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Do metal grain silos benefit women in Kenya, Malawi, Zambia and Zimbabwe?

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ABSTRACT

Metal silos can reduce maize losses during storage in smallholder farm systems, contributing towards international goals of reducing food waste and moving towards Sustainable Development Goal 2, Zero Hunger. However, technologies are introduced into farming systems with complex sets of relationships. These may differentially affect the ability of women and men to secure the expected benefits of metal silos. This, in turn, may affect adoption rates and expected outcomes. To better understand these relationships, a mixed methods study was conducted in Kenya, Malawi, Zimbabwe and Zambia where metal silos were introduced through the Effective Grain Storage Project (EGSP). EGSP distributed 1717 metal silos across the four countries.

Quantitative surveys using random sampling were conducted in Kenya (124 respondents) and Malawi (100 respondents) with metal silo owners. Qualitative surveys, using purposive sampling, were conducted in all four countries covering 14 ethnic groups using focus group discussions (360 respondents), key informant interviews (62 respondents), and household case studies (62 respondents). The aim was to understand gendered post-harvest management and storage strategies in traditional systems and to map changes when metal silos were introduced.

The findings suggest roles and responsibilities regarding the ownership and management of storage structures are strongly gendered with some differences between ethnic groups and countries. Men benefit more than women from the introduction of metal silos. Ownership of the grain storage facility, and the benefits attached to ownership, can switch from women to men with women having less scope for bargaining over their rights to use the stored grain for their own needs and the benefit of all household members. Women and men fail to fully follow guidelines for effective use of metal silos. They differ in their preferred attributes for their ideal storage system. Whilst some attributes are shared, women's preferences were sharply differentiated from men in others.

1. Introduction

Sustainable Development Goal (SDG) Target 12.3 aims to halve per capita global food waste at the retail and consumer levels and to reduce food loss along value chains (including post-harvest losses - PHL) by 2030. Achieving this goal is expected to directly contribute to the Zero Hunger goal (SDG 2) (FAO et al., 2019). Reducing waste could be more cost-effective and sustainable than trying to boost yields to compensate for post-harvest losses (Tefera et al., 2011). Focusing on strengthening productivity in the absence of adequate post-harvest management and storage does not make sense (Abass et al., 2014).

When grain is stored effectively, it has the potential to boost livelihoods (Tefera et al., 2011). For instance, it can be used to pay labourers in kind - this can be especially important for women who may have less access to cash than men - and for on-farm enterprises

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such as poultry production, brewing beer, and cooking foods for sale as snacks in local markets. Stored grain can be used as collateral for obtaining credit and can be sold when prices are high (Tefera et al., 2011). Managing when to sell enables households to plan their household budgets more effectively and to benefit from regular flows of income (Abass et al., 2014). Hermetic storage technologies, such as metal silos, when managed correctly, hold strong potential for contributing towards farm household food and income security needs (Gitonga et al., 2015).

Beyond these significant benefits, growing understanding that households are not necessarily altruistic units working to maximize benefits for all members, but rather 'small open systems' (Bevan, 2004) which exhibit both cooperation and conflict (Sen, 1990) have led to important research insights. For example, a study conducted in Zimbabwe suggests that women in male-headed households deploy their agency in a variety of ways to maximize their access to stored maize grain. This involves facilitating, manipulating, managing, and strengthening relationships within their household, and using grain to foster wider kinship networks and friends (Manda and Mvumi, 2010). Mutual exchange and social reciprocity networks can be important survival mechanisms (Neves and Du Toit, 2013). This is all the more important for women, who generally rely much more on bonding social capital - informal connections to family, kin and friends, than do men who more often are able to access bridging and linking social capital - connection with people in power and to formal institutions (Perez et al., 2015).

The need for effective grain storage technologies is urgent. Stored grain - including maize, the focus crop in this article - can suffer significant losses due to insect pests, including the maize weevil (*Sitophilus zeamais* Motschulsky*)*, the larger grain borer (*Prostephanus truncates* Horn*)*, the angoumois grain moth (*Sitotroga cereallela* Olivier*),* and the lesser grain weevil (*Sitophilus oryzae* L.*)* (Tefera et al., 2011). Ear and kernel rot, caused by a variety of fungi, can cause serious losses. The incidence of pest attack on stored grains is also linked to mycotoxin contamination and poisoning (Tefera et al., 2011). Other pests include rodents and their predators - snakes. PHL are notoriously difficult to measure (Hodges and Maritime, 2012) and estimates vary widely. For instance, one study estimates that poor post-harvest management in sub-Saharan Africa leads to 14%–36% losses of maize grain (Tefera, 2012). Another study suggests annual grain losses of up to 50% in cereals and 100% in pulses with average losses estimated at roughly 20% (Nukenine, 2010). Respondents to a Kenyan study consider they lost on average 40% of their grain during storage in traditional granaries (Midega et al., 2016). A study on post-harvest losses across seventeen crops in semi-arid parts of Central and Northern Tanzania indicates that losses occur in the field (15%), during various forms of processing in the field, at the homestead (13–20%), and during storage (15–25%) (Abass et al., 2014).

Other studies produce lower PHL estimates. A World Bank study, based on data from the African Postharvest Losses Information System (APHLIS), estimates grain losses between 10% and 20% in sub-Saharan Africa (Zorya et al., 2011). Based on the same data, losses in maize without large grain borer infestation in grain or cobs typically amount to 4%–5% (Hodges and Maritime, 2012). They are substantially higher with large grain borer infestation. Another study, based on nationally representative surveys in Malawi, Uganda and Tanzania, estimated on-farm PHL to comprise between 1.4% and 5.9% of the national maize harvest (Kaminski and Christiaensen, 2014). Finally, a meta-analysis of existing studies (published and grey literature) in six sub-Saharan countries concluded that average losses in cereals (maize, rice) amount to 25.6% ± 27.4% without any intervention; however, these could be decreased to about 5.6% ± 5.4% with appropriate interventions (Affognon et al., 2015).

Maximizing the efficacy of grain storage systems provides an important contribution to stemming PHL. The technical focus of this paper is on metal silos. These are simple cylindrical structures constructed from a galvanized iron sheet and hermetically sealed. A metal silo must be airtight so the oxygen is replaced with carbon dioxide. This kills insect pests and locks out other pests and pathogens. Metal silos hold between 100 kg and 3000 kg of maize grain and can store maize for up to three years. Pesticides do not need to be applied, reducing farmer costs and benefiting human health given that recommendations on safe use of pesticides are often not followed adequately (Tefera et al., 2011). On-station experiments have shown that metal silos and hermetic bags are very effective in the control of maize weevils. Unlike hermetic bags, metal silos cannot be perforated by the larger grain borer (De Groote et al., 2013). Adoption studies of hermetic technologies are promising. A survey of metal silo adopters in Kenya found that they stored maize for two months longer and were more food secure than other farmers (Gitonga et al., 2013), and an impact evaluation of a World Food Programme initiative in Uganda found that farmer incomes increased by around 30% when they had been trained in improved post-harvest handling techniques and used subsidized hermetic grain storage technologies, including medium and large metal silos. These reduced post-harvest losses by 98% (Costa, 2015; FAO et al., 2019). However, the same study found that initial investment costs for metal silos present a significant barrier to adoption, as it can take farmers up to seven years to pay back the initial investment cost (Costa, 2015). Finally, appropriate post-harvest management practices, in particular effective drying, is a pre-requisite to the successful use of hermetic storage technologies like metal silos (Walker et al., 2018).

This article aims to deepen understandings of gender dynamics in post-harvest storage in Kenya, Malawi, Zambia, and Zimbabwe. The purpose is to see whether modern storage structures provide equal benefits to women and men farmers. We hypothesize that existing gender norms differentially influence the ability of women, in particular, to secure such benefits. We reflect upon the implications of our findings for the future development and dissemination of storage structures, and more widely on the implications of our findings for global goals around securing food security.

The article is structured as follows. We first provide an overview of research on gender dynamics in post-harvest management and storage in our target countries. This context allows us to consider the ways in which gender relations configure how technologies and management are managed, and the ways in which women and men secure benefits. This is followed by an explanation of the mixed methods research methodology and a short site description. Our results focus on findings in relation to cultural norms in relation to post-harvest storages, gender dynamics of grain storage in metal silos, gender differences in how metal silos are managed and how the attributes of metal silos are viewed, and finally how men and women perceive their "ideal" storage facility.

2. Background

2.1. Gender dynamics in post-harvest management

Technologies and management practices to improve post-harvest management often focus on technical solutions. However, it is increasingly accepted that a better understanding of gender dynamics - including women's ability to invest in technologies, gendered processes in knowledge development, gender roles and responsibilities, gendered intra-household decision-making processes, and a deeper understanding of the shifting cultural norms which underpin gender dynamics - is necessary if improved technologies are to be adopted at scale (Badstue et al., 2018; Lusiba

et al., 2017).

Post-harvest management systems in Sub-Saharan Africa can underperform because women lack sufficient assets and opportunities to access technologies and services to help them better manage the process from field to product transformation (Affognon et al., 2015). A visible testimonial of the gendered nature of these inequalities is the way in which, in many locations, women can still be seen head-loading crops, whereas men and boys have long graduated to transport like bicycles and oxcarts (FAO et al., 2019). Women frequently have weaker access to financial services and credit than men, hampering their ability to make post-harvest investments (FAO et al., 2019). Farming women are generally less likely to be members of production and marketing organizations and are less likely to be reached by the rural advisory services. This can limit their capacity to learn about new post-harvest technologies (FAO et al., 2019). In Kenya, awareness of how to manage storage pests can be correlated with higher levels of education and farming experience (Midega et al., 2016). However, women are pgzr often less well reached than men by the rural advisory services (Manfre et al., 2013). This is part of a wider, often unremarked cultural bias whereby rural actors, including the rural advisory services, researchers and policy makers, may face a 'conceptual lock in' regarding who the 'real' farmer is (Farnworth and Colverson, 2015). Conceptual lock in refers to the idea that when men are normatively viewed as main farmers and decision-makers, it appears 'logical' to primarily target men for technology dissemination and training. Women, who do in fact farm, regularly complain that men rarely pass this information to them (Totobesola, 2017). A study in Ethiopia found that women are not often invited to agricultural technology-related trainings and, when the husbands attend, the exchange of technical information to their wives is limited (O'Brien et al., 2016). Women may also struggle to balance time-consuming competing tasks: to a greater degree than men women are involved in a 'zero-sum game', a closed system in which time or energy devoted to any new effort must be diverted from another activity (De Schutter, 2012). As a consequence women's labour can become fragmented, potentially resulting in reduced efficiency and effectiveness regarding their ability to manage post-harvest tasks (Totobesola, 2017). This can have psychological effects as well. For instance, women in Burkina Faso, due to a combination of limited time, weak access to improved technologies, and low participation in intra-household decision-making, often simply lack motivation to improve their post-harvest management practices (Sawadogo-Ouedraogo et al., 2017). Constraints at the level of self-esteem may hamper women's willingness to invest. A Nigerian study found that cultural norms construct women farmers as ineffective and subordinate to men (Enete and Amusa, 2010), and in Ethiopia, cultural norms identify farmers with ploughing – which is almost exclusively conducted by men – serving to negate women farmers as farmers, which in turn affects the perceptions of value chain actors, rural advisory services, and others and thus influences targeting strategies (Gella and Tadele, 2015).

At the same time, women farmers try to deploy their agency to maximize outcomes in their favour. Research in Zimbabwe, for instance, shows that normative gender roles in stored grain management and marketing were present in all case study households (Manda and Mvumi, 2010). However, women engaged in subtle bargaining and strategizing to exercise their personal control over stored maize. Their success depended on their ability to mobilize and manipulate existing degrees of cooperation between women and men, and between women, in the household. There was also a temporal dimension. Men bargained more strongly with women immediately after harvesting since they wished to sell maize in bulk so as to purchase large assets, whereas women dominated bargaining and sales at mid-season, as this is the time when women must meet urgent household needs. Some strategies at first glance appeared counter-intuitive. For instance, some women opted to pay farm labourers in grain at mid-season, thus reducing their potential future income from sales. However, the goal of improving food security from a variety of crops (grown with the assistance of hired labour) later in the year trumped immediate cash needs. Overall, the study found that women are more concerned with issues of household food security than men, and that women deploy their bargaining power to ensure that they and the children are food secure. Women are also more likely to signal warnings of store depletion earlier than men (Manda and Mvumi, 2010). Other studies similarly highlight women's concerns with ensuring household food security. Cash cropping was found to have a negative influence on per capita food availability in male-headed but not female-headed households (Kiriti and Tisdell, 2004). Per capita food availability in FHH rises with increased agricultural commercialization but not in male-headed households because men are more likely to spend income on their own needs than on family food requirements. It is indeed widely documented that women are more likely to ensure family food security than men, though of course some men are strongly interested in providing for the family's food needs (Bertelli and Macours, 2014; Brody et al., 2015; Chirwa et al., 2011; Hyder et al., 2005; Ragasa et al., 2019).

Ethnic community can also play an important role in how storage assets are acquired and managed. A study in Zimbabwe (Chingarande and Kandiwa, 2015) researched Zezuru and Korekore households and found that among the Zezuru the entire homestead - and the traditional granary, the *dura*, with its contents - belongs to women, whilst among the Korekore only the kitchen can be owned by women, with men owning the *dura*. An examination of intra-household dynamics indicate there is no simple correlation between asset ownership and decision-making: men's decisions with regard to post-harvest management are final in both ethnic communities, though Zezuru women have a stronger say than Korekore women. At the same time, the degree of women's ability to participate in decision-making shifts over time and space, depending on the crop, type of asset, and decision to be made. Women need to negotiate with men in order to secure monies to invest in storage systems (Chingarande and Kandiwa, 2015).

3. Materials and methods

The current study was conducted under the Effective Grain Storage Project (EGSP), which had three goals. The first was to promote post-harvest technologies such as metal silos and hermetic bags, and to support testing and promotion of these technologies through targeting, training, demonstrations, and documentation. Second, the project aimed to foster the development of a strong private sector-led post-harvest technology market through capacity building and support, particularly by training artisans to build metal silos (Ndegwa et al., 2015). Third, the project engaged in policy research and dialogue. The first phase (2008–2010) promoted metal silos and targeted Kenya. The second phase (2012–2015) promoted metal silos and hermetic bags in Kenya and Malawi, and it initiated activities in Zambia and Zimbabwe.

Sheet metal artisans were identified in each country and were trained on how to make the silos. They were provided with tools and some capital, and were given initial orders to get them started in the business. The first silos were provided free to groups and community leaders. Later, a subsidy was provided to promote the silos, and by the end of the project all silos were sold at commercial rates. In total, EGSP distributed 1717 metal silos across the four EGSP countries (Table 1). Nearly half of the metal silos (48%) were distributed in Kenya and the remainder in Malawi (18%), Zambia

Table 1
Provision of metal silos by the Efficient Grain Storage Project (EGSP).

Country	Men	Women	Gender disaggregated data not available	Institutions	Faith-based and self-help groups	Totals	Percentage by country
Kenya	213	309	229	57	13	821	47.8%
Malawi	130	84	62	7	20	303	17.6%
Zambia	230	102	–	10	15	357	20.8%
Zimbabwe	157	73	–	6	–	236	13.8%
Overall	730	568	291	80	48	1717	
	42.5%	33%	16.9%	4.8%	2.8%	100%	

(21%) and Zimbabwe (14%). The recipients of the silos ranged from individual farmers, to institutions, self-help groups and faith-based organizations. Most of the silos went to individual farmers: men (42.5%) and women (33%).

3.1. Quantitative research

Quantitative research consisted of household surveys, both baseline surveys and surveys of households who had adopted metal silos, in Kenya (Gitonga et al., 2013) and Malawi in 2011 (unpublished data) (see Map in Fig. 1 for the sites). The purpose was to assess the use and impact of metal silo storage technology on farmer livelihoods to guide the project in its scale-out efforts. They aimed to help the project understand different aspects of existing traditional and new storage technology ownership, metal silo use efficiency, and other factors affecting the utilization of improved post-harvest technologies.

In Kenya, no specific baseline survey was conducted as another household survey, conducted for another project in 2010, could be used (Gitonga et al., 2013). For the adoption survey, a list of 124 metal silo owners was compiled, of whom 59% were clustered in Migori and Homa Bay counties (Western Kenya) and 41% in Embu County (Eastern Kenya), so these counties were maintained for the quantitative survey. In Malawi, the baseline survey was conducted in Dowa and Dedza districts, which were purposively selected due to their geographical position covering all three agro-ecological zones in Malawi: the high, mid and low altitude zones. Seven extension planning areas (EPAs) were selected for the baseline survey, three in Dowa and four in Dedza. One or more villages were selected in each EPA, all households in those villages listed, then six households randomly selected from each village. In total, 30 villages were covered resulting in a sample of 180 households (Table 2). For the adopters survey in Malawi, because only few farmers had acquired metal silos in the first phase of the project, all farmers with metal silos who could be identified - 100 in total - were interviewed, 93 men and 7 women. These adopters were all found in two districts: Lilongwe and Mchinji. The data covered in the survey included households' socioeconomic and demographic characteristics, maize production, storage and sale behaviour, silo usage, and farmer assessment of the technology.

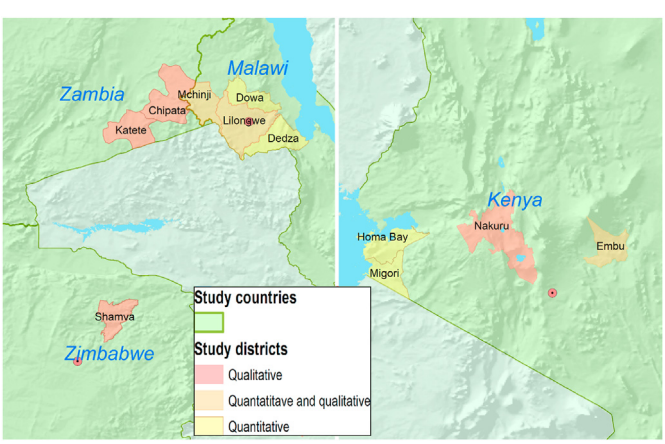

Fig. 1. Map with districts selected for quantitative and qualitative research.

Table 2
Sample design of metal silo adopters survey in Malawi.

District	AEZ	EPA	Villages	Households
Lilongwe		Mpenu	18	25
		Nyanja	6	15
	Mid Altitude	Demera	3	3
		Chitsime	3	7
		Mlonyeni	5	26
Mchini		Chiopsya	1	1
	Mid Altitude	Kalulu	7	20
		Msitu	2	3

3.2. Qualitative methods

Qualitative research was conducted in 2014 in Kenya, Malawi, Zambia, and Zimbabwe. Study sites were purposively selected based on the intensity of exposure to improved post-harvest storage technologies. Four detailed country reports and additional unpublished data provide the qualitative data used in this article: Kenya (Nzioki and Kandiwa, 2015), Malawi, Zambia (Mulunga and Kandiwa, 2015) and Zimbabwe (Chingarande and Kandiwa, 2015). The study covered eight districts in four countries and 14 ethnic groups (Table 3). In each country, data were collected by a team including a team leader and four women and four men research assistants with local language skills, which facilitated probing, data capture and transcriptions.

Empirical qualitative research was structured according to the steps farmers take in post-harvest management. The research team built on a four step diagnostic framework (Rugumamu, 2009): field work, transport, homestead work and actual storage and use, and added another step (which became the first step): storage construction and maintenance of traditional storage structures. This was included to help the project understand existing gender roles and responsibilities around storage, and to see if and how these changed when metal silos were introduced.

Table 3
Qualitative research sites and ethnic community of respondents.

Country	Region/district	Ethnic community
Kenya	Embu	Aembu, Mbeere
	Naivasha	Agikuyu, Maasai
	Nakuru	Agikuyu, Kalenjin, Kisii, Luo, Luhya, Maasai
Malawi	Lilongwe	Chewa, Ngoni
	Mchinji	Chewa,
Zambia	Chipata	Chewa, Ngoni, Nsenga
	Katete	Chewa, Ngoni, Nsenga
Zimbabwe	Shamva	Shona, Korekore, Zezuru

Table 4
Overview of qualitative research instruments and respondents.

Characterization and Purpose	Number of fieldwork exercises conducted				Total
	Kenya	Malawi	Zambia	Zimbabwe	
Gender-disaggregated Focus Group Discussions (FGD)					
Respondents: maize farmers	13	6	18	8	45 FGDs: 360 respondents
➢Gender norms in the farming systems					
➢Gender roles in post-harvest management					
➢Gender in relation to improved post-harvest storage technologies					

Step 1, construction and maintenance, includes structure design, sourcing materials such as reeds, timber, and bricks, and building the structure including brick laying, thatching, and plastering. The second step, field work, involves cutting the maize plants, stoking the plants, de-sheathing, and piling in preparation for transport. The third step, transportation, involves moving the cobs to the homestead by carrying or other means. The fourth step, homestead work, entails drying and grading of cobs; shelling, drying, winnowing, grading, and applying pesticides. The final step is storage and utilization. This involves loading grain into the storage structure; bagging and stacking bags in rooms within homes; retrieving grain for re-treatment with pesticides to maintain quality; and retrieval for home consumption or sales.

Table 4 summarizes the research instruments and number of respondents. In total, 45 gender-disaggregated Focus Group Discussions (FGD) were conducted with maize farmers - 360 participants with roughly equal numbers of women and men. The FGDs had three modules. The first included traditional cultural and gender norms, agricultural farming systems and general post-harvest loss assessment. The second focused on gender roles in post-harvest management; post-harvest storage technologies and practices; post-harvest storage technologies ownership and management strategies; community storage. The third module addressed gender in relation to improved post-harvest storage technologies, preferences, and access to information; and the effectiveness of improved PH technologies.

We also conducted 62 Key Informant Interviews (KIIs) with men and women, including local extension workers, traditional leaders, local political leaders, government and non-governmental representatives. The objectives were to deepen understanding of cultural norms, post-harvest management and gender roles; gender and technology adoption, ownership and management of technologies; technology preferences; access to information; effectiveness of the improved post-harvest technologies. Finally, we conducted 29 household case studies in farming households that had adopted metal silos. We interviewed the head of household and the spouse separately, including the senior and second wife in four polygamous households in Zambia, leading to 62 respondents in total.

3.3. Site description

Agriculture is the key form of livelihood for all respondents in all study sites (Table 5). In Kenya, maize is grown by both men and women for home consumption and sale, whilst beans are grown by women for household consumption. Other cash crops include coffee, tea and dairy. In Malawi, tobacco and maize are mainly grown by men for cash, while groundnuts are grown by women for cash and household consumption. In Zambia, beans and groundnuts are grown by women for household consumption, whilst maize and cotton are the main cash crops, grown by men. In Zimbabwe, maize, tobacco and cotton are cash crops grown by men, while women grow maize and sweet potatoes for household consumption. It should be noted that women in all countries provide considerable labour on all cash crops managed primarily by men.

Locally developed post-harvest storage technologies are common. They are generally fashioned with simple tools and low-to zero cost materials, though their construction requires expertise (Table 6). In Malawi and Zambia, the *nkhokwe*, a stand-alone woven structure, is commonly used for maize cob storage. Nkhokwe are made from grass, small wooden poles, and bamboo. In Zimbabwe, the *dara* (crib) is often used for drying maize cobs before they are shelled and stored in a *dura*, a traditional granary made out of brick and plastered with cement or mud (or a mixture of the two), and then cow dung to repel insects. Roofing is usually made of grass thatch. In Kenya, women construct stores called *gala*, and different ethnic communities may use their own specialized storage technologies. In all countries, polypropylene bags are increasingly popular for maize grain storage. They are usually stacked in bedrooms or other rooms in the house due to the risk of theft.

The metal silo was the least used maize storage technology at the time of the study. This is despite the fact that EGSP household survey data from Kenya (Gitonga et al., 2013) and Malawi (unpublished data) shows that metal silos have been in use for the last twenty years. In Kenya, the data indicate a five year time lag between the time men started owning silos (1995) and when women reported doing so (2000). In Malawi, men reported owning metal silos from 2003 whilst women first reported owning metal silos in 2008 - again a five-year gap. In both countries, many more men than women own metal silos.

Table 5
Main cash and food crops in qualitative research sites.

Country	Main Cash Crops	Main Food Crops	Comments
Kenya	Maize, coffee, tea, dairy	Maize, beans, sweet potatoes.	• Maize is grown by both men and women, for home consumption and market. • Beans are grown by women for household consumption.
Malawi	Tobacco, maize and groundnuts	Maize, beans and groundnuts.	• Tobacco and maize is mainly grown by men for cash. • Groundnuts are grown by women for cash and household consumption.
Zambia	Maize, groundnuts and soybean	Maize, beans and groundnuts.	• Beans and groundnuts are grown by women for household consumption. • Maize and cotton are cash crops for men.
Zimbabwe	Maize, cotton and tobacco	Maize, beans, groundnuts, and sweet potatoes.	• Maize grown by men for sale. • Women grow maize and sweet potatoes for household consumption. • Tobacco and cotton are cash crops for men.

Table 6
Common Maize Storage Technologies in EGSP Countries (qualitative study).

Countries	Storage Technologies
Kenya	Traditional granary - including *gala*/round-bottomed crib, gunny bag, storage over fire/smoke (for maize seed), baskets and large pots.
Malawi	*Nkhokwe* (traditional granary), hessian sacks/bags, baskets and pots, storage over fire/smoke (for maize seed).
Zambia	*Nkhokwe*, sacks and bags, mud and cement plastered baskets, brick bins, *ferrumbu* (improved storage bins).
Zimbabwe	*Dara* (crib), *dura* (traditional granary), bags.

4. Results

4.1. Cultural norms and gender roles in post-harvest technologies

In this subsection, we use qualitative survey data to investigate gender roles and responsibilities across all four countries in post-harvest activities and management. The findings indicate that in each country all household members – adult men, adult women, young men, and young women - play important and complementary roles in post-harvest management of maize. Table 7 provides an overview of the first three steps (from construction to transport) and Table 8 depicts the last two steps (homestead work and storage and utilization). In most cases different tasks within a particular step are further gender-disaggregated and gender-sequential. The exact combination differs according to gender and cultural norms in each location, the degree of market or subsistence orientation of each household, and its grain storage requirements. In this section, we discuss step 1 (storage construction) and step 5 (post-harvest management of the grain).

In step 1, the construction of traditional storage technologies such as the *dura* among the Zezuru and Korekore in Zimbabwe, and the *nhokhwe* among Ngoni in Malawi, demonstrate how intertwined gender roles can be (Table 7). To build the *dura*, adult women locate and cut grass for thatching, fetch water for moulding bricks, and plaster the inside and outside of the *dura* with mud or cow dung. Young women bring additional water and grass, and young men bring timber and cow dung. Adult men locate and cut thin long straight timber for thatching. They spend a long time scanning local forests in order to select appropriate wood which must be malleable and resistant to insect damage. Men also design the *dura*, lay the bricks, and thatch. To construct *nhokhwes*, adult women fetch reeds and men weave them into sophisticated granaries. In Kenya, Maasai women construct and manage granaries without male assistance, whereas in other ethnic communities in Kenya men are primarily responsible for construction, with women performing similar tasks to those described for Malawi and Zimbabwe.

Moving forward to step 5, grain treatment and protection from insect damage before and during storage also demonstrates a relatively complex gender division of labour. In Shamva, Zimbabwe, for instance, adult women, young women, and young men locate and gather dry eucalyptus leaves. Adult women burn these leaves to make ash. For small quantities, women mix the ash and maize. However, when large quantities of maize are involved, men mix the grain with the ash (or inorganic chemicals). In most locations men are responsible for buying and applying storage pesticides such as Actellic dust (active ingredient pirimphos-methyl, a broad spectrum organophosphate pesticide). In all four countries most FGD respondents considered that women lack knowledge on application rates, and many women did not want to apply Actellic dust because they feared being blamed if insects nevertheless attacked grain whilst in storage. In Malawi, respondents believed Actellic dust can damage a women's womb. Respondents in Kenya made a similar point, but noted that since women are increasingly taking on men's roles in farming women are now purchasing and applying chemicals including Actellic dust. In all locations, women remove stored maize regularly from storage, re-dry it, and apply purchased chemicals or various forms of ash before replacing it in the storage.

Table 7
Gender roles across post-harvest management – Preparation and transport.

	Kenya	Malawi	Zambia	Zimbabwe
1. Traditional Storage Technology Construction and Maintenance				
Sourcing of Materials	Men, women, youth	MenFHH hire men	Men and boys, FHH	Men, women, youth
Building and Thatching	Men (except Maasai)	MenFHH hire men	Men, boys, FHH	Men
Plastering	–	–	–	Women and girls
2. Field				
Cutting Stalks	Men, women, and youth,Maasai: women and youth	Men, women, boys	Men, women and youth	Zezurus: women, men, youthKorekore: women and youth
Heaping or Stooking	Men, women, and youthMaasai: women and youth	Women and girls	Men, women, and youth	Women and youth
Removing Cobs from stalks	–	Men, women, youth	–	–
Dehusking	–	Men, women, and youth	Women	Men, women and youth

3. Transportation				
Headloading, buckets or sacks	Men, women, youth	Women and girls	–	Women
By wheelbarrow	–	–	–	Men and women
By scotch/ox carts	Maasai - youth	–	–	–
Loading	–	Men	Women	Men and women
Transporting	–	Men	Men and boys	Men and boys
Offloading	–	Women	Women	–

Table 8
Gender roles across post-harvest management – homestead and usage.

	Kenya	Malawi	Zambia	Zimbabwe
4. Homestead				
Drying	Women	Women	–	Women, girls
Checking moisture	–			HH
Shelling				
Hand	–	Women communally, payment by *zisononkho* (empty cobs used as fuel)Men if paid in cash or for fundraising	Men, women, youth	Women, youth
Sticks	Maasai and Kalenjin women	Communally	–	Men, boys
Machines	Men, youth, Maasai: youth	–	–	Men
Winnowing				
Traditional trays	Women, youth	Women	Women	Women
Machine, sieves	Men, youth	Men	–	–
Grain Treatment				
Sourcing materials, making ash	Women	–	–	Women, youth
Ash application	Women	–	–	Women if small quantities Men if larger quantities
Mexican marigold layering	Women	–	–	–
Pesticides, purchase and application	Women	Men	Men	Men
5. Storage and Utilization				
Storage in bags				
Loading	Men, women, youthMaasai: women and youth	Men and boys	Women	Men
Sewing bags	–	Men and boys	–	Men
Stacking/organizing bags	-Men carry bags (90 kg)	–	–	Men
Storage in granary				
Loading	–	Women	–	Men and boys
Smoking of maize cobs for seed	–	Women	–	
Keeping Keys to Granary	–	Women	–	Zezurus women Korekore men
Grain Retrievals	–	–	–	Women with men's knowledge and approval

Post-harvest management is carried out communally in some locations in Malawi and Zambia. Rather than working individually, households pool labour for all PHM processes and move from one household to another. This system is designed to ensure fairness in terms of sequencing activities across various households. Throughout this process, gender roles are usually maintained. For example, only women are involved in shelling by hand and winnowing with traditional baskets or trays. In Malawi, women come together for shelling, and payment is often in kind, typically in the form of left over cobs (*zisononkho)* that are used as fuel for cooking. Malawian men sometimes participate in communal shelling to help raise money for religious causes.

During the qualitative research, the research teams found that women generally deferred final decision-making to men in all study locations. The primacy of men was very clear in Zimbabwe where a *de facto* woman head of household nevertheless explained she had to consult a male figurehead over grain utilization. "Unotanga wasuma, chibage chine zvirango" ("You first of all have to seek permission, maize has protocols to be followed"). When both parents are absent, the most senior male child normatively assumes the role of the household head.

4.2. Gender dynamics of grain storage in metal silos

In this section we first present EGSP household survey data from Kenya and Malawi, disaggregated by household typology, in relation to how recipients are actually using the silos. We then examine access, control and ownership of metal silos and maize through the lens of the qualitative research conducted in all four countries. Using EGSP data, we assess whether metal silo owners in Kenya and Malawi are practicing appropriate management. We combine quantitative and qualitative data from all four countries to explore the respondents' preferred attributes in relation to metal silos.

4.2.1. EGSP household survey data from Kenya and Malawi

In Kenya, the EGSP household survey of metal silo owners showed that households, regardless of the gender of the head, had 11 months of adequate food provision (Table 9). This signals a high degree of food access by metal silo owners. Male-headed households' average annual income (US$5609) was double that of female-headed households (US$2679) yet maize consumption was about the same in both male- and female-headed households. However, male-headed households on average sold four more bags (more than double) than female-headed households. We also see that male-headed households shelled four more bags on average. Both household typologies stored maize for about six months - which in areas with bimodal rainfall is the time it takes for the next harvest to come in. This behaviour might also explain why the difference in quantities stored is about the same. Storage losses from pest damage are very low at below half a percent in both male and female headed households.

In Malawi, the heads of 100 metal silo owning households were interviewed, only 7 of whom were women. We found no statistical differences regarding storage and maize handling behaviour. However, the difference of some variables might have some economic meaning, whilst not being significantly different due to the small sample size of female-headed households. Metal silos are used to store maize both for household consumption and sale, with only small amounts sold right after harvest. Female-headed households filled 66 bags of maize after shelling, eight more than those headed by males. Male-headed households sold on average nine bags immediately after shelling, compared to only two by women. Male-headed households also had an average metal silo capacity of 35 bags compared to 16 bags average capacity by female-headed households. Maize consumption is relatively high in both male and female-headed households, signalling a possibility of maize being put to other uses like making a local brew or being fed to animals. The average annual quantities consumed were

Table 9
Collated preferred attributes of metal silos over other storage technologies according to qualitative study participants.

Attribute	Sub-attribute	Women	Men
Economic	Food Security and Income	• Reduced (or no) grain losses due to moulds/insects/rats • No losses due to theft • Increased income • Increased food security • Saves costs of buying pesticides	• Reduced (or no) grain losses • Increased income • Increased food security • Saves costs of buying pesticides
	Labour and time Savings	• No fetching grass and water • No plastering with mud and or cow dung • No mid-season retrievals • No mid-season winnowing	• No fetching timber • No moulding bricks • No construction • No maintenance • No pesticide purchase and application
Health and Safety	Grain Quality	•No pesticides (including in bedroom) •No weevils, rats, or snakes in the home •No pesticides in bedroom •No children retrieving grain with dirty feet •No pesticides in maize consumed at home	•No chemicals needed
Social	Prestige	• Silo is a big household asset	• Silo is a big household asset
	Household Aesthetics	• Silo is big and shiny and improves the household's appearance	
	Space	• No bags in house, leaving more space for accommodating guests	

365 kg and 471 kg in male-headed and female-headed households respectively, suggesting that female household heads direct considerably more maize to household food security. The percentage of maize storage losses in female-headed households was twice that in male-headed households, suggesting differences in metal silo handling.

4.2.2. Qualitative survey data from Malawi, Kenya, Malawi and Zimbabwe

The qualitative research investigated whether ownership over the granary, and control over the stored maize within, changed when metal silos were purchased. In all four countries cultural norms tend to result in men typically owning all large household assets - such as land, water pumps, ox-ploughs and carts, bicycles and motorbikes, as well as large livestock. They generally take key decisions about how these assets are to be used as well. Furthermore, the income differential between women and men in male-headed households means that it is considerably more difficult for women than for men to make a large purchase like a metal silo. As a consequence of these factors we found men were more likely to own metal silos in each country. The implications differed, though, by ethnic group. In Zimbabwe, Zezuru women, who had previously owned and managed the *dura*, lost control over maize grain reserves when metal silos were introduced. However, for Korekore women nothing changed: men used to be in control of traditional storage technologies and they continued to control metal silos and the maize within. This finding indicates that Zimbabwean women lost out when metal silos were introduced, through either losing control over storage structures, or because male ownership was not challenged. More broadly, most women in all countries were not able to purchase silos.

A common scenario in each country, particularly in monogamous households, is for male household heads to control maize and to dominate decision-making around how much maize to sell and how much to retain for household consumption. This did not change when metal silos were purchased. Some women in all countries reported that although they were supposed to manage maize set aside for household consumption men could still force them to sell this maize for their own needs. The situation is slightly different in polygamous households. Among Luo, Kisii and Maasai in Kenya, each wife has her own maize store. Whilst women cannot access the stores of their co-wives, the husband can access each wife's store. Female household heads tend to exercise similar authority to male heads of household and are generally able to take all decisions around stored maize. However, as noted earlier, this does not always apply in Zimbabwe, and in Kenya Maasai female heads are expected to consult brothers-in-law or older sons on how to manage their stored maize. Since women find it difficult to maintain their claims to maize, several women respondents indicated that they wish to have their own metal silo located in a safe place together with silos owned by other women, rather than locate the silo in their own home.

There were exceptions. Some women who previously owned the household's granary also came to own the metal silo. For instance, a Kenyan couple, which had always equitably discussed how to manage their granary and grain together, continued to do so after they obtained two metal silos through the wife's membership of a woman's group. She had previously owned the traditional maize granary, and she owned the metal silos too, including holding the key. Her ownership did not mean that she restricted her husband's access to maize.

Across all study sites, households adopting metal silos accrued labour savings because it is no longer necessary to construct the traditional granary. Once installed, metal silos save women labour as they no longer need to re-winnow and re-treat grain, and men no longer need to purchase and apply chemicals.

4.3. Gender differences in the management of metal silos

Metal silos are only effective in protecting grain if they are used appropriately. The EGSP surveys conducted in Kenya and Malawi queried whether respondents used candles or lamps to deplete oxygen before closing the silo, whether they used rubber bands to seal off inlets and outlets - both when loading the silo and when taking out grain, and whether they use storage pesticides in the metal silos. The ideal situation is that all men and women follow the necessary procedures that help to maintain hermetic conditions in the silo and that they do not waste resources on purchasing chemicals.

The data shows that in both countries the majority of men and women fail to adhere to optimal management practices and thus fail to maintain hermetic conditions. In Malawi (Fig. 2), 92% of men and 97% of women do not light candles or use lamps after loading the grain. About 77% of men and 71% of women apply pesticides to the grain before loading it in the silos. In Kenya, the patterns are similar: about 79% of men and about 88% of women do not light candles or use lamps. However, they use fewer pesticides with about 47% of men and 41% of women applying chemicals. Despite

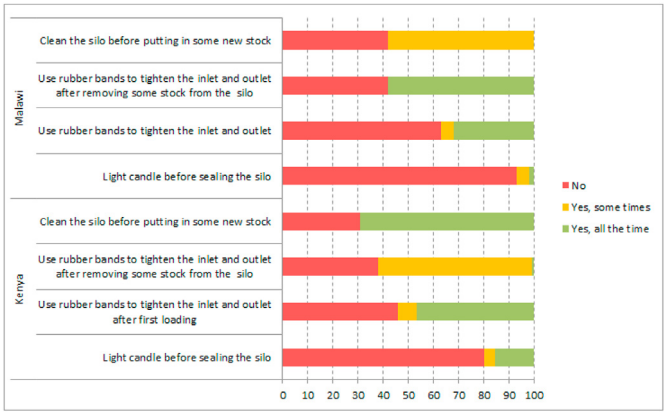

Fig. 2. Use of recommended practices with metal silos in Malawi.

the large numbers of extension workers and farmers trained through the EGSP, both men and women in Kenya and Malawi are not following good practices for grain storage in metal silos.

4.4. Gendered differences in perception of metal silo attributes

In the qualitative research, women and men were asked which attributes they valued in metal silos as compared to other storage methods. The findings show their preferred attributes can be classified according to three dimensions: economic, health and social attributes (Table 10). Regarding economic benefits, men and women appreciated the reduction in post-harvest losses as this increased their food security and income. Respondents noted that planning how to use maize has become more feasible, in particular with respect to long-term planning on when to sell maize and ensure benefits from higher prices. This is particularly important as it allows households to sell maize during the planting season when money is needed for agricultural inputs. Income flows into the household have also become more regular. Labour savings accrue to men and women differently due to their different gender roles. As was shown in the previous sections, women and men have different and time-consuming roles for granary construction and maintenance. Women in particular appreciated the fact that metal silos eliminate many of their activities associated with these roles, providing them with more leisure or time for other activities.

Turning to health, both women and men highlighted the fact that reduced use or elimination of chemicals is beneficial, although only women mentioned that this also benefits their children's health. Women further argued that metal silos improve their personal safety. When maize bags are stored in the house, including bedrooms, snakes may enter seeking prey such as rats. Women also feared human thieves, who sometimes enter the house, including the bedroom, to steal maize. Metal silos are not accessible to rodents - or people without a key.

Regarding social benefits, both men and women stated that metal silos were big household assets which confer prestige and pride on the household and its members. Women highlighted other positive aesthetics. For instance, when metal silos are located in the kitchen, they improve the overall look of the room since they are big and shiny. Many women added that an end to storing maize in living rooms and bedrooms frees up space for hosting visitors.

To deepen our understanding of which attributes are important to farmers, EGSP respondents in Kenya and Malawi were asked to share their opinion on eight attributes related to the design and operation of storage technologies. These attributes included effectiveness against pests, in particular insect pests and rodents, cost of purchase as well as cost of maintenance, safety and security, ease of operation, lifespan, and availability. For each attribute, respondents were asked if it was very important, important, of medium importance, or slightly important.

The results for Kenya (Fig. 3) and Malawi (Fig. 4) show that effectiveness against pests and rodents, cost, and safety and security (i.e. freedom from fear of theft and thieves), are very important to both men and women. Availability and lifespan are valued to a lesser degree. Women in both Kenya and Malawi, to a greater degree than men, prefer technologies that are easier to operate. The order of importance, however, varies between the two countries.

In Kenya, the three most important attributes, for both men and women, are effectiveness in controlling insect pests, safety/security, and efficient control of rodents. For each of these attributes, 10–15% more women than men give these attributes the highest score, "very important". The next attributes, in order of importance, remain the same for men and women. Men provide higher scores than women to lifespan, costs, ease of operation and availability.

In Malawi, gendered perceptions of the relative importance of attributes are more pronounced. For both groups, safety and security is the most important, but for women this attribute is followed by ease of operation, availability and lifespan. More women than men (10%–20%) give them the maximum score, "very important". For men, after safety/security, the next most important attributes are costs (both for purchase and maintenance) and effectiveness (against insects and rodents). Costs are less important for women than for men in Malawi. This may be because men are more likely to have purchased the silo.

Table 10
Suggestions by qualitative study participants for improving metal silo design.

Attribute	Women	Men
Cost	Low cost	Low cost
Durability	High	High
Size	Mixed - Some small; some large	Large
Height	Short	Tall
Locking System	For security and control of retrievals	For security and control of retrievals
Calibration	Window that shows levels of grain for control and accountability	Window that shows levels of grain for control and accountability
Retrieval	Legs on silo so that nozzle is not too close to the ground Tap mechanism	–
Cleaning	Easy to clean	–
Installation Ease	No need for destroying existing wall structures of a house	–
Compartments	For multiple grain storage. Malawi and Zimbabwe – groundnuts; Kenya - green grams and beans For storing grain belonging to different household members	–

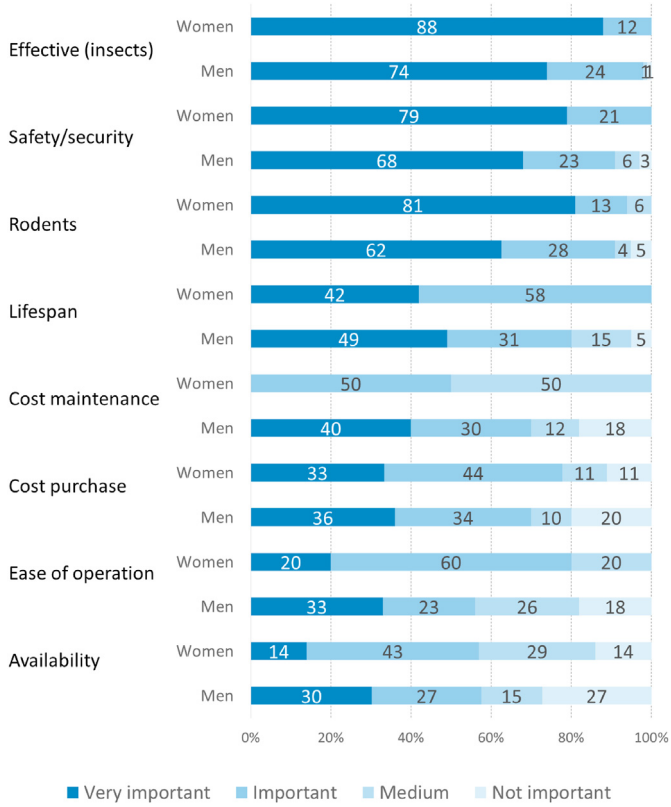

Fig. 3. Attributes that are important in the choice of storage technology in Kenya, by gender.

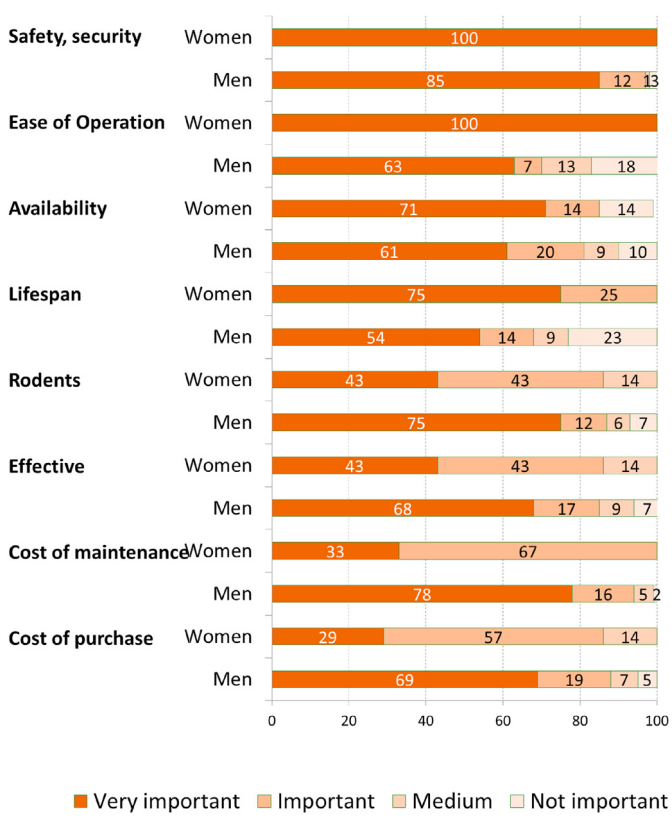

Fig. 4. Factors that are important in the choice of storage technology in Malawi, by gender.

4.5. Gendered perceptions on an ideal maize storage technology

Qualitative survey respondents were asked in FGDs to share their thoughts on what an ideal storage technology would look like. Two open-ended questions were asked: *'If you were to design an improved post-harvest technology that could meet your needs, what would it look like? What design attributes would it have?"* We have categorized their preferences into ten attributes (Table 10). These are: cost, durability, size, height, locking system, calibration, retrieval, cleaning, ease of installation, and compartments.

For both women and men, the ability to lock the silo is important. This is to prevent theft. Women also stressed the importance of having a window so that they can track what is happening to the grain. They want to have oversight over the rate and amount of grain depletion. Women were very concerned that men may sell maize without consultation. Having a window, they argued, would help women to force some accountability upon their husbands, and it also allows women to plan household food security needs better. Men considered that the metal sheets used to manufacture silos are very light and are easily damaged. They suggested using thicker metal. In Kenya, one man suggested that portable drier and moisture testers be supplied so they can be sure the maize is dry before it is stored. Regarding grain retrieval, both women and men wanted the opening at the bottom of the silo to be a tap which can open and close safely. The floor of the silo should slope so that the maize can flow out instead of having to be scooped out using one's hands. Respondents also wanted the silo to be raised on a platform or legs.

Beyond this, respondents requested a wider variety of shapes and sizes, ranging from silos that are easy to fit within a house to ones that can stand outside. Women in particular requested a range of sizes for different crops and purposes. In Kenya, the majority of women wanted six bag capacity metal silos for storing maize, two bag capacity for storing beans, and one bag to store flour for home consumption. Some women suggested that a single silo could have compartments with different chambers for different purposes. In general, women want shorter, wider silos which are easier to load. Women explained that since they wear dresses, skirts and *kitenges* (fabric wraps) it is considered immodest to climb onto stools to load the tall silos. The alternative is to call for male assistance, which they do not want. Men express very different preferences for silo shape to women. They typically argued for tall thin silos with a capacity of six to thirteen bags, so that all the grain is in one place. A few wanted a silo able to store 20 bags to allow them to store maize until the next harvest. This would enable them to have maize ready for sale when market prices were at their highest. Finally, men and women asserted that metal silos are too expensive at about $200 for a silo for 900 kg grain. They need credit facilities, tailored to the needs of women, men and young women and men, to buy them.

5. Discussion and conclusion

Our literature review showed that maize post-harvest losses in smallholder farming systems in Sub-Saharan Africa result in significant costs at household and national level. This makes it difficult to move towards achievement of SDG2, Zero Hunger. Effective grain storage technologies have the potential to contribute towards this goal through a number of synergetic outcomes: strengthening food security, reducing losses, boosting smallholder farmer incomes and livelihood portfolios, and contributing to overall wellbeing, including through reducing drudgery and exposure to pesticides.

Our research was aimed at understanding whether modern storage structures such as metal silos provide equal benefits to women and men farmers. Our literature review suggested this is important because women are, more than men, culturally tasked with putting food on the table in our target societies. We also found

that women require access to maize to meet a variety of goals important to them. Our hypothesis was that existing gender norms may differentially influence the ability of women to benefit from the introduction of metal silos.

Our findings show that women and men, traditionally, exercise complex and complementary roles in the construction and maintenance of storage structures. Women exercise more, or less, control over the maize within the structure in different locations. Our findings indicate, however, that when metal silos are introduced, ownership of the grain storage facility and the benefits attached to that ownership typically switch from women to men, or that men's control over stored maize is deepened. Women suggested that this compromised their ability to access sufficient maize because men may insist on taking grain set aside for this purpose to meet their personal needs. We did not measure how much grain is taken and whether food security is indeed negatively affected, but our research registers that women are concerned about this issue.

The expected technical benefits of metal silos are being compromised because few metal silo holders are managing their new structures correctly despite extensive training and outreach. The lack of a hermetic environment compromises the ability of the silo to store maize free from pest infestation. Also, farmers are continuing to use pesticides on the stored grain, potentially endangering their health as well as spending money unnecessarily. There are no significant gender differences in silo management.

Although the management of metal silos is not optimal, women and men respondents agree that they provide significant benefits. They note a reduction in post-harvest losses and a strengthening in their ability to plan over the longer term how to consume and sell maize. They also appreciate the reduction in labour now that they no longer have to spend time building traditional structures. Metal silos are lockable and airtight, keeping out rodents and their predators, and human thieves. Women in particular appreciate this improvement to their personal safety.

When asked to describe their ideal storage facility, women and men agreed that controlling insects and rodents and safety and security are important. Women and men, however, showed strongly different design preferences. Women prefer squat short structures because they are easily accessible whereas men prefer tall thin structures. Women also want windows to track consumption with the aim on monitoring food security and also to try and prevent husbands from removing and selling grain. Both genders agreed that silos were too expensive. Financial constraints certainly appear to reduce adoption, especially by women who tend to have less access to capital and thus have adopted in very low numbers across all study countries.

There are a number of implications. First, understanding gender dynamics is important in order to design and disseminate effective post-harvest technologies that meet gender-differentiated needs and preferences. This suggests a collective, farmer-orientated effort from social scientists, entomologists who carry out on-farm testing, engineers who design alternative post-harvest storage technologies, and other stakeholders with an interest in fostering better and gender-equitable access, need to come together with women and men farmers to co-design improved storage facilities (Murray et al., 2016).

Second, priority should be given to ensure that women have equal access to improved technologies. This is important not only to permitting women to meet their many goals, but also to ensuring that household level food security goals are met, and thus, household by household, move to the goal of zero hunger. As part of this, men need to be strengthened in their role as co-providers of household food and nutrition security (Ambikapathi et al., 2020; Otieno et al., 2016; Ragasa et al., 2019).

Third, metal silos and other expensive structures may not be the best solution. Metal silos are expensive (about $200 for a silo for 900 kg), and are only cost-effective at larger sizes, usually at least one ton, depending on grain prices and expected losses (Kimenju et al., 2009). Attention should be paid to providing a wider range of technologies to appeal to different needs and budgets. Alternative hermetic storage technologies exist, for example hermetic plastic bags which currently sell in Kenya at $2.5 for a 90 kg bag. Indeed, a study on hermetic bag use in Eastern Kenya shows high take up and good practice in maintaining the bags, and shows the particularly strong interest of women in hermetic bags and the need for ensuring women are effectively targeted and trained (Baributsa and Njoroge, 2020).

Overall, our evidence suggests that understanding the social context is important in order to design and disseminate post-harvest technologies that meet the needs and preferences of men and women farmers in various cultural contexts. Social scientists, entomologists who carry out on-farm testing, engineers who design alternative post-harvest storage technologies, all have a stake in fostering improved and gender-equitable access to improved technologies in smallholder farming contexts.

CRediT authorship contribution statement

Cathy Rozel Farnworth: Conceptualization, Writing - original draft, Writing - review & editing, Visualization. **Lone B. Badstue:** Conceptualization, Methodology, Writing - review & editing, Supervision, Funding acquisition. **Hugo de Groote:** Methodology, Formal analysis, Writing - review & editing, Visualization, Project administration, Funding acquisition. **Zachary Gitonga:** Formal analysis, Data curation, Visualization, Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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