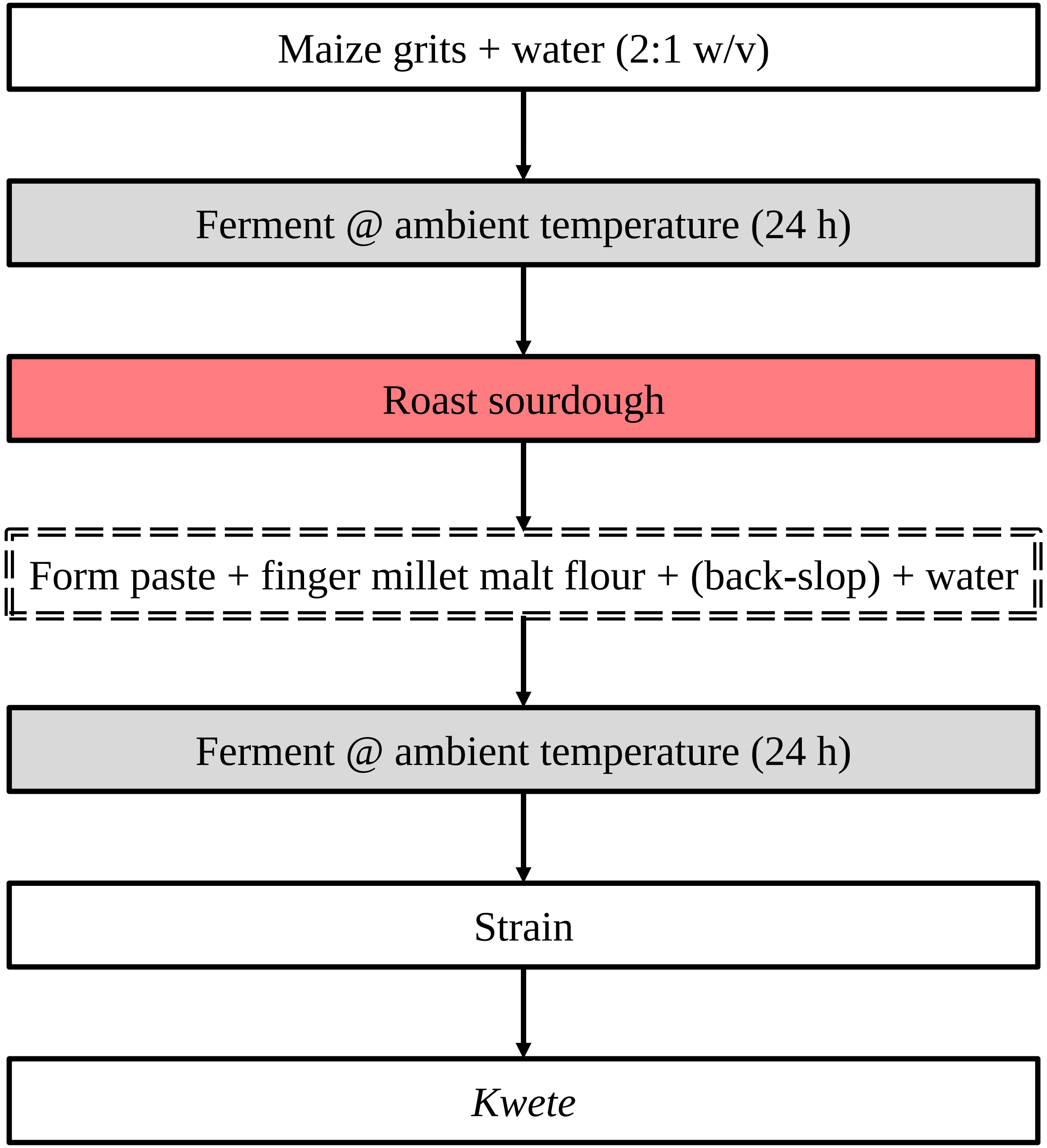
Sorghum grains + sorghum malt flour

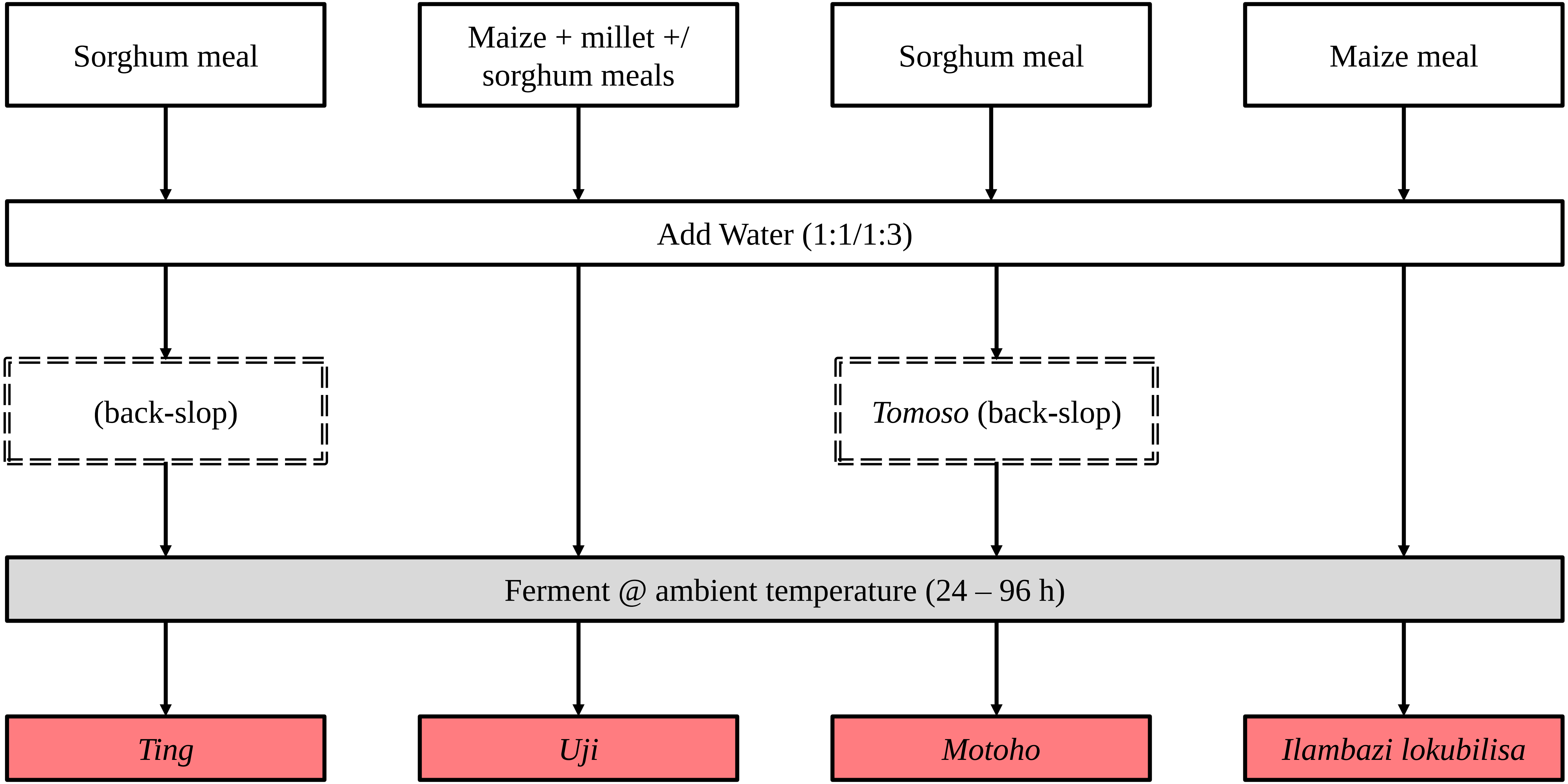
Add water, spices + kisra sourdough

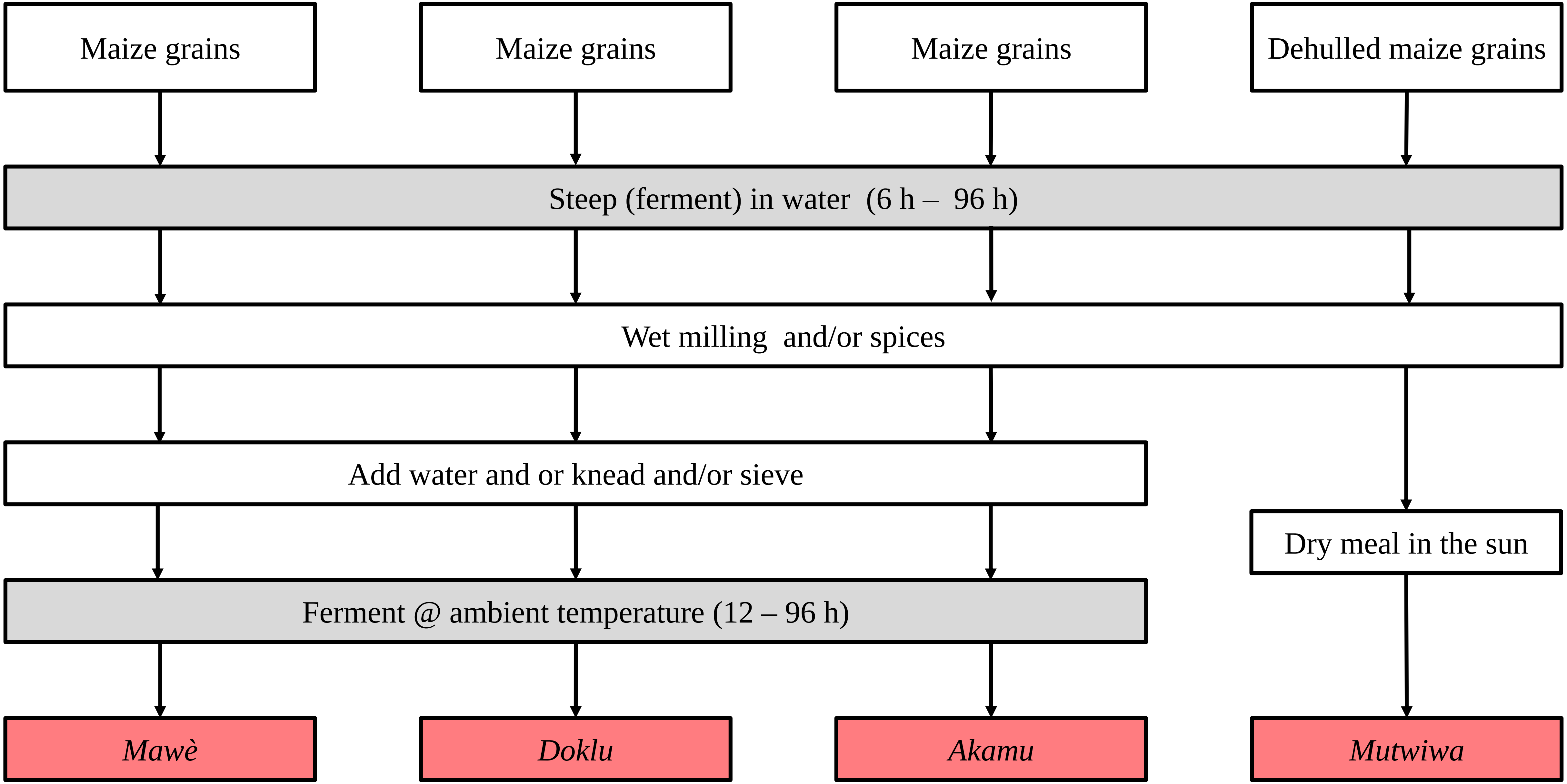
Ferment @ ambient temperature

Bake into flat sheets

Hulu mur


Maize grits + water (2:1 w/v)
Ferment @ ambient temperature (24 h)
Roast sourdough
Form paste + finger millet malt flour + (back-slop) + water
Ferment @ ambient temperature (24 h)
Strain
Kwete


Sorghum meal
Maize + millet +/ sorghum meals
Sorghum meal
Maize meal
Add Water (1:1/1:3)
(back-slop)
Tomoso (back-slop)
Ferment @ ambient temperature (24 – 96 h)
Ting
Uji
Motoho
Ilambazi lokubilisa



Maize grains

Maize grains

Maize grains

Dehulled maize grains

Steep (ferment) in water (6 h – 96 h)

Wet milling and/or spices

Add water and or knead and/or sieve

Dry meal in the sun

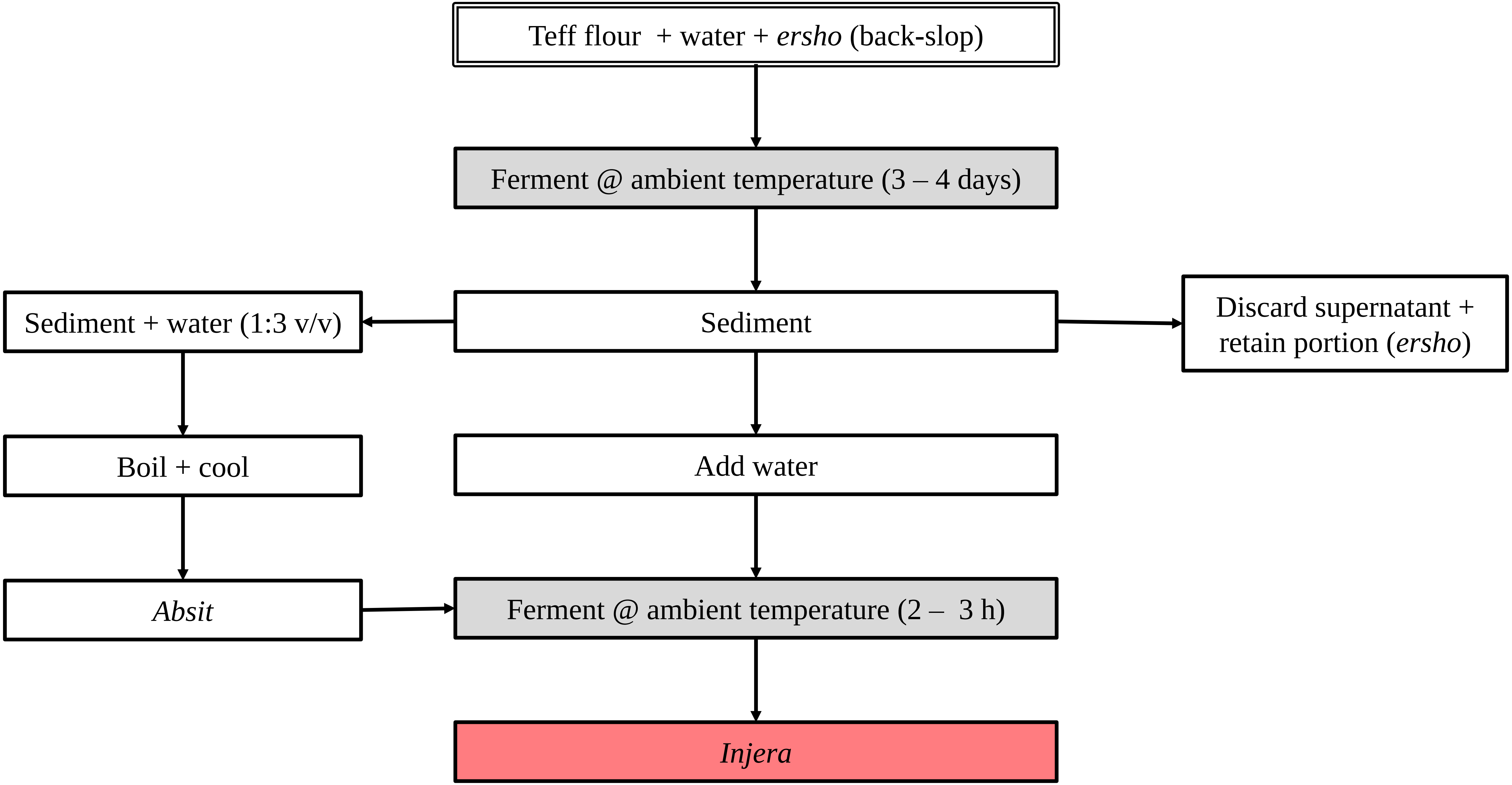
Ferment @ ambient temperature (12 – 96 h)

Mawè

Doklu

Akamu

Mutwiwa


Teff flour + water + *ersho* (back-slop)

Ferment @ ambient temperature (3 – 4 days)

Sediment

Sediment + water (1:3 v/v)

Discard supernatant + retain portion (*ersho*)

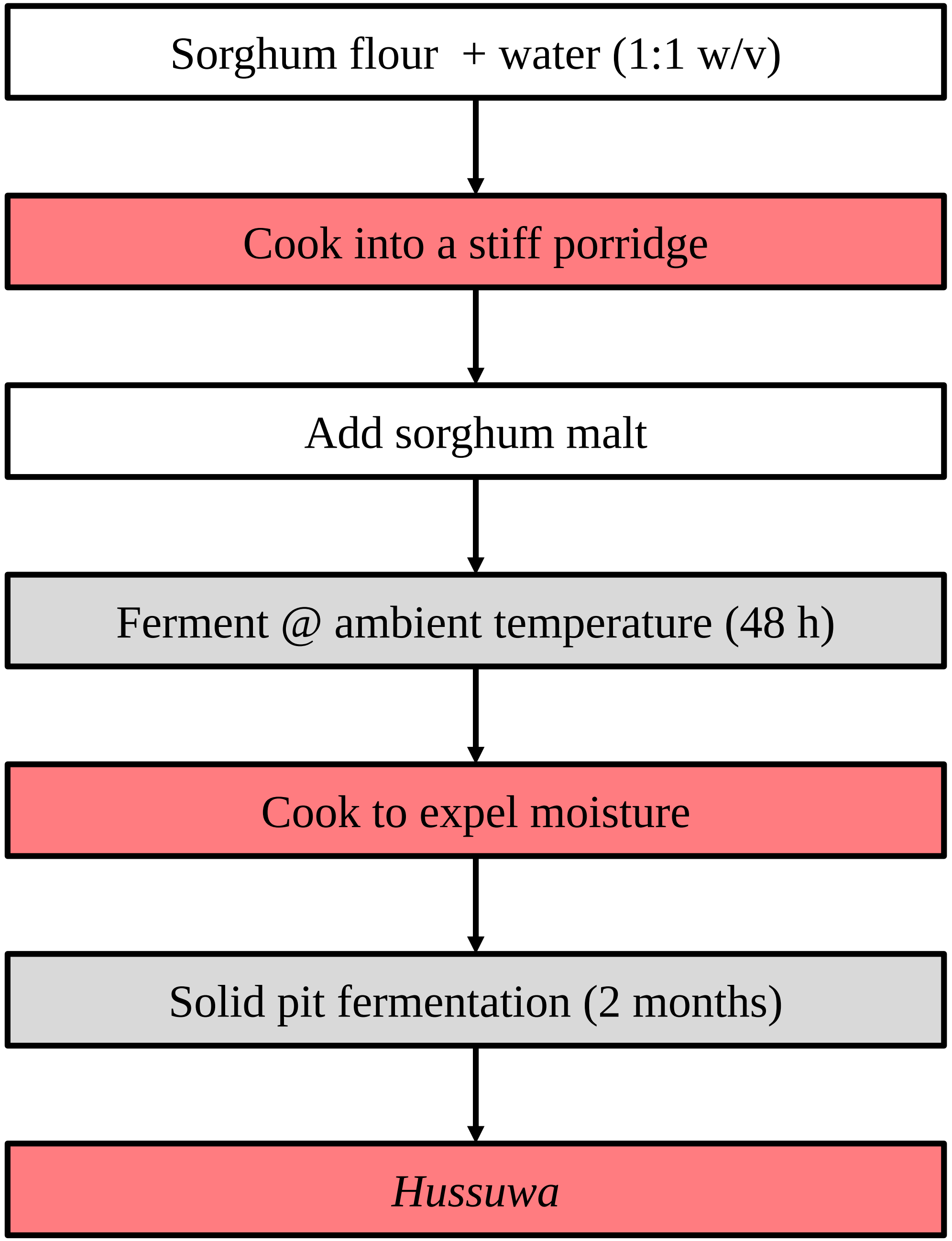
Boil + cool

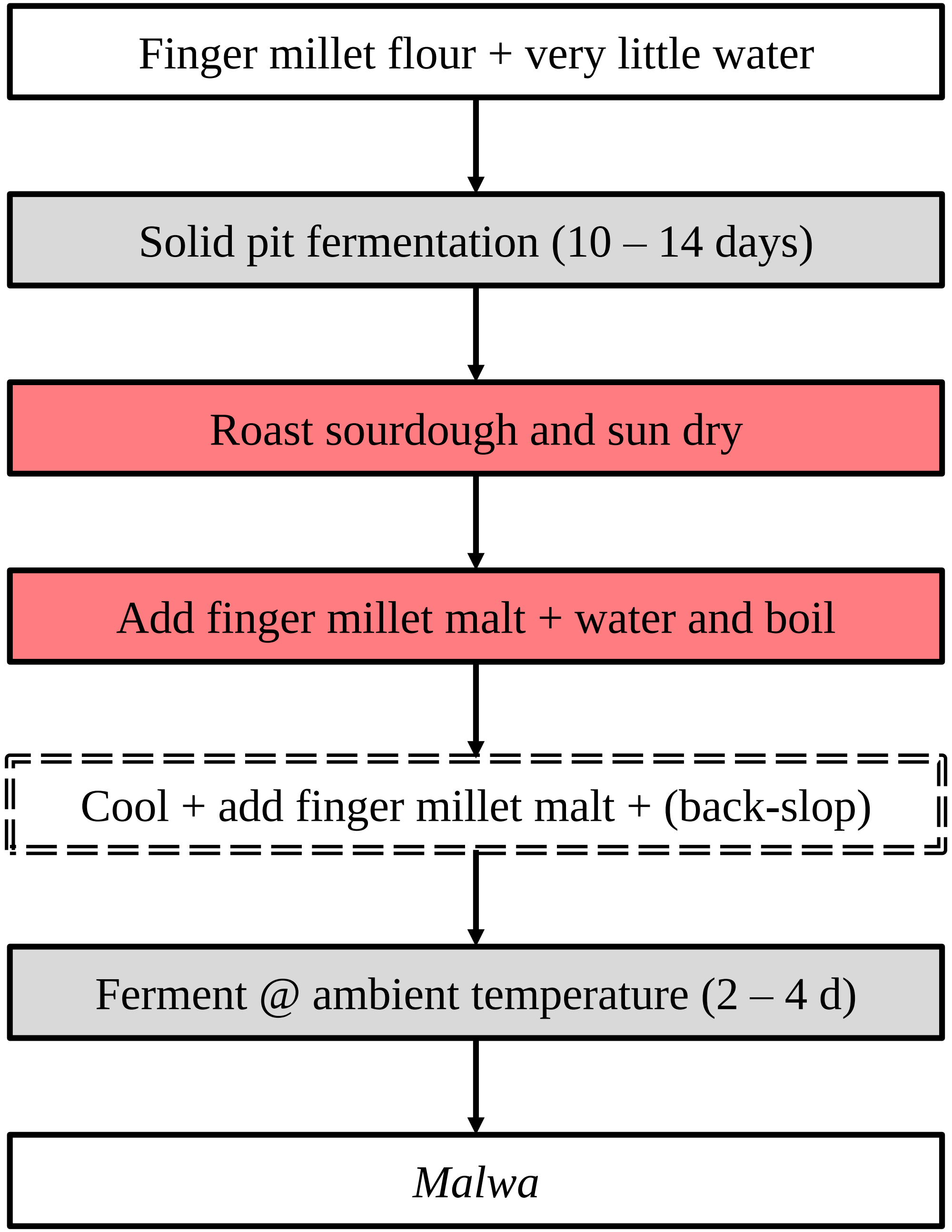
Add water

Absit

Ferment @ ambient temperature (2 – 3 h)

Injera


Sorghum flour + water (1:1 w/v)
Cook into a stiff porridge
Add sorghum malt
Ferment @ ambient temperature (48 h)
Cook to expel moisture
Solid pit fermentation (2 months)
Hussuwa


Finger millet flour + very little water
Solid pit fermentation (10 – 14 days)
Roast sourdough and sun dry
Add finger millet malt + water and boil
Cool + add finger millet malt + (back-slop)
Ferment @ ambient temperature (2 – 4 d)
Malwa