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Evaluation of techniques for drying goat meat: moving local knowledge from fish to goat meat, Malawi

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Abstract: *The need for high-iron-containing animal protein products that are safe, cheap, and suitable for dietary diversification within rural communities presents a development challenge in Malawi. Although fish drying is widely practised, the drying of high-iron-containing goat meat is not well established. In this study, techniques for drying goat meat were established by borrowing from local practices of fish preservation in Malawi. Goat meat and fish samples in pieces of varying sizes were prepared as follows: 1) 6 per cent vinegar soak; 2) 6 per cent lemon juice soak; 3) salt dry rub; or 4) no marinade. The study results describe 576 samples, dried with a solar dehydrator (*n *= 192), an electric oven (*n *= 192), or a wood-fired drum oven (*n *= 192). The costs were lower for drying fish than for drying goat meat. Although the solar dehydrator offered good potential for drying goat meat, the presence of mould and insects on the samples and the long drying time were trade-offs. Inconsistent product quality was found with the drum oven, necessitating its further refinement. The electric oven was not suitable for rural communities. Within the larger context of supporting rural communities in Southern African countries through innovative developments to improve their diets and health, processing small pieces of goat meat with the solar dehydrator during the dry season (in line with practical national food safety guidelines that should be established) combined with promoting consumption of the product in the rainy season offers the greatest potential.*

Keywords: diet, fish, food security, goat, Malawi, meat science

Sustainable Development Goal 2 aims to 'End hunger, achieve food security and improved nutrition and promote sustainable agriculture' (United Nations, 2017). There has been a lot of discussion on the need for dietary diversification in Malawi (Darmon et al., 2002; Joy et al., 2015; Riley et al., 2018) where dietary mineral deficiencies are widespread

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and the nutrient supplies in both rural and urban households indicate that the poorest households have the lowest median dietary supply of iron (Joy et al., 2015). Low levels of blood haemoglobin (Hb) in children can cause impaired cognitive development, stunted growth, and increased morbidity from infectious diseases. In Malawi, 63 per cent of children aged 6–59 months are reported to have anaemia (Hb < 11.0 g/dl), and 2 per cent of children have severe anaemia (Hb < 7.0 g/dl). Additionally, one in three women aged 15–49 years are anaemic (non-pregnant women, Hb < 12.0 g/dl; and pregnant women, Hb < 11.0 g/dl). Furthermore, 37 per cent of children under 59 months of age are categorized as chronically undernourished on the basis of height assessment for age (National Statistical Office and ICF, 2017). Joy et al. (2015) noted that most dietary iron intakes are from non-haem sources, with only 14 per cent being from animal products. Darmon et al. (2002) further found that although preschool children in rural Malawi had some of their energy diet provided by available meat, fish, and eggs, the nutritional adequacy was insufficient especially during the non-harvest season. In Malawi, the prevalence of anaemia in pregnant women is highest in the rainy season, and pregnant women with moderate or severe anaemia have a higher incidence of malaria (Rogerson et al., 2000). Thus, the need for a safe and cheap animal protein product that is high in iron presents a development challenge in Malawi.

Dietary supplies of haem iron, such as that from animal meat sources, are easily absorbed. Salted dried meat, commonly known as biltong in Southern African countries, is an uncooked meat prepared from beef or antelope that is marinated and cured in a mixture containing vinegar and salt and then dried. The biltong-producing process in Southern African countries is different from jerky production in other countries in that the meat is not heated during processing or before consumption. However, when processed properly, biltong is safe as a ready-to-eat meat product (FAO, 1990). For uncooked products, the inhibition of *Escherichia coli* relies mainly on the water activity and the pH of the product, where a more acidic pH can prevent the growth of the pathogen (McQuestin et al., 2009). However, if not processed properly, moist biltong samples may not be safe for consumption (Naidoo and Lindsay, 2010; Petit et al., 2014). For dry-cured goat meat in Morocco, an improved manufacturing process (based on microbiological and physicochemical characterizations) was tested with locally available treatment variations, including the salting time and the addition of olive oil and a paprika covering (Cherroud et al., 2014). Despite biltong being popular in other Southern African countries, a recent household survey in Mzuzu, Malawi, found that 50 per cent of households had purchased dried fish in the previous month and the purchasing of dried meat was not common (Riley et al., 2018). Goat meat in Malawi can be purchased from informal and formal slaughter facilities (Tanganyika et al., 2017).

In Malawi, Lake Malawi serves as a source of both protein for household diets and economic activity (Government of Malawi, 2016, 2017). Fish is dried by sun drying and smoking, without the use of marinades or salt. Most Malawian households in both urban and rural areas lack a refrigerator for food preservation (National Statistical Office and ICF, 2017). The sun drying of fish becomes difficult during the rainy season owing to high humidity and rain falling on the traditional open drying grass mats, whereas smoking the fish over an open fire contributes to deforestation.

The FAO (1990) has practical recommendations for using local knowledge and available treatment variations that are suitable for Southern African countries for the production of dried meat in order to reduce the risk of foodborne illnesses. To support Malawian rural communities through improvements in their diets and health there is a need to explore food preservation techniques that will be practical enough to produce a safe and cheap animal protein product that is high in iron (Colwell, 2017). Czerwonka and Tokarz (2017) noted that red meat, including goat meat, was the best source of haem iron in the diet and contained higher amounts than that found in fish. Although important work has gone into value-added goat meat products such as snack sticks that are vacuum packaged and stored at refrigeration or freezer temperatures (Cosenza et al., 2003), these are not practical interventions for rural households in Malawi that lack access to electricity. As a result, rural households have to ensure that all the meat is consumed or sold when a goat is slaughtered, making it difficult to maintain a consistent supply of red meat throughout the year.

The successful introduction of high-iron-containing meat sources to rural communities in Malawi depends on the costs of production, the moisture content of the product, the presence of mould, insects, and/or *E. coli* on the meat, and the suitability of the drying technique, all of which must have a demonstrated proof-of-concept before moving to human dimensions, including sensory testing and consumer research. This present study was conducted to evaluate different techniques for drying goat meat by borrowing from local practices of fish preservation. Such innovative adaptation of local knowledge of fish drying to the drying of goat meat can potentially be applied to rural communities in other Southern African countries aside from Malawi. The development of a value-added dried (uncooked) product that is shelf stable at ambient temperature would benefit communities in the entire region, especially pregnant women and children.

Materials and methods

Drying of goat meat and fish was performed twice in Mzuzu, Malawi; once during the dry season (November to December 2017) and again during the rainy season (March 2018).

Meat preparation

Samples of *Diplotaxodon* species, a local fish from Lake Malawi, were purchased from fishers soon after they had landed their catch in the town of Nkhata Bay, 50 km from Mzuzu. The samples were transported by a project researcher back to Mzuzu University on the same day of capture. The fish transportation chain is known to introduce contamination so this variable was eliminated by purchasing directly from the fishers (Samikwa et al., 2019). The whole fish was first rinsed with tap water and then gutted and rinsed again. Two types of samples (with skin) were then prepared as follows: 1) minced samples, by cutting into approximately 2 cm × 2 cm pieces using a knife; and 2) whole fish. Goat meat was purchased from the local open-air market in Mzuzu. Slaughter was performed by the seller and the meat was purchased on the day of slaughter. The meat was rinsed with tap water to remove excess blood and then hand deboned, following which the fat was removed. Three types of goat meat samples were then prepared as follows: 1) ground samples, using an electric meat grinder (purchased in Mzuzu); 2) minced samples, by cutting into approximately 1 cm × 1 cm pieces using a knife; and 3) strips of whole muscle, cut to approximately 10 cm × 1 cm × 1 cm using a knife.

The goat meat and fish samples were then marinated as follows: 1) vinegar soaking, by combining 6 ml of 5 per cent vinegar (commercially purchased in Mzuzu) and 200 g of tap water per 100 g of meat; 2) lemon juice soaking, by combining 6 ml of fresh *Citrus limon* (a local fruit purchased from the open-air market in Mzuzu and hand squeezed) and 200 g of tap water per 100 g of meat; 3) salt dry rubbing, at a concentration of 4 g of salt per 100 g of meat; and 4) whole fish with no marinade, prepared similarly to local practices of fish preservation.

In a pilot study, samples were marinated at ambient temperature for 3 days and a high rate of spoilage was observed (based on visual discoloration and smell). Therefore, for this present study, the vinegar marination and lemon juice marination were first conducted at ambient temperature overnight (<12 h) in a covered plastic container, and then the samples were rubbed with 4 g of salt before the drying process. The dry salt-rubbed samples were refrigerated overnight and then rubbed with 4 g of salt before the drying step.

Drying methods

Borrowing from the local practices of fish preservation in Malawi, the following three drying methods (Figure 1) were selected:

1. Solar dehydrator, made from locally available materials, in a greenhouse-style design with walls of plastic sheeting covering a wooden frame and concrete floor. Samples were spread thin by hand onto mesh racks which allowed for air flow and evaporation from the entire surface area. The temperature was checked three times each day, and ranged from 24.8°C to 31.5°C during the dry season and 20.5°C to 28.8°C during the rainy season. The samples were flipped 180 degrees daily. The presence of mould and insects was observed visually throughout the drying period and for 30 days after drying.
2. Electric oven, at 127°C for 6 h. The presence of mould and insects was observed visually for 30 days after drying.
3. Wood-fired drum oven, made from locally available materials, traditionally also used to make cookies and bread. The temperature ranged from 120°C to 140°C for 2 h. The presence of mould and insects was observed visually for 30 days after drying.

We did not consider other drying methods, such as hanging the goat meat in an open-air kitchen with fire and smoke as this is not commonly done to dry fish in Malawi. Qualitative observations on the ease of operation for each drying method were made by the researchers.

The techniques of meat preparation and drying are summarized in Table 1. Forty-eight trials were conducted to assess the meat preparation and drying methods,

Figure 1 Drying methods used in this study: (a) solar dehydrator; (b) electric oven; (c) wood-fired drum oven

Table 1 Experimental design: techniques of meat preparation and drying

Meat preparation	*Drying methods*		
	Solar dehydrator	*Electric oven*	*Drum oven*
6% vinegar marinade, then salt rub	Ground goat meat	Ground goat meat	Ground goat meat
	Minced goat meat	Minced goat meat	Minced goat meat
	Strips of goat meat	Strips of goat meat	Strips of goat meat
	Minced fish	Minced fish	Minced fish
	Whole fish	Whole fish	Whole fish
6% lemon juice marinade, then salt rub	Ground goat meat	Ground goat meat	Ground goat meat
	Minced goat meat	Minced goat meat	Minced goat meat
	Strips of goat meat	Strips of goat meat	Strips of goat meat
	Minced fish	Minced fish	Minced fish
	Whole fish	Whole fish	Whole fish
Salt rub (dry)	Ground goat meat	Ground goat meat	Ground goat meat
	Minced goat meat	Minced goat meat	Minced goat meat
	Strips of goat meat	Strips of goat meat	Strips of goat meat
	Minced fish	Minced fish	Minced fish
	Whole fish	Whole fish	Whole fish
No marinade	Whole fish	Whole fish	Whole fish

and six replicates of 100 g each were prepared for each season (dry and rainy). In total, 576 samples were prepared for the study.

Mould and insect observation

Following the drying process, the samples were stored in locally available plastic bags. For all three drying methods, samples were observed visually for 30 days post drying for the presence of mould and insects. The planned taste testing was cancelled owing to the observation of mould and insects on some samples during the course of the study.

Escherichia coli analysis

In this study, *E. coli* was used as the microbiological indicator (United States Department of Agriculture, Food Safety and Inspection Service, 2014) and the laboratory analysis (destructive method) was performed at Mzuzu University. At 30 days post drying, the dehydrated meat was analysed for the presence of *E. coli* and total coliform simultaneously using Petrifilm *E. coli*/Coliform Count Plates (3M™, Saint Paul, MN). Each meat sample (one piece) was weighed and then chopped with a flame-sterilized knife, following which the sample was transferred to an aseptic vial containing 4.5 ml of water (previously boiled tap water cooled for a minimum of 2 h) with no preservatives. The vial was hand shaken for 5 min. Then, 1 ml of sample from the vial was transferred by pipette onto a Petrifilm plate and incubated at 35 ± 0.5°C for 24 h. Total coliform and *E. coli* were subsequently counted using a hand lens, and the results were adjusted for the dilution and reported as colony forming units. Two independent samples from each trial were analysed for *E. coli* and the mean results were computed.

Statistical analysis

Owing to the small sample size, Fisher's exact test was used for the quantitative data analysis. Statistical analysis was performed using the R Project 3.3.2 statistical package (Vienna, Austria). Differences were considered to be statistically significant at a p value of less than 0.05.

Ethics

This study was approved by the Government of Malawi National Commission for Science and Technology (Protocol No. P10/17/222).

Results and discussion

The study results describe 576 samples that were prepared and dried with a solar dehydrator ($n = 192$), an electric oven ($n = 192$), or a drum oven ($n = 192$). Goat meat and fish samples in pieces of varying sizes were prepared as follows: 1) 6 per cent vinegar soak; 2) 6 per cent lemon juice soak; 3) salt dry rub; or 4) no marinade to represent traditional fish drying methods.

Cost

There is a trade-off between the immediate consumption of animal meat sources versus an increase in cost of time and supplies for drying the meat to consume at a later date. In our study area of Mzuzu, freshly slaughtered goat meat and beef are readily available at the local open-air market. At the time of study, goat meat cost Malawian Kwacha (MK) 2,000 (US$2.76)/kg, whereas the same quantity of beef cost MK2,500 ($3.45)/kg. Fish cost MK3,000 ($4.14)/kg. Although the cost of goat meat per kilogram was cheaper, approximately 48 per cent was lost (~480 g discarded per kilogram) once the bones and fat had been removed. After meat cutting, the cost of the goat meat was adjusted as MK3,850 ($5.31)/kg. In the case of the fish, approximately 21 medium-sized individuals equated to 1 kg, and only about 20 g per 1 kg was lost during gutting. Therefore, the cost of the gutted fish was adjusted as MK3,060 ($4.22)/kg.

The additional costs of the vinegar, lemon juice, and salt added to each 100 g of sample were also considered. The cost to add 4 g of salt to every 100 g of sample was MK4 ($0.006). The cost to add 6 ml of vinegar plus 4 g of salt to 100 g of sample was MK8 ($0.011). Lemons were seasonally available at a cost of MK200 ($0.28) per four lemons, which were hand squeezed and produced approximately 80 ml of full-strength juice; therefore, the cost to add 6 ml of lemon juice plus 4 g of salt to 100 g of sample was MK19 ($0.026).

The time taken to prepare the samples before drying was also a cost consideration. During the rainy season, rural households are usually busy farming subsistence crops in the fields, whereas there is more time available for other activities during the dry season. The time taken to prepare and dry 100 g of sample included that for 1) deboning the goat meat or gutting the fish (2 min); 2) cutting or grinding the samples into pieces (2–5 min); 3) marinating the samples (<12 h); and 4) applying the final salt rub (3 min).

Moisture

Moisture is a parameter that indicates the quality of the product for storage. The moisture loss in the solar dehydrator was 56 per cent to 74 per cent, whereas that in the electric oven was 62 per cent to 80 per cent. The drum oven had the widest range of moisture loss, at 39 per cent to 81 per cent.

Drying with the solar dehydrator is dependent on the weather conditions. During the drying in the dry season, the daily outside temperature ranged from 24.0°C to 30.0°C, whereas the temperature inside the solar dehydrator ranged from 24.8°C to 31.5°C. The outside relative humidity was 59 per cent to 92 per cent. During the rainy season, the daily outside temperature ranged from 21.7°C to 28.8°C, whereas the temperature inside the solar dehydrator ranged from 20.5°C to 28.8°C. The outside relative humidity was 74 per cent to 97 per cent.

Presence of mould and insects

At 30 days post drying, there were more samples (11 per cent; 65/576) showing the presence of mould than those that had insects (1 per cent; 6/576). Differences (Fisher's exact test, $p = 0.00$) were observed between the solar dehydrator, drum oven, and electric oven drying methods and whether or not mould was observed. More often, mould was observed in the samples dried in the drum oven (28 per cent; 53/192), and occurred within the 30-day post-drying period. Mould was also observed in the samples dried in the solar dehydrator (6 per cent; 12/192), but appeared during the drying activity; that is, from days 2 to 4 during drying for the fish samples, and at drying days 3 or 4 for the goat meat samples. None of the samples (0/192) from the electric oven displayed mould.

With regard to the marinade effects, mould was observed in samples prepared with vinegar (13 per cent; 23/180), lemon juice (9 per cent; 16/180), salt (11 per cent; 20/180), or no marinade (17 per cent; 6/36). Fisher's exact test showed no differences ($p = 0.45$) between the marinade options, and each marinade method had at least some samples with observable mould. There were also no differences (Fisher's exact test, $p = 0.51$) in the amount of mould observed between the fish and goat meat samples, with 12 per cent (31/252) fish and 10 per cent (34/324) goat meat samples observed to have mould.

Notably, there were differences (Fisher's exact test, $p = 0.00$) in the amount of mould observed between samples of different sizes, with the smaller pieces being better preserved. Mould was observed in the strips (21 per cent; 23/108), whole fish (15 per cent; 21/144), and mince (10 per cent; 21/216), whereas no mould was observed in the ground samples (0/108).

There were further differences (Fisher's exact test, $p = 0.00$) in the amount of mould observed between the rainy and dry seasons. More of the dry season samples (56/288) were observed to have mould than the rainy season samples (9/288). Despite the findings on the presence of mould, there may be a benefit to dry season meat preservation on the basis of two aspects: First, the rainy season (January to March) typically falls within the time when the previous year's stores of subsistence crops have been depleted and the next year's crops are not yet matured in the fields, and consequently are the months when households experience difficulty in accessing food (Riley et al., 2018). Second, Rogerson et al. (2000) noted the need for iron for pregnant women during the rainy season. A focused strategy of meat preservation in the dry season for consumption in the food scarcity period of the rainy season may work well in the Malawian context. Practically speaking, the shelf life of a dried goat meat product needs to be at least 4 months, which would be long enough to get rural households through the rainy season.

Each of the samples with insects (mainly small worms) was whole fish that had been dried in the solar dehydrator (6/192). No insects were observed on the goat meat samples. None of the samples from the electric oven (0/192) or drum oven (0/192) had insects. Fisher's exact test showed significant differences ($p = 0.00$) between the different drying methods in terms of whether insects were observed, indicating that the samples placed in the solar dehydrator were more susceptible to insects than the samples from the other drying methods. Fisher's exact test also showed significant differences ($p = 0.00$) between the samples of different sizes with regard to whether insects were observed, where all of the samples with insects were whole fish (6/144), whereas no insects were observed in mince (0/216), strips (0/108), or ground samples (0/108). Furthermore, Fisher's exact test showed differences ($p = 0.01$) between the fish and goat meat samples in terms of whether insects were observed, indicating that the goat meat was less susceptible to insects in this study. The whole fish samples with insects were from both the dry (4/6) and the wet seasons (2/6), with Fisher's exact test showing no differences ($p = 0.69$) between the two in terms of insects observed. Although the sample size was small, most of the insect-infested samples (5/6) were non-marinated whole fish. In this regard, Fisher's exact test showed significant differences ($p = 0.00$) between the marinade options, indicating that samples that had been marinated were less susceptible to insects than the non-marinated whole fish.

Presence of Escherichia coli

E. coli is an indicator of faecal contamination and of food safety. Although fish do not naturally have *E. coli* in their faeces they can act as a carrier of the bacterium through cross-contamination with other sources (Hansen et al., 2008). In contrast, goats do have *E. coli* in their faeces (Akanbi et al., 2011) and cross-contamination to meat through poor hygiene practices during goat slaughter has been reported in Nigeria and Malawi (Akanbi et al., 2011; Tanganyika et al., 2017).

E. coli was observed in only one sample; that is, the ground goat meat that had been marinated in vinegar and dried in the solar dehydrator. Therefore, most of the other samples could be considered safe for consumption, indicating that it is generally possible to prepare and dry meat samples that are free of *E. coli* by each of the three drying methods within the Malawian context—at least in a laboratory setting and using tap water for processing. As discussed by Cherroud et al. (2014), there is also a potential marinade option to use local paprika on dry-cured goat meat for its antimicrobial effects.

Evaluation of the drying techniques

Practically speaking, the success of drying techniques in terms of food storage is based on the ease of operation and the final moisture level attained. Although the performance of the electric oven for drying samples was promising, the oven required electricity; therefore, its use is impractical, given that only 4 per cent of rural households and 49 per cent of urban households have access to electricity in Malawi (National Statistical Office and ICF, 2017). The qualitative evaluation of each technique for drying goat meat is presented in Table 2. Of the three drying methods, the solar dehydrator had the most promising results as observed by researchers.

Application of national standards for scaling up goat meat drying

Most fish drying activities are done by small-scale operators (Government of Malawi, 2017), and goat meat drying is likely to follow this small-scale model in rural communities. For goat meat drying, the following national standards – implemented by the Malawi Bureau of Standards (MBS) to assess compliance of meat producing companies and their products – apply:

- MS 19: 2001 Labelling of prepacked foods – General standard: Applies to the labelling of prepacked foods offered to consumers in Malawi and intended for human consumption (MBS, 2001).
- MS 21: 2002 Food and food processing units – Code of hygienic conditions: Applies to the food processing chain (MBS, 2002).
- MS 200: 1989 Meat animals for ante-mortem slaughter and post mortem – transportation, handling and inspection – Code of practice: Applies to the transportation and handling of goat meat as a raw material (MBS, 1989a).

- MS 808: 2011 Cooked cured chopped meat – Specification: Applies to packaged chopped meat, including solar drying methods (MBS, 2011).

The implementation of this next standard is voluntary:

- MS 206: 1989 Meat grading – Code of practice: Applies to the grading of meat from cattle, sheep, goats, and pigs (MBS, 1989b).

The MBS guidelines on the butchering and veterinarian inspection of goat meat, as well as formal food processing, may initially limit innovations for goat meat drying, as it would be challenging for rural communities to take up this nutritional programme if they cannot easily comply with the codes. From the report by Abass et al. (2018) – in which scientific and technological innovations used in Africa to move cassava from a subsistence crop to a shelf-stable product were reviewed – there are lessons to be learned by researchers in terms of fine-tuning a promising technology and by policy makers in terms of the policies and strategic institutional arrangements that can be implemented to encourage private sector investment for scale-up. However, the work by Masters et al. (2016) highlighted that for low- and middle-income countries, the attainment of uniformity in both the ingredient ratios and production practices for premixed and packaged foods is difficult and independent testing within the country manufacturing the products is not consistent, which are

Table 2 Qualitative evaluation of drying techniques

Drying method	*Reasons to dry goat meat using this method*	*Reasons not to dry goat meat using this method*
Solar dehydrator	1. Does not require electricity or firewood 2. Constructed from locally available materials 3. Low heat 4. Requires only limited oversight during drying	1. Slowest drying time of the methods used owing to low heat, and an even longer drying time in rainy season conditions 2. Requires an experienced builder with construction knowledge, although available within Malawi 3. Unequal distribution of heat based on the time of day and shadows of the surrounding area
Electric oven	1. Fast drying time 2. Uniform distribution of heat 3. Requires only limited oversight during drying	1. Requires electricity 2. Ovens are not manufactured within Malawi and are expensive to purchase, repair requires an experienced technician 3. Low knowledge of electric oven operation in rural areas
Drum oven	1. Does not require electricity 2. Locally available energy source, firewood is widely available in rural areas 3. Constructed from locally available materials 4. Knowledge of oven operation is available in rural areas 5. Short drying time	1. Use of firewood contributes to deforestation 2. Unequal distribution of heat inside the oven 3. Labour intensive during drying, requires high level of oversight of samples

findings that would likely also apply to the scaling up of any dried meat product production in the Malawi context.

Recommendations

The methodology of this study allowed a proof-of-concept in moving local knowledge from fish drying to goat meat drying in Malawi and contributes to the larger context of innovative developments to support rural communities in sub-Saharan Africa. A similar approach using locally available proof-of-concept testing methods in situations where conventional testing is difficult to employ for innovation has been undertaken in Malawi to support rural households with sanitation technologies, by applying local materials and construction by an experienced builder for a pit latrine design that is simple to operate (i.e. requiring no formal education) and is low in cost (Chidya et al., 2016).

However, further research is needed before scale-up of a dried goat meat product can be realized. The cost savings of buying goats in higher numbers or raising them communally needs to be further researched, as does the cost for goat meat based on seasonal and geographic availability. Further work is also needed on microbial analysis and mould identification. There is also potential to refine the drum oven design so that it matches the electric oven in terms of uniform heating and drying time for the efficient production and commercialization of dehydrated goat meat.

With regard to the regulatory framework to support Malawi in dietary diversification, there is an opportunity for the MBS to establish new food safety guidelines to ensure that small-scale operators (e.g. rural households or small community groups) can make a dried goat meat product while maintaining safety and low costs. One way would be to adapt the practical guidelines that have been set by the United States Department of Agriculture (2014).

Study limitations

Moisture loss was not studied because a water activity meter was not available. We did not determine the type of mould observed but its visual presence indicated that the sample was spoiled and should not be consumed. That the solar dehydrator was not disinfected prior to the study may have been the source of the mould and insects.

Conclusions

This paper contributes to emerging debates about meeting Sustainable Development Goal 2 for human health and food security, as well as to the larger context of innovative developments to support rural communities in Southern African countries by improving their diets and health.

This study found that the cost of drying fish was lower than that for drying goat meat. With regard to moulds, the levels were lowest with the electric oven, during the wet season, and in the smallest pieces. However, we cannot confidently claim any difference in performance in terms of the marinade method (as samples from each marinade method had mould) or the meat type (fish versus goat). Furthermore, insect infestations were the lowest with the goat meat, where drying with the electric oven or wood-fired drum oven gave better results. Moreover, no insects were observed in the smallest pieces (ground samples), and samples that used marinade were less susceptible to infestation. However, we cannot confidently claim any difference in observed insects between the rainy and dry seasons. Finally, *E. coli* was observed in only one sample in our study; that is, ground goat meat that had been marinated in vinegar and dried in the solar dehydrator.

Although the solar dehydrator that is traditionally used for fish offers a good potential for goat meat, the presence of mould and insects on the samples and the long drying time were trade-offs. Inconsistent product quality was found with the wood-fired drum oven and the technique needs further refinement. The electric oven was not suitable for scale-up for rural communities. Dried (i.e. uncooked and shelf-stable) goat meat remains an innovative, safe, and cheap animal protein product that is high in iron. Therefore, the processing of goat meat in small pieces (in line with practical national food safety guidelines that should be established) and drying them with the solar dehydrator during the dry season, combined with the promotion of their consumption in the rainy season, offers the greatest potential for improving the diets and health of the people in rural communities of Malawi.

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