Project Title: Postharvest management technologies for reducing aflatoxin contamination in maize grain and exposure to humans in Zimbabwe

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Research Organizations involved in the study: Institute of Food, Nutrition and Family Sciences, University of Zimbabwe and Action Contre la Faim

Location of Study: Shamva district and Makoni district in Zimbabwe

By: Dr. Loveness K. Nyanga, Institute of Food Nutrition and Family Sciences, University of Zimbabwe

and

Charlene Pellsah Ambali, Action Contre la Faim, Zimbabwe

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Executive Summary

Maize is the most important staple food in Zimbabwe. Unfortunately the traditional and conventional practices for storage of maize cannot guarantee protection against major storage pests and pathogens of maize as staple food. This study therefore, sought to investigate the efficacy of hermetic storage technology in reduction of mycotoxins contamination of maize grain and hence, the reduction in exposure of humans to these toxins, in Shamva and Makoni districts of Zimbabwe.

Twelve wards comprising of communal, old resettlement, new resettlement and small-scale farmers were identified as study sites in the two Districts. Five hundred and thirty three community leaders were sensitized on the need to reduce mycotoxin contamination during pre, harvest and postharvest management and hence the reduction of human exposure to these toxins. Interactions with the Ministry of health during the development and implementation of the research project have resulted in inclusion of a component on mycotoxins in the 2015 national survey on rural livelihoods by Zimbabwe Vulnerability Assessment Committee.

Four hundred and seventy five households from the two districts agreed to participate in the research by signing an informed consent. Selected households with women of childbearing age, pregnant and breastfeeding mothers, and children under five years were randomly assigned to the treatment group which was given the hermetic technology (150 households with metal silos and 120 households with hermetic bags), and control group (205 households) which continued using conventional methods for storing maize grain.

Aflatoxin B1 (AFB1) and fumonisin B1 (FB1) levels were determined in maize grain stored in both hermetic and conventional storage vessels for two farming seasons (2014/2015 and 2015/2016). Aflatoxin B1 levels were determined during storage of legumes (ground nuts, bambara nuts, cowpeas and sugar beans). The exposure of women and children to aflatoxins was determined by testing aflatoxin biomarkers, i.e aflatoxin M1 (AFM1) in breastmilk and urine samples, and aflatoxin-albumin adducts from serum samples of women.

Changes in Knowledge, Attitudes and Practices (KAP) were assessed through KAP surveys conducted at baseline, midpoint and endpoint. Gender surveys were also conducted to assess the impact of the hermetic technology on gender roles. In KAP1, when few farmers had knowledge on moulds, 33% of the farmers reported moulds cases in stored grain. However, in KAP2 and KAP3, as knowledge on moulds improved, the proportion of farmers who reported moulds on stored grain increased to 96% and 98%, respectively. In terms of gender, both male and female members of the

households have shown increased collaborative partnerships when carrying out pre and post-harvest tasks at household level –in KAP1 52% of respondents reported that both males and females members of the households take part in drying the maize and this increased to 79% in KAP3. This was also confirmed through the gender midpoint survey which showed a 7% increase in cooperation between spouses. The introduction of the hermetic technology increased workload for processing of maize for storage. However, this has long term benefits of reduced labour and resources for management of grain during storage. However, women's drudgery was generally reduced as there is now greater sharing of tasks such as shelling and loading of grain after the introduction of hermetic technology. All interviewed respondents were willing to purchase hermetic technology using their own money, 75% indicating that they prefer to buy metal silos.

The effectiveness of the hermetic technology (hermetic metal silo and hermetic grain bag) in reducing AFB1 and FB1 in stored maize grain was tested against conventional storage facilities. The results showed that hermetic technology is effective against increase of aflatoxin B1 in stored maize as there were less occurrence and levels of AFB1 in hermetic storage than in conventional storage facilities. The occurrence of AFB1 increased from 0.68 - 8.8%, 0 - 8.2%, and 1.7 - 14.4% in hermetic metal silo, hermetic bags and conventional storage facilities, respectively during the 2014/2015 storage season. A similar trend was observed in the 2015/2016 storage season. The highest mean concentration of AFB1 (86.85±128.18 µg/kg) obtained over the storage seasons was from the maize stored in conventional storage facilities and its 17 times higher than the maximum regulatory limit of 5 µg/kg in Zimbabwe.

In the study, although the levels of aflatoxin exposure to humans increased with increased storage time of the harvested crops, results indicated a lower occurrence and concentration of aflatoxin M1 in the urine samples of women and children from households that used the hermetic technology to store maize grain, as compared to the urine samples of women and children from households that used conventional storage facilities.

An analysis of reduction of economic loss from use of improved post-harvest technologies was conducted between November 2016 and March 2017 in order to evaluate the level of post-harvest losses for farmers using hermetic grain storage technologies and those using conventional storage facilities. The study concluded that hermetic technologies are better than conventional methods and can therefore be used to reduce economic loss due to insect damage. The average weight loss was 6.11% for conventional storage; 3.54% for metal silos and 2.54% for hermetic bags.

2. The Research Problem

Maize is the most important food staple in Zimbabwe, with a highly seasonal production but it is consumed throughout the year. Maize grain is therefore stored to bridge seasons. Unfortunately the traditional and conventional storage practices cannot guarantee protection against major storage pests of staple food crops like maize, leading to 20-30% grain losses, particularly due to post harvest insect pests and grain pathogens (Tefera et al., 2011). Grain losses result in household food insecurity. It is, therefore, essential to come up with good storage methods to reduce postharvest losses in order to improve household food security by bridging the period between the two harvests. This will also stabilise prices by taking produce off the market during the peak season, and releasing it back when the grain is in short supply (Proctor, 1994).

Apart from physical weight losses, pest attack is linked to mycotoxins contamination. Mycotoxin contamination represents one of the most challenging and prominent food safety threats in groundnuts, maize, rice and other grains. In Zimbabwe, testing of harvested maize has revealed significant levels of contamination by mycotoxins (Gamanya and Sibanda, 2001). Mycotoxin contamination makes grain unsafe for food and animal feed. Depending on the level of contamination, food sources may be deemed unfit for human or animal consumption leading to a decrease in food stores, which is an undesirable situation given that world hunger is an issue of concern (Hove et al., 2016). Aflatoxin B1 and fumonisin B1 are two toxicologically most relevant mycotoxins occurring in maize. Aflatoxins are highly toxic to humans and animals and well documented to cause liver disease and cancer, and contribute to immune system suppression. Babies are at risk through their mother's breast milk. In young children, aflatoxins can cause stunting, poor cognitive development, and greater susceptibility to infectious diseases.

Hermetic technology, which involves the use of airtight containers such as metal silos, has been developed and proven to be effective in protecting the harvested grains from attack not only from storage insect but also from rodent pests (SDC, 2008a; FAO, 2008; CIMMYT, 2009a). However, their effectiveness in reducing mycotoxins contamination in grain is poorly understood. Therefore, in the study, we investigated the efficacy of hermetic storage technology in reduction of AFB1 and FB1 contamination in maize grain and hence, the reduction in exposure of humans to these toxins, in Shamva and Makoni districts, Zimbabwe. The research provides reliable and systematic data regarding aflatoxin and fumonisin contamination in maize stocks and exposure in humans in Zimbabwe. It raised awareness on the dangers of eating contaminated grain and importance of improved grain storage to reduce postharvest losses and safety of the grain for food.

3. Progress towards milestones (see Annex 1)

3.1 Analyze changes in knowledge, attitudes and practices (Objective 1)

a. Knowledge, attitudes and practices in postharvest management determined and documented

Baseline, midpoint and endpoint Knowledge, Attitudes and Practices (KAP) surveys, were carried out in Makoni and Shamva districts of Zimbabwe. The objectives of the surveys were to assess changes of farmers' pre and postharvest management practices on maize and legumes after trainings on good pre and postharvest management practices to reduce aflatoxin contamination. A total of 182 females and 176 males were interviewed in the KAP surveys.

- *Output 1 – KAP 3 report. (KAP 1 and KAP 2 reports have been submitted with previous technical reports)*
- *Output 2 – KAP 1 draft manuscript to be submitted to Food Additives and Contaminants Part A Journal (Note that this manuscript was rejected by Journal of Stored Food Products*

The KAP report was reviewed and gaps on gender that required further investigation were identified after which Focus Group Discussions (FGDs) were conducted as baseline gender survey to get in depth information on pre, harvest and postharvest management gender roles. Gender differences, attitudes and practices of pre, harvest and postharvest management were determined and documented.

At midpoint, a quantitative gender analysis survey was done to assess the impact of hermetic technology on gender dynamics especially on the issue of technology ownership and women and men's drudgery. A total of 238 small holders farmers who received the hermetic technology were interviewed from both districts.

After the Midpoint Gender survey, Theatre for Development (TfD) was developed to address some of the challenges that were faced by the communities due to the introduction of the hermetic technology especially ownership of the technology within families. A ToT for Extension officers was done for three days (20 males and 14 females). TfD was then performed through forum theatre to engage the communities in dialogue and come up with their own solutions. The forum theatre dramas were performed with 887 participants (325 men and 562 women) in the two districts in September and October 2016. However, the project intended to evaluate the impact of the forum theatre and conduct gender endpoint survey but it was not possible due to financial constraints.

- *Output 3 – Baseline Gender results published in Gendered Food Practices from Seed to Waste – Year Book of Women's History.*

3.2 Analysis of impact of hermetic technologies on aflatoxin contamination in stored maize completed and documented (Objective 2)

Reduction of aflatoxins in maize stored in hermetic technologies was tested over two farming seasons, 2014/2015 and 2015/2016 seasons. Collection of maize grain samples (1654 samples) and analysis were completed. For the 2015/2016 season, maize grain was collected thrice from the smallholder farmers instead of four times to complete the storage season, due to financial constraints.

The maize grain samples taken from hermetic technologies (and conventional technologies were analysed for aflatoxin B1 (AFB1) and fumonisin B1 (FB1) and the results documented. The impact of the hermetic technologies in reducing AFB1 and FB1 was determined and documented.

- *Output 4 - Baseline results published in Food Control Journal*
- *Output 5 - The impact of hermetic technologies on aflatoxin and fumonisin contamination in stored maize grain manuscript to be submitted to World Mycotoxin World in a special Issue on Mycotoxin in Africa*
- *Output 6 - Factors that influence levels of Aflatoxin and fumonisin in maize in the field to be submitted to Food additives and Contaminants Part B*
- *Output 7 - Mphil Thesis entitled "Effectiveness of hermetic storage vessels in reducing aflatoxin B_1 and fumonisin B_1 in maize grain" Submitted in April 2017 and is under examination.*

3.3 Analysis of impact of hermetic technologies on AF exposure in humans (Objective 3)

Baseline serum samples (238 women serum samples) were analysed at the University of Georgia, Athens, USA in August 2016 and the results were documented. Endpoint blood samples (392 serum samples) were collected in November 2016. The analysis was completed and the results have not yet been released to the project because the services have not been paid for due to financial constraints.

For urine (3248 samples from women and children) and breast milk samples (607 samples from women) quarterly collections were done for the two farming seasons,. Samples for 2014/2015 farming season were collected and analysed. For the 2015/2016 season, only two collection points were done instead of four due to financial constraints.

Anthropometric and individual dietary diversity (IDD) data of 408 women and 200 children under five were collected and analysed for the 2014/2015 and 2015/2016 storage seasons.

- *Output 8 – Manuscript entitled "Determinants of nutritional status in children under three years of age in rural Zimbabwe: the case of Shamva and Makoni districts" was resubmitted to Central African Journal of Medicine after revising using comments from the journal reviewers.*
- *Output 9 – Manuscript for Baseline results on aflatoxin exposure in women and children was submitted to Journal of Maternal and Child Health in January 2017.*
- *Output 10 – Seasonal variation*
- *Output 11 – Mphil Thesis being finalized whilst waiting for appointment of examiners)*

3.4 Longitudinal study on aflatoxin contamination in stored legumes (Objective 4)

A longitudinal study was conducted to determine the levels of aflatoxin contamination during storages. Legume stored samples were collected quarterlyfor the 2014/2015 and 2015/2016 seasons. The total number of legumes samples collected from both districts were 573, 366, 273, and 238, groundnuts, cowpeas, sugar beans and bambara nuts respectively. All these legumes have been analysed for aflatoxin B1, B2, G1 and G2.

- *Output 12 Baseline results accepted for publication in Journal - Food Additives and Contaminants: Part B*
- *Output 13 – Postharvest manangement practices associated with aflatoxins in stored groundnuts collected from smallholder farmer from Shamva and Makoni districts, Zimbabwe to be submitted to Food Additives and Contaminats Part B Journal*
- *Output 14 – A longitudinal study of levels of aflatoxins in stored groundnuts produced by smallholder farmers in Shamva and Makoni districts, Zimbabwe to be submitted to Food Control Journal*
- *Output 15 – Mphil thesis entitled "The effect of storage time on the levels of aflatoxins in legumes produced by smallholder farmers in Makoni and Shamva districts, Zimbabwe" submitted in March 2017 and is under examination.*

3.5 Dissemination of information (Objective 5)

a. Policy makers at national and provincial level and the scientific community are aware of aflatoxins risk and impact of hermetic technologies

As part of the study, and in particular objective 5, the project disseminated relevant information to various stakeholders on post-harvest management and mycotoxins. Dissemination strategies differed according to the targeted audiences.

Five different information products (posters, leaflets, a video documentary, a television programme, conference papers and project posters)were produced to disseminate information on post-harvest management, what the study is about and on laboratory results. .

In addition, the research results were disseminated in April and May 2017 to 82 community members (175 males and 407 females) in the 12 wards in Makoni and Shamva districts Seven hundred pamphlets with research results written in Shona, the local language were also distributed to the communities. Farmers (mainly the research participants), local leaders (chiefs, village heads, councilors), government ward stakeholders (Ministry of Agriculture, Mechanisation & Irrigation Development, Gender Ministry, Ministry of youth, Ministry of Health and Child Care- MoHCC) attended the meetings The research results were also shared with various stakeholders at district and provincial levels (Ministry of Local Government, Ministry of Agriculture, Mechanisation & Irrigation Development-MAMID; and MoHCC) in December 2016 where 48 stakeholders attended .

Due to financial constraints, a national dissemination of results workshop was not conducted. However, results were presented to the MAMID and MOHCC, where some Directors, Policy Makers, Government researchers, Agronomists and Engineers attended the meeting. The results were of great interest to the ministries such that the Ministry directors then invited the CultiAf research project to make a presentation on a future date to be advised to higher management (where all ministry heads of departments will be present) so that a way forward can be mapped on mycotoxins in the country.

Dissemination report (submitted in the previous reporting period)

b. Scientific community is aware of impacts of hermetic technologies on aflatoxin contamination and exposure to humans

Six posters and one video clip (submitted in the last reporting period) were developed and presented at the following regional and international conferences:

- 9th World mycotoxins Forum and XIV IUPAC International Symposium on mycotoxins and phycotoxins, 6-9 June 2016, Winnipeg, Canada
- FoodMicro 2016 Conference. The 25th International ICFMH Symposium on One health meets Food Microbiology, 19-22 July 2016, Dublin, Ireland
- Research and Intellectual Output – Science and Technology (RIO-SET) 2016, August 2016, Bulawayo, Zimbabwe

- African Green Revolution Forum, Nairobi, Kenya. UN Complex, 5-9 September 2016.

One more poster presentation to be done at 1st Mycokey International Conference, Global Mycotoxin reduction in the Food and Feed Chain, 11-14 Septemebr 2017.

In addition one outcome story has been developed, three scientific papers have been published in international journals 2 have been submitted in regional and international journals, and six more scientific publications will be submitted. The papers published and submitted are indicated under the respective objectives/milestones.

Output 16– Story of change

c. Farmer skills on post harvest management to reduce aflatoxins are enhanced

A refresher TOT for 32 extension officers (21 female) was conducted in May 2016 and the officers were from Shamva and Makoni districts of Zimbabwe. The broad objective was to further equip the extension officerswith knowledge and practical techniques to cascade farmer training on postharvest management and on how to use and handle the hermetic technologies (metal silos and hermetic bags) through a refresher course. The course tests showed that the participants are now well grounded in the subject with a pre-course test of 78% and a post-course of 82%, showing they still managed to gain more knowledge. Based on the training strategy, the extension staff conducted farmer project participant trainings. For the farmer trainings the objective was to equip farmers with knowledge and practical skills on postharvest management to reduce aflatoxin contamination in maize grain and exposure to humans. In June 2016, a total of 941 farmers (594 females, representing 63%) were trained in their respective wards. The participants requested for refresher training and for more community-wide dissemination of such valuable information through field days and to include non-project participants. One key recommendation that came out was that the training needs to be institutionalized by relevant Government departments to ensure sustainability.

Farmer Training Report (submitted in the last reporting period)

d. Scientific report/paper on analysis of reduction of economic loss from use of improved post harvest technologies completed.

An analysis of reduction of economic loss from use of improved post-harvest technologies was conducted between November 2016 and March 2017 in order to evaluate the level of post-harvest losses (both physical and economic) for farmers using hermetic grain storage technologies and those using conventional storage facilities. The analysis adopted a mixed methodology, combining quantitative and qualitative research methods. Due to financial constraints, the assessment managed to collect 3 out of the planned four grain samples for analysis.

The analysis concluded that hermetic technologies are better than conventional methods and can therefore be used to reduce economic loss due to insect damage. The average weight loss over a 5-month period was 6.11% for conventional storage; 3.54% for metal silos and 2.54% for hermetic bags. Households that had hermetic bags saved 10.67 kg per metric tonne, which translates to US$3.75 at US$0.35 per kg. Households that had metal silos saved 3.31 kg, which translated to US$1.15 after storing the maize for five months (November 2016 and March 2017). Reduction in post-harvest loss result in increased income US$20.20 from sale of additional 57.7 kg for those using super bags and US$12.57 from sale of an additional 3.31 kg for those using metal silos. Quality determines the type of market and price that will be achieved by the household. Those with low post harvest losses (good quality grain) access better paying markets. In January and March 2017, households with metal silo and super bag technologies managed to sell their grain at US$7.00 and US$7.50 per 20 kilograms respectively while the control group sold at US$5.50 and US$4.00 during the same period. Hermetic technology is therefore important in preserving grain quality which will achieve better prices.

The study thus concluded that households benefit more from hermetic technologies; and, between the two hermetic technologies, the hermetic grain bag reduces economic loss more than the metal silo.

Output 17 – The analysis of reduction of economic loss from the use of hermetic technologies Report

e. Document changes in production, use and impacts of hermetic technologies on reducing post-harvest loss

An end of project evaluation could not be conducted because of financial constraints. The project requested for supplementary budget for this activity but it was not granted.

4. Synthesis of research results and development outcomes

Researchers investigated the efficacy of airtight metal silos and thick plastic 'super bags' in reducing aflatoxin contamination in maize grain and assessing exposure of women and children to these toxins. In addition, a longitudinal study of aflatoxin contamination in stored legumes (groundnuts, cowpeas, beans and bambaranuts) was conducted. To achieve the goal, the researchers conducted the following activities in Shamva & Makoni districts and the findings are as documented:

Five hundred and thirty three communities leaders were sensitized on the need to reduce mycotoxins contamination during pre, harvest and postharvest management and hence the reduction of human exposure to these toxins. Four hundred and seventy five households from the two districts agreed to participant in the research by signing an informed consent.

4.1 Conduct KAP survey on pre and postharvest practices and aflatoxin management (Objective 1)

4.1.1 KAP surveys

KAP results show that there was a reduction in fungal/ mould attack during storage from 44% during baseline KAP to 7% in endline KAP. In terms of gender, both male and female members of the households have shown increased collaborative partnerships when carrying out pre and post-harvest tasks at household level – 79% in KAP 3 stated that drying of maize is done by both men and women in a household compared to 52% respondents in KAP 1. Shelling of maize is increasingly being done by both men and women (56% KAP1, 86% KAP2 and 88% KAP3). 31% of respondents in KAP 3 stated that the male spouse makes a decision on which crops to grow (41% in KAP 1), while 44% (KAP 3) said it's the responsibility of both spouses (32% in KAP 1). At endline 33% further dried their maize after shelling, while 28% did further dry at baseline. There was an increase in respondents who were knowledgeable about *aflatoxins* that affect maize and legumes, from 35.9% in KAP 1 to 95% in KAP 3. All interviewed respondents are willing to purchase hermetic technology using their own money, 76% indicating that they prefer to buy metal silos. A summary of more results, showing differences between KAP 1 and KAP 3 is provided in Annex 2.

4.1.2 Impact of hermetic technologies on gender roles and relations

The major gender issues revealed by the baseline survey were a shift of roles which men play in the storage and management of grain due to the introduction of the hermetic technology, which in a way was reducing women's drudgery. It was also reported that women might be losing ownership of the *dura* (maize granary with its contents) due to the introduction of the hermetic technology yet traditionally *dura* is owned by women. Ownership of the hermetic technology was therefore reported as contentious issue that could affect adoption of the technology in the community.

It emerged that the introduction of the hermetic technology heralded positive change in gender relations including uniting spouses in terms of decision making and workload sharing related to the maize value chain. The farmers reported that the technology had offered security against grain pilferage and also reduced conflict emanating from sourcing and application of chemical protectant to the stored grain. Farmers estimated that the farmers are saving between $40 - $120 per year (i.e when multiplied by the maximum number frequency of application per year) by storing maize grain in hermetic technologies, which was used for purchasing chemical protectants.

Although new technology is often viewed as labour saving, it is important to determine whose labour is saved and at what point during the crop value chain (Doss et al., 2001). To assess reduction of women and men drudgery the maize value chain due to the introduction of the hermetic technology the farmers were asked about gender roles in maize processing activities. An increase of 7.1% (from 22.3% to 29.4%) in cooperation between spouses in drying the maize was reported and it was men's drudgery that was reduced. The survey revealed a decrease of 2.1%, 5.4%, 25.3% and 4.1% in the number of women carrying out activities such as shelling ,winnowing, applying protectant and loading grain respectively as shown Annex 3. Men's drudgery was mainly reduced in shelling and drying. The reduction in both men and women's drudgery was attributed to sharing of the tasks among men and women. In terms of applying grain protectant both men and women had their workload reduced as the hermetic technology does not require protectant application. Winnowing is a task mainly for women and the time was reduced due to hand shelling which results in less chaff being introduced to the shelled maize. Overall, the introduction of hermetic technology increased the time for processing the maize grain for storage as they have to hand shell the maize, take more time to ensure that the grain is completely dry, the loading and sealing of the technology is more involving and time consuming as compared to conventional storage facilities (Annex 4). However, the use of hermetic technology reduces women and men's drudgery in management of the grain during storage as there will be no repeated winnowing and applying of grain protectant as was with the case with conventional storage facilities. The farmers also pointed that the grain will remain clean throughout storage period and they don't have to winnow it for milling. The use of hermetic technology has long term benefits such as reduction in grain weight loss caused by insect feeding thus maintain quality and quantity of the grain. Research indicates that adult insect mortality can reach up to 98% after just one month of storage in hermetic technologies due to creation of a low-oxygen environment that reduces development of stored-grain insects (Williams et al., 2014).

In terms of the management of grain, the results showed that there was a positive (22.7 % to 41.6%; 27.8% to 41. 2%) shift (Annex 5) in the proportion of households exercising joint monitoring of grain quality and use since the introduction of the hermetic technology, respectively. The former shift was at the expense of the separate monitoring by men and women within the households both of which experienced a drop in prevalence.

4.2 Analysis of impact of hermetic technologies on AF contamination in stored maize completed and documented (Objective 2)

a. Effectiveness of hermetic technologies in reducing aflatoxin B1

The effectiveness of the hermetic technology (hermetic metal silo and hermetic grain bag) in reducing aflatoxin B1 (AFB1) in stored maize grain was tested against conventional storage facilities. Aflatoxin B_1 was determined using high performance liquid chromatography with fluorescence detection and post-column derivatisation. The level of aflatoxin contamination in the stored maize grain increased with increase in storage time (Annexes 6 and 7). Overall, occurrence and levels of AFB1 in maize grain stored in hermetic technology was less than in the conventional storages (Figure 1). For the 2014/2015 season the highest contaminated sample was 158 times higher the maximum regulatory limit of 5 µg/kg and the 2015/2016 season the highest contaminated sample was 95 times higher than the regulatory limit. These highest contaminated samples were from the conventional storages. The results also showed seasonal variation in the contamination levels of maize grain with AFB1. The number of contaminated samples increased with storage time. Overall, the mean levels of AFB1 contamination in hermetic metal silos (ranged from 0.37±0 - 2.48±3.08 µg/Kg) was significantly lower than mean levels of AFB1 detected in hermetic grain bags (0 – 5.42±5.99). Hence, hermetic metal silos proved to be more effective in reducing aflatoxin contamination levels during storage than hermetic grain bags. Off- farm tests carried in Kenya also showed superior performance of hermetic metal silos over Grain Pro super bags (Walker, 2015).
Aflatoxins have serious health and economic consequences. The results of this study clearly indicate that storage of maize grain in hermetic technology can effectively

reduce aflatoxin contamination. Similar results were reported with another form of hermetic technology called Purdue Improved Crop Storage (PICS), which demonstrated that storage of maize in PICS bags is a viable management tool for preventing aflatoxin accumulation in storage by Williams et al. (2014)

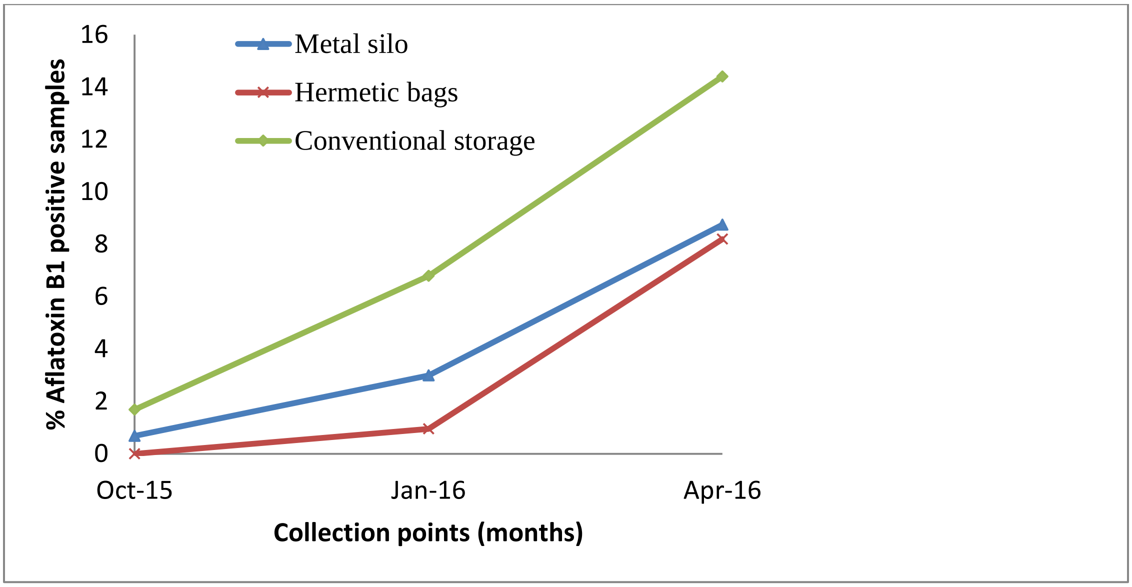

Figure 1. Percentage of maize grain samples contaminated with aflatoxin B1 collected from hermetic and conventional storage containers from smallholder farmers from Shamva and Makoni districts.

b. Assessment of reduction fumonisin B1 levels in maize stored in hermetic and conventional storage facilities

In Zimbabwe research shows that fumonisins are the most predominant mycotoxins that contaminate maize grain (Hove et al., 2016; Gamanya and Sibanda, 2001; Doko et al., 1996). Therefore, the effectiveness of the hermetic technology in reducing fumonisin B1 in stored maize grain was also tested against conventional storage facilities. Maize grain was tested for contamination by fumonisin B1 (FB1) using Europroxima® ELISA kits. All the samples were contaminated by FB1. Surprisingly, the hermetic technology did not seem to reduce fumonisin increase during storage as there was no significant difference in the concentration ranges and means of FB1 contamination of maize stored in hermetic technology and the conventional storage facilities (Annex 8). There was a marked increase in both concentration ranges and means of FB1 contamination of maize grain taken from the field and the first sample taken (September 2015) from stored maize. The range of FB1 concentrations for maize samples collected in January 2016 and April 2016 (Annex 8) appeared similar but there was significant differences ($p< 0.05$) in the means obtained in maize collected from hermetic metal silos, hermetic grain bags and conventional bags respectively in those two months. The FB1 mean concentrations showed a significant increase in fumonisins.

The fact that hermetic technology reduced increase in AFB1 contamination but did not seem to have any effect on the production of fumonisins can be explained by the physiological differences between the fungi that produce these mycotoxins. *Fusarium verticilliodes* and *Fusarium proliferatum* are fungi that produce fumonisins and are part of the normal component of the microflora present on maize throughtout the growth cycle of the crop (Nesic et al., 2014). The trend of FB1 contamination observed in both hermetic technology and conventional methods can be attributed the physiological characteristics of *Fusarium* species and environmental conditions. Research has shown that fumonisin production in *Fusarium* species appears to be enhanced under anaerobic conditions (Musser and Planter, 1997). The enhancement of fumonision production under aerobic condition can explain the ineffectiveness of hermetic technology in reducing FB1 contamination of maize grain.

4.3 Analysis of impact of hermetic technologies on AF exposure in humans (objective 3)

The effect of hermetic technology in reducing exposure of women and children to aflatoxin was assessed through collection and analysis Aflatoxin M1 (AFM1) in urine and breast milk samples. Aflatoxin M1 was determined using high performance liquid chromatography with fluorescence detection and post-column derivatisation.

a. Aflatoxin M1 in urine of women and children under five years of age and breastmilk samples from women from households using hermetic and conventional storage facilities.

Aflatoxin M1 (AFM1) is the most potent metabolite of aflatoxin B1 and its detection in urine and breast milk is a useful tool to estimate AFB1 ingestion. In both breast milk and urine samples there was an increase in the number of contaminated samples and AFM1 concentration over the agricultural season hence increase in exposure over storage time (Annexes 9 and 10). The range of AFM1 concentrations detected in women and children urine samples were significantly higher than reported elsewhere, such as 5.6μgL^{-1} in United Arab Emirates (Abdulrazzaq et al., 2003), 19.7 μgL^{-1} in Egypt (Piekkola et al., 2012) , 0.05 μgL^{-1} in Brazil (Romero et al., 2010) and 1.3-180.2μL^{-1} in China (Lei et al., 2013)

In breast milk samples taken in January and May 2016, 64.1 % and 55.5% of the breast milk samples were contaminated with AFM1 indicating a high percentage of infants exposed to the potent carcinogen AFM1. The fact that children under five and women of children bearing age were found to be exposed to AFB1 and AFM1 is of great concern as they are vulnerable population groups.

On considering the treatment, the results indicated reduction in exposure to aflatoxin of women and children (Figure 2) from households using hermetic technology for maize storage. The highest reduction in exposure was found in households using metal silos as compared to Grain Pro super bags. For instance, in urine samples taken in May 2016, there were only five contaminated samples from the metal silo treatment groups as compared to 56 and 261 contaminated samples from hermetic grain bags and conventional storage treatments groups, respectively. This further confirms the reduction in AFB1 contamination in maize stored in hermetic metal silos. Therefore, use of hermetic technology is essential for reducing women and children exposure to the carcinogenic toxin, AFB1.

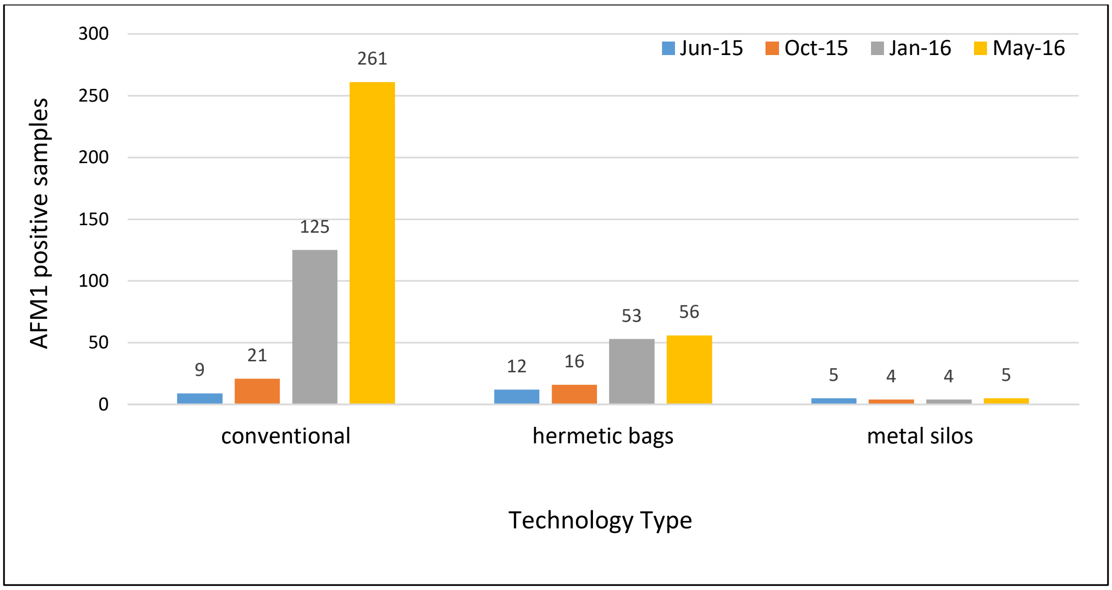

Figure 2. Distribution of AFM1 contaminated urine samples of women and children from households using hermetic technology and conventional methods for storing maize grain

The nutritional status of children was correlated with aflatoxin occurrence in their urine samoles. The results indicated that AFM1 was detected in urine samples of children in all forms of malnutrition (Figure 3). However, there was signicant correlation ($p < 0.05$) between occurrence of AFM1 in urine samples and wasting as well as underweight.

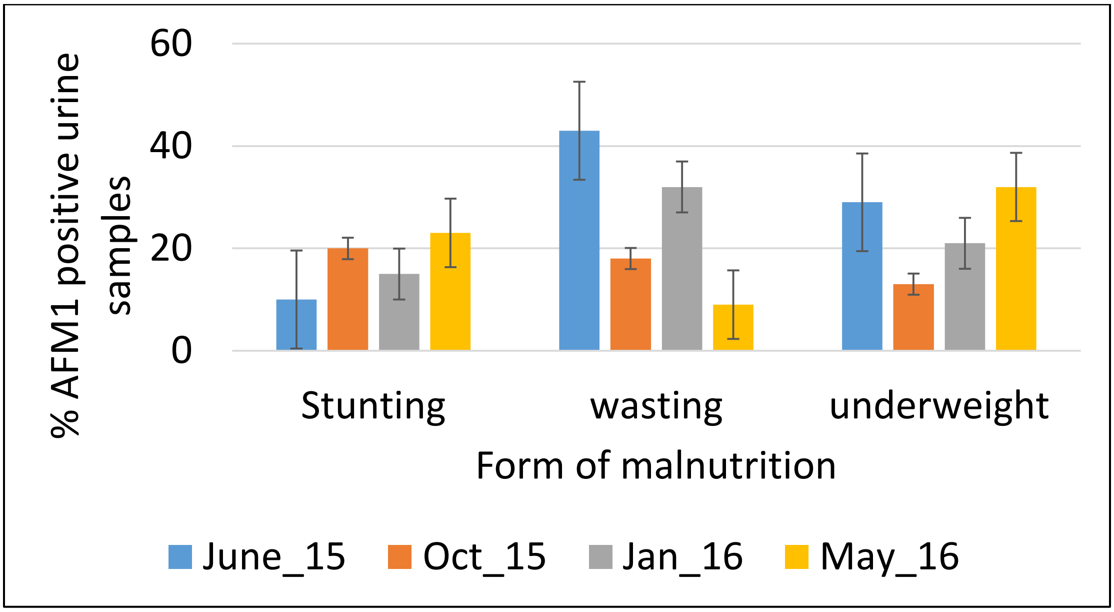

Figure 3. Malnutrition and Aflatoxin M1 occurrence in urine samples of children under five years of age

Regression analysis was used to assess the relationship between hermetic technology and aflatoxin exposure in children with different classes of malnutrition. The results showed that the occurrence of AFM1 was significantly higher (p<0.005) in urine samples from children from the control group (using conventional storage) regardless of if they had wasting, stunting or underweight (Annex 11). Children from the control group were more likely to have wasting and stunting (OR 5.04 [2.94,9.18] and OR 4.76 [1.41,80.72] respectively 95% CI $p<0.005$). This relationship was weak for children with underweight (0.21 [2.52,74.33] 95% CI $p<0.005$). Table 12 presents these results.

b. Women exposure to aflatoxins: AFlatoxin –lysine adduct in serum samples.

Baseline serum samples from women were tested for aflatoxins –lysine adduct to determine long term exposure of the women from Shamva and Makoni districts. The results indicated that 99% of the women were exposed to aflatoxin B1 with concentration of AFB1-lysine ranging from 0.40 – 1080.67pg/mg Albumin. Figure 3 shows the frequency of distribution of AFB1-lysine concentration among the women. Majority (76.8%) of the women exposed to AF had AFB1-lysine levels below 5 pg/mg Alb (Figure 3) and there was one outlier woman with 1080.67 pg/mg Alb.

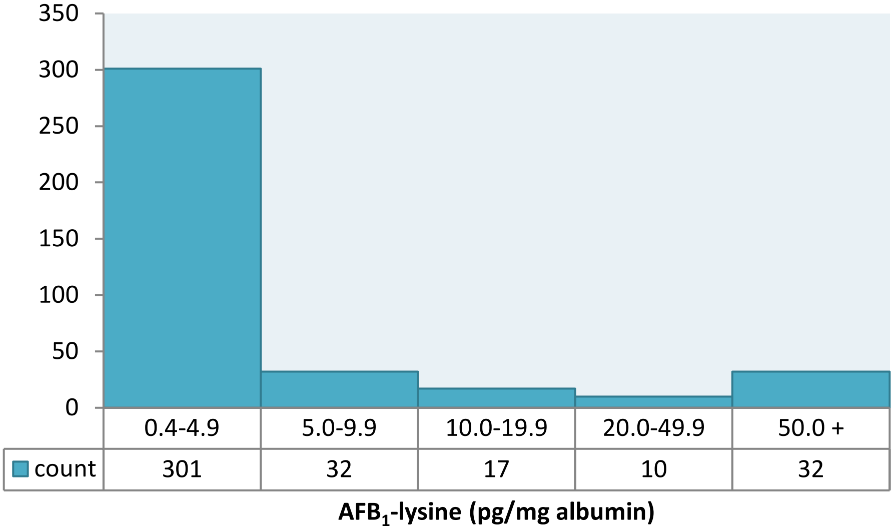

Figure 3. The frequency distribution of AFB1-lysine adduct levels in women from Shamva and Makoni districts in Zimbabwe.

4.4 Conduct assessment of levels of aflatoxin contamination in stored legumes (Objective 4)

A longitudinal study of the levels of aflatoxin contamination of legume (groundnuts, bambara nuts, cowpeas and sugars beans) was done taking into consideration that women and children do not only consume maize as a source of aflatoxin exposure.

Aflatoxins (B_1, B_2, G_1, G_2) were detected at various concentrations in groundnuts, cowpeas, beans and roundnuts produced by smallholder farmers in Shamva and Makoni districts during storage in 2014/2015 farming seasons (Annex 12). Groundnuts had the highest level of AFB1 and total aflatoxins with a concentration range of 3.0 – 123.0 µgKg $^{-1}$ and 3.0 – 697 µgKg $^{-1}$ compared to the other legumes. Up to 44.4% of the groundnut samples were contaminated with aflatoxins. Cowpeas, Bambara nuts and sugar beans were contaminated to a lesser extent as compared to groundnuts. The most AFB1 contaminated sample of cowpeas, bambara nuts and sugar beans had 47 ppb, 137.9 µgKg $^{-1}$ and 28.2 µgKg $^{-1}$, which all exceed the regulary limit of 5 µgKg $^{-1}$ Some of the legumes had concentration of AFB1 and totals aflatoxins exceeding the Zimbabwe regulatory limit of 5 µgKg $^{-1}$ and 15 µgKg $^{-1}$, respectively. The results show that women and children are also exposed to aflatoxin though legumes. Ground nuts are used for making peanut better which form an essential component for complementary foods given to children under five years.

4.5 Research Partnerships

To date, the research project has contributed to the establishment of a partnership between research partners and key policy makers in the Ministry of Health & Child Care, and Ministry of Agriculture, Mechanisation and Irrigation Development at national, provincial, district and ward levels. The two ministries have been involved, and at times take a technical lead in farmer/community trainings, as well as the fabrication of metal silos.

Since the research results have been shared with the two partner ministries, it is envisaged that the project will directly contribute to better policies to govern pre and post harvest management, as well as mycotoxin regulations in Zimbabwe.

The CultiAF research project on mycotoxins led the University of Zimbabwe research mycotoxin research group to partner with other researchers who are experts in mycotoxins to form an International Thematic Network called Partnership to improve food security and food safety in developing countries: Mitigation of mycotoxins – MYTOX SOUTH. In MYTOX SOUTH partnership the lead researchers are from Ghent University, Belgium, other partners include mycotoxin experts from countries that include Kenya, Ethopia, South Africa, Nigeria, Malawi, Tanzania, Uganda, China, USA and Ghana. The main objective for establishing MYTOX SOUTH is to consolidate the scientific network between South and North partners around the theme of mycotoxins and toxicogenic moulds with the ultimate goal of strengthening the capacity of the Southern partners, making collaborations and research output more sustainable.

The capacity for University of Zimbabwe and Action Contra le Faim improved during the course of the research project as the research team members were trained in various aspects of research especially on the importance of gender sensitive research.

4.6 Governance

The research project did the following to promote principles of good governance:

Transparency and accountability: Project plans were shared with stakeholders in operational areas. Regular reports on project progress were also submitted to relevant stakeholders and research participants in operational areas. The research team clearly explained to the research participants about the project and what was expected of them (particularly on voluntarily giving grain and biological samples). Allocation of research participants into the three treatment groups was done in a transparent manner, as local leaders and government ministries randomly picked household numbers to allocate into the three groups. Numbers, instead of names were also used to ensure that there is no favoritism.

Participation and inclusion, non-discrimination – The household listing exercise conducted in March 2015 to select eligible households for the research had a 100% coverage of the chosen Enumeration Areas. This ensured that there was no bias in selecting households for the research. The involvement of Agriculture and health extension staff in research activities resulted in stakeholder buy-in and a smooth flow of activities as we worked with already established government structures.

4.7 Research Ethics

The research project was approved by Medical Research Council of Zimbabwe. In addition the research team members were trained on Good Clinical Practices. Thus, the research team followed the procedures that are important when conducting research in which humans are the research participants. The research participant data is being treated as private and confidential information. During sample collection only participant's project identification was labelled on the sample. Documents with participant information and names such as consent forms are being kept under lock and key.

4.8 Use of research results

The research result have been disseminated to the communities in the research areas and most of the smallholder farmers in these communities have knowledge on aflatoxins and how they can be reduced in food to reduce human exposure to the toxins.

Results were presented to the Ministry of Agriculture, Mechanisation & Irrigation Development and Ministry of Health and Child Care and there were of great importance to the directors as it was realized that there is need to:

- include mycotoxin information in training manuals of Agritex extension workers,
- Interrogate presence of mycotoxins in the country's strategic grain reserves – this is currently not being done.
- Further pursue farmer trainings on the whole maize value chain (from cultivation, seed selection all the way to post harvest management) as there is a link with mycotoxins in the whole chain.

- Seriously consider alternative cereals to maize for Zimbabwean households as maize is greatly affected by mycotoxins
- Intensify information exchange between various partners in Zimbabwe (e.g. other partners now promoting 'aflatoxin-free groundnuts from Malawi)
- The nutrition department was tasked by the Permanent Secretary for Health to identify advocacy partners that will further disseminate the research results.
- The research team was asked to present the results the National Food and Nutrition Cluster and the ministers' meetings (for both Agriculture and Health)

We envisage that the research results will contribute to evidence based policy making for mycotoxin management in Zimbabwe (particularly to inform the Post harvest policy that is soon to be drafted) and hence reduce public health risks associated with the consumption of food contaminated with mycotoxins as we continue to discuss the results with the policy makers.

5. Contribution of the research to Agriculture and Food security themes

5.1 Increasing agricultural productivity (Availability)

In this study researchers investigated the effectiveness of hermetic technology in reduction of aflatoxin contamination in maize grain and raising awareness on the use of hermetic technology to reduce postharvest losses. The study has shown that aflatoxin contamination in maize grain during storage can be reduced by using hermetic storage facilities, in addition to reduction of physical weight loss. Households that have been given hermetically sealed metal silos and 'super bags' are now incurring decreased physical maize grain losses and save money that they were supposed to use to buy storage bags every season and grain protectant for their harvest. One hundred and fifty households were given on tonne metal silos and 120 household were given hermetic bags that can store 1 tonne of maize. These households are able to store their maize produce for longer period securing food for their family all year round and are free to decide when to sell surplus harvest. In addition, the research project conducted pre and postharvest farmer trainings on how to properly handle grain both in the field, during harvesting and after harvesting. These trainings have increased farmers' knowledge on good farming practices, which will in turn increase agricultural productivity.

5.2 Improving access to resources, and /or markets and income

Contributing to improved income

Conclusions made during the analysis of reduction of economic loss from use of improved post-harvest technologies indicate that hermetic technologies increase income and opens markets. From the study results, it was concluded that the scaling up of hermetic technology to reduce post-harvest loss would be technically feasible as the technology actually reduces post-harvest losses better than the conventional technology. Use of the technology is also socially and economically feasible as its use is profitable and viable. It improves food security as well as incomes as households can hold onto their produce after harvest when there is surplus and sell when prices are good during the lean period. These are key selling points for the hermetic technology scale-up on both the demand (households) and the supply side (manufacturers of silos and bags).

5. 2 Improving nutrition (Utilisation)

Reduction in postharvest losses through the use of hermetic technology may improve nutrition security since hermetic technology has been proven to reduce aflatoxin contamination in maize grain. Consumption of mycotoxins contaminated grain poses a health risk to humans. Researchers took anthropometric measurements for children under five to monitor growth and assessing the nutritional status of women including pregnant and breast feeding mothers. The project has thus trained Village health workers on taking anthropometry measurements, as well as on Nutrition & health behaviour change. VHWs assisted the research team during quarterly anthropometric measurements.

A follow-up refresher training on Nutrition & Health was conducted for VHWs during the coarse of the research project, and in turn the VHW cascaded key nutrition & health messages to the communities. The VHWs are now expected to be key ambassadors on nutrition behaviour change in the communities as they make use of listening and learning skills with caretakers and other family members of infants and young children from 0 – 59 months. Key nutrition messages were around the following:

- Awareness of the importance of exclusive breastfeeding until 6 months
- Dietary diversity for children 6-59 months in improving the nutrition and health potential of the nation
- Use of building-confidence skills with caretakers and other family members of infants and young children from 0-23 months
- Integration of key messages on aflatoxin management and prevention

5.3 Informing Policy

The research has contributed to the national strategy called Zimbabwe's Agenda for Sustainable Socio-Economic Transformation (ZimASSET) in which the Zimbabwe government under the Food and Nutrition Security Cluster is aiming to improve storage of harvested crops and quality of food among other things.

Awareness campaigns have been key in sensitizing the general public, farmers and policy makers on the use of hermetic technology to reduce postharvest losses and the possible health risks associated with the consumption of mycotoxins contaminated food could inform policy. In Shamva and Makoni districts a total of 433 community leaders were sensitized on the need to reduce mycotoxins contamination and the health implications associated with consumption mycotoxins contaminated food. Interactions with the Ministry of health during the development and implementation of the research project have resulted in inclusion of a component on mycotoxins in the 2015 national survey on rural livelihoods by Zimbabwe Vulnerability Assessment Committee.

The results were presented to the Ministry of Agriculture and Health officials who have shown great interest and have advocated for presentation of the results to the ministers and the permanent secretaries of the two ministries, so as to enable us to come up with a policy brief that can be used for evidence based planning by the policy makers in the relevant ministries. The policy brief will include the evidence that women and children are exposed to aflatoxins which have serious health consequences efficacy of hermetic technology in reducing aflatoxin contamination in maize grain and human exposure to aflatoxins.

It was difficult to schedule the meetings with the senior government officials as they kept on postponing the dates due to their busy schedules.

6. Project Outputs

The main outputs achieved are as follows:

- Two articles published in international journals and one article as a book chapter.
- Writing of six manuscripts is in progress and they should be all submitted by end of August 2017.
- Three student thesis that will be published online in the University of Zimbabwe repository once they have been examined.
- Three masters students will graduate by end 2017.
- Four newspaper articles and one TV programme broadcasted

- Video clip explaining effects of aflatoxins on human health and mitigation strategies for reducing aflatoxins

7. Problems and Challenges

Overall, the project commencement was delayed – community sensitisation started three months after contract start date due to late funds disbursement. This, among other challenges, necessitated a No Cost Extension.

One of the Masters students could not be registered at the beginning of the project due to a change in University procedures. An alternative student was identified and registered in April 2015. As a result, the student is still finalising her thesis, pending approval of thesis examiners.

The analysis of AFB1-lysine adduct in women serum samples could not be done loccaly due to unavailability of assay kits. The project identified the University of Georgia laboratory to analyse the samples. Baseline sample results have been received. However, due to financial constraints, endline sample results have not been released by the University of Georgia.

The project incurred huge losses due to the Canadian and United States dollars exchange rate losses. This had a negative impact on the research as some important milestones (last round collection of biological & grain samples, Gender survey end point (which included evaluation of Theatre for Development), End of project evaluation, part-distribution of hermetic bags to the control group could not be conducted. In addition, the research project had received services that still need to be paid for (Georgia University, hermetic bags for control group, research Assistant salary, students' stipend). We still hope that our request for supplementary funds will be approved by IDRC to offset the arrears in order to safeguard our reputation as part of Cultivate Africa's future research team and as institutions.

8. Overall assessment and recommendations

The CAD-USD exchange rate losses were mainly a result of the project reporting in its operational currency as a contractual obligation. This has derailed the research and made close-out very difficult because of the limited financial resources. In future, it is recommended that:

- Projects monitor and report their budgets in CAD in order to avoid over/under expenditures. This would ensure that necessary measures are taken before a financial situation gets worse.
- Budget analysis should be done regularly and feedback (especially on exchange rate losses) should be timely communicated to projects.

The Zimbabwe team greatly appreciates the untiring technical support and trainings given by the IDRC team. This went a long way in improving the quality of research and the research teams have gained a lot of technical skills and knowledge. We also greatly appreciate the opportunity to interact with other CultiAf research teams from different countries – this enabled us to exchange ideas and share experiences.

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Annex 1. Progress towards milestones

Milestone	Achievement (in %)	Evidence/Indicator	Comment
		6 months milestones	
• Inception workshop conducted • Revised research work plan and schedule of activities are developed and approved	100%	Inception Workshop report 6 months work plans	Submitted with previous technical reports
• Research and coordination team set up • All project administration procedures set up • Financial and technical reports prepared	100%		
Baseline and analytical protocols developed	100%		
Identification of distribution channels for post-harvest technology and distribution of technologies done	100%		
		12 months milestones	

• Current pre and post-harvest management practices for managing aflatoxins and gender roles in post-harvest management determined and documented • Skills of project team and students in research methods, gender communication, M&E enhanced	100%	KAP 1 report produced and shared	
Baseline levels of AF contamination of field and stored maize determined and documented	100%	Scientific report produced and shared	
Baseline levels of aflatoxins n humans determined and documented	100%	Scientific report produced and shared	
Baseline levels of contamination of aflatoxin in legumes and other stored grains determined	100%	Scientific report produced and shared	
Local small and medium enterprises, local tinsmiths and farmers are aware of hermetic technologies	100%	Scientific report produced and shared	
Mid-review and monitoring of project progress carried out	100%	Report produced and shared	
18 months milestones			
Economic feasibility of commercial production of hermetic technologies in Zimbabwe determined and documented (Objective 1)	100%	Scientific report produced and shared	
Changes in AF prevalence from baseline for different postharvest practices documented (Objective 2 & 4)	100%	Scientific report produced and shared	
Changes in aflatoxins exposure to humans documented (Objective 3)	100%	Scientific report produced and shared	
Stakeholders sensitised on different postharvest management practices and their implications on aflatoxin contamination (Objective 5)	100%	Posters, leaflets, video documentary and TV programme produced. In addition, four newspaper articles published.	
Annual review and monitoring of project progress	100%	Activity report produced.	
24 months milestones			

Knowledge, attitudes and practices in postharvest management determined and documented	100%	Baseline, Midpoint and Endline KAP survey reports produced	
Gender analysis of the impacts of hermetic technologies completed (Objective 1)	75%	Baseline and Midpoint Gender Analysis reports produced	Endpoint Gender survey could not be conducted due to financial constraints
Analysis of impact of hermetic technologies on AF contamination in stored maize completed and documented	100%	-Report on reduction of economic loss produced	-See attached Output 15
Analysis of impact of hermetic technologies on AF exposure on humans completed	90%	-Scientific paper on infants exposure to AF M1 in the control and interventions group documented -Scientific paper on association between anthropometric data and levels of AF in children under 5 in control and intervention groups completed	Output 10 Analysis of association between anthropometric data and levels of AF in children under 5 in control and intervention groups was completed and is part of the technical report. A separate scientific paper could not be produced because of little information derived from the data. Baseline AFB1 exposure of women in blood is documented in the technical report and the endpoint results have not been released

			because we did not pay for the services due to financial constraints.
Farmers' skills on postharvest management to reduce AF are enhanced	100%	Report produced and shared	
Scientific community is aware of impacts of hermetic technologies on AF contamination and exposure to humans	100%	-6 posters developed and presented in scientific conferences. -2 MPhil theses completed and submitted for examination. The third student registered late in April 2015 and her thesis will be submitted once examiners have been approved by the Academic committee. However, her draft thesis is attached. Report of student training on writing and presentation of their results	- Two Mphil thesis completed – output 7 and 13. One Mphil thesis to be finalised and submitted -Output 11 The students had two workshops on thesis writing in March 2015 and August 2016 offered by Post-Graduate studies, University of Zimbawe. Therefore, the students were not trained on the project as such.
30 months milestones			
Document changes in production, use and impacts of hermetic technologies on reducing post-harvest loss	%	Evaluation report not produced.	Not conducted due to financial constraints (result of CAD-USD exchange rate losses)
Policy makers at national and provincial level and the scientific community are aware of aflatoxins risk and impact of hermetic technologies	70%	Research results have been presented to some senior government officials in Ministry of Agriculture and Health at national and provincial level. Policy briefs not yet done – to be developed after meeting with ministers.	Dissemination outputs reported in previous report. Dissemination to the ministers and permanent secretaries to be

		One outcome story completed. 3 papers published in international journals. 2 papers submitted to regional and international journals. 6 papers to be submitted and have been included as outputs.	done on a future date to be advised by the ministries
Project closeout		Technical report completed and submitted Financial report to be submitted in July 2017.	

Annex 2. Changes in knowledge, attitude and practices (KAP) of smallholder farmers in Shamva and Makoni districts, Zimbabwe

	% Respondents	
Issue	**KAP 1**	**KAP 3**
Observed fungal/mould attack during drying	19	24
Observed fungal/mould attack during storage	44	7
Winnowing grain to remove dirt before storage	59	76
Assessment of moisture content before storage	64	88
Sorting maize & legumes before storage	28.2	53
Pre-storage treatment of maize	98.7	49
Observed disease attack on maize in the field	28.2	23
Hand shelling of maize	35.6	42
Familiar with aflatoxins	36	95

	KAP 1 (%)			KAP 3 (%)		
	Males	**Females**	**Both**	**Males**	**Females**	**Both**
Who makes a decision on which crops to grow	40.6	17.8	38	31	12	44
Who shells maize	2	42	56	1	7	88

Annex 3. Distribution of workload during maize grain processing for storage before and after the introduction of the hermetic technology

	Frequency % before(after) the introduction of hermetic technology

	Men	Women	Hired labour	Both	Family
Cutting	9.7(10.5)	3.4(2.9)	7.1(8.8)	16.8(16.4)	64.7(63.0)
Shelling	5.0(0.8)	7.6(5.5)	4.6(5.0)	12.6(17.2)	71(71.8)
Drying	27.7(18.8)	31.5(33.6)	0.4(1.3)	22.3(29.4)	18.1(18.5)
Winnowing	1.3(1.7)	89.9(84.5)	2.1(2.9)	1.3(2.9)	5.9(8.4)
Applying protectant	53.4(1.3)	26.1(0.8)	0(0)	5.5(0)	5.5(1)
Loading grain	37.0(30.3)	11.3(7.1)	1.7(2.5)	17.6(24.8)	32.4(34.9)

Annex 4. Mean time spent of processing activities in preparation for maize grain storage before and after the introduction hermetic technology

Process	**Mean time spent (minutes) before and after the introduction of hermetic technology**	
	Before	**After**
Shelling	48.04	124.44
Winnowing	17.67	14.42
Applying protectant	11.81	0
Loading	7.69	10.17
Sealing	4.63	14.29
Total	**89.84**	**163.32**

Annex 5. Gender roles in grain storage management before and after the introduction of the hermetic technology.

Activity	Before Hermetic Technology Frequency % (N = 238)				After Hermetic Technology Frequency % (N= 238)			
	Men	**Women**	**Both**	**Other**	**Men**	**Women**	**Both**	**Other**
Grain quality monitoring management	28.9	48.3	22.7	0	16.8	41.2	41.6	0.4
Grain use management	29.8	37.4	27.8	5.0	18.9	37.4	41.2	2.5

Annex 6. Aflatoxin B1 contamination in maize grain samples stored in hermetic and conventional storage facilities for the 2014/2015 farming season

Type of storage facility		Month of sampling/Source			
		June 2015/ Field samples	September 2015/ Storage facilities	January 2016/ Storage facilities	April 2016/ Storage facilities
Hermetic metal silos	No. of samples containing AFB1	1 N = 148	1 N = 147	4 N = 134	7 N = 80
	% of samples containing AFB1	0.68	0.68	2.98	8.75
	Concentration range µg/kg	3.38	0.37	0.06-2.77	0.03-7.59
	Mean concentration µg/kg	3.38±0	0.37±0	1.12±1.16	2.08±2.75
Hermetic grain bags	Number of samples containing AFB1	0 N = 121	0 N = 121	1 N = 105	5 N = 61
	% of samples containing AFB1	0	0	0.95	8.20

	Concentration range µg/kg	0	0	2.97	0.03-12.55
	Mean concentration µg/kg	0	0	2.97±0	5.42±5.99
Conventional storages	No. of samples containing AFB1	2 N = 179	3 N = 179	11 N = 162	13 N = 90
	% of samples containing AFB1	1.11	1.67	6.79	14.44
	Concentration range µg/kg	5.55-7.32	0.22-21.99	0.01-791.85	0.03-11.81
	Mean concentration µg/kg	6.44±1.25	7.88±12.24	86.85±235.24	3.37±3.64

Annex 7. Aflatoxin B1 contamination in maize grain samples stored in hermetic and conventional storage facilities for the 2015/2016 farming season

Type of Storage facility		**Month of sampling**		
		June 2016/ Field Samples	August 2016 / Storage Facilities	Nov 2016/ Storage Facilities
Hermetic metal silos	No. of samples containing AFB1	3 N= 129	4 N = 101	6 N=89
	% of samples containing AFB1	2.32	3.96	6.74
	Concentration range µg/kg	0.6 - 4.02	0.65 -2.78	0.16 – 8.60
	Mean Concentration µg/kg	1.79±2.03	1.53±0.92	2.48±3.08
Hermetic super bags	No. of samples containing AFB1	2 N=98	6 N=92	5 N=75

	% of samples containing AFB1	2.04	5.43	6.67
	Concentration range µg/kg	0.40 – 6.34	0.20 -9.43	0.66 – 8.37
	Mean Concentration µg/kg	3.37±4.20	2.79±3.77	3.17±3.01
Conventional Storage	No. of samples containing AFB1	2 N=149	12 N=138	18 N=120
	% of samples containing AFB1	1.34	8.70	15.00
	Concentration range µg/kg	0.03-24.98	0.18 -18.39	0.35 – 474.97
	Mean Concentration µg/kg	1.25±17.64	4.84±6.17	3.15±111.31

Annex 8. Fumonisin B1 contamination in maize grain samples stored in hermetic and conventional storage facilities for the 2014/2015 farming season

Types of storage technology		**Month of sampling/Source**			
		June 2015/ Field samples	September 2015/ Storage facilities	January 2016/ Storage facilities	April 2016/ Storage facilities
Hermetic metal silos	Number of samples containing FB1	148 N = 148	147 N = 147	134 N = 134	80 N = 80
	Concentration range µg/kg	10.47-450.92	6.05-515.15	9.28-635.59	42.05-670.84
	Mean concentration µg/kg	186.85	288.63	289.77	485.21
Hermetic super bags	Number of samples containing FB1	121 N = 121	121 N = 121	105 N = 105	61 N =61
	Concentration range µg/kg	11.56-459.21	7.92-519.66	6.42-555.23	64.79-680.23
	Mean concentration µg/kg	185.09	286.47	290.02	486.31
Conventional storages	Number of samples containing FB1	179 N = 179	179 N = 179	162 N = 162	90 N = 90
	Concentration range µg/kg	11.16-461.79	12.28-533.63	31.85-641.27	62.19-681.40

	Mean concentration µg/kg	186.25	289.52	292.21	489.12

Annex 9. Aflatoxin M1 concentrations of women and children under five years' urine samples, Shamva and Makoni districts, Zimbabwe

Biological Sample	**Maize grain storage facility**	**Total No. of Samples Collected**	**Min µgL^{-1}**	**Max µgL^{-1}**	**Geometric mean µgL^{-1}**	**% Prevalence**
Women Urine						
At Harvest	Metal silo	150	<LOQ	8.27	1.29	3.3
	Hermetic bag	120	<LOQ	25.75	1.66	10
	Conventional	178	<LOQ	23.64	1.75	5.1
3 months Postharvest	Metal Silo	129	1.48	16.66	8.07	3.1
	Hermetic bag	107	<LOQ	43.75	8.51	7.5
	Conventional	151	<LOQ	90.09	8.86	15.2
6 months Postharvest	Metal silo	134	1.02	12.11	4.47	2.9
	Hermetic bag	107	<LOQ	12.83	15.04	40.2
	Conventional	138	<LOQ	43.17	33.16	53.6
9 months Postharvest	Metal Silo	125	<LOQ	89.01	31.87	7.14
	Hermetic bag	106	<LOQ	157.71	31.95	53.8
	Conventional	155	<LOQ	217.29	62.28	89.7

Children Urine						
At Harvest	Metal Silo	50	0.62	1.52	0.97	4
	Hermetic bag	45	0.41	0.96	0.62	4.4
	Conventional	67	<LOD	<LOD	<LOD	ND
3 months Postharvest	Metal Silo	53	<LOD	<LOD	<LOD	ND
	Hermetic bag	45	<LOQ	12.15	3.77	11.1
	Conventional	67	3.88	16.52	7.04	5.9
6 months Postharvest	Metal Silo	48	3.66	4.35	3.99	4.2
	Hermetic bag	41	<LOQ	12.83	5.21	12.2
	Conventional	66	<LOQ	43.17	10.50	68.2
9 months Postharvest	Metal Silo	47	<LOQ	40.68	13.13	20.6
	Hermetic bag	37	<LOQ	62.16	22.23	59.5
	Conventional	60	<LOQ	135.00	24.34	98.3

LOQ = limit of quantification, LOD = limit of detection, ND = Not detected

Annex 10. Aflatoxim M1 concentration in breastmilk samples from women in Shamva and Makoni districts, Zimbabwe

Biological Sample	**Maize grain storage facility**	**Total No. of Samples Collected**	**Min μgL^{-1}**	**Max μgL^{-1}**	**Geometric mean μgL^{-1}**	**% Prevalence**
Breast Milk						

At Harvest	Metal silo	40	<LOD	<LOD	<LOD	ND
	Hermetic bag	40	<LOD	<LOD	<LOD	ND
	Conventional	45	<LOD	<LOD	<LOD	ND
3 months Postharvest	Metal Silo	32	0.72	2.71	1.56	15.6
	Hermetic bag	40	<LOQ	6.59	1.58	17.5
	Conventional	44	0.77	3.43	1.52	18.2
6 months Postharvest	Metal silo	38	0.58	2.61	1.48	23.7
	Hermetic bag	37	<LOQ	9.77	3.57	89.2
	Conventional	40	<LOQ	20.33	5.79	85.0
9 months Postharvest	Metal Silo	34	0.92	11.23	2.23	20.6
	Hermetic bag	31	1.29	17.15	4.44	32.2
	Conventional	40	<LOQ	26.23	5.76	85.0

Annex 11: Odds ratios of treatment group effect on child malnutrition and occurrence of urinary Aflatoxin M1

	Children urine AFM1

		n (%)	GM	Min	Max	OR[95% CI]	*p*-value[a]
Underweight	Metal silo	0 (0.0)	<LOD	<LOD	<LOD	-	
	Hermetic bag	11 (7.6)	9.80	2.30	25.82	1.00	
	Conventional	12 (8.3)	21.32	3.22	105.00	0.21 [2.52,74.33]	0.041
Wasting	Metal silo	1 (0.7)	5.31	5.31	5.31	1.00	
	Hermetic bag	0 (0.0)	<LOD	<LOD	<LOD	-	
	Conventional	2 (1.4)	10.49	2.32	11.82	5.04 [2.94,9.18]	0.037
Stunting	Metal silo	3 (2.1)	6.97	<LOQ	40.68	1.00	
	Hermetic bag	13 (9.0)	12.68	1.57	62.16	0.14 [2.86,54.20]	
	Conventional	29 (20.1)	15.21	<LOQ	135.00	4.76 [1.41,80.72]	0.012

Note: GM=Geometric Mean. LOD=0.014µg/L LOQ=0.04µg/L. [a]statistical significance set at $p<0.05$

Annex 12. The distribution of aflatoxin contamination levels of stored legumes in Shamva and Makoni districts.

Legumes	**Collection point (months) / source**			
	June 2015	September 2015/stored	January 2016/stored	April 2016/stored

	Just harvested grains			
Groundnuts	Concentration range - µgKg $^{-1}$			
Shamva District	N = 105	N = 80	N = 26	N = 20
AFB1	3.1 - 176	0 – 93.0	3.0 – 17.6	3.9 – 9.9
Total AF	9.2 – 551.0	1.6 – 525.2	5.7 – 33.6	3.6 – 16.6
% No. of Positive samples	13.3	26.3	26.9	20
Makoni District	N = 103	N = 45	N = 9	No samples available
AFB1	0.7 – 108.4	2.3 – 123.0	6.4 – 15.5	
Total AF	10.4 – 697.9	3.4 – 548.9	6.4 – 117.8	
% No. of Positive samples	11.7	28.9	44.4	
Cowpeas	N = 117	N = 48	N = 10	N = 42
AFB1	1.4 – 47	2.2 – 37.6	3.9 – 11.0	2.7 – 7.3
Total AF	1.4 – 103.4	2.5-98.6	3.9 – 33.3	2.0 – 28.3
% No. of Positive samples	4.3	25.0	70.0	31.0
Bambara nut	N = 123	N = 71	N = 25	N = 31
AFB1	28.2	4.8 – 7.2	1.4 – 15.2	2.5 – 10.4
Total AF	27.3 – 70.9	7.3 – 32.2	1.4 – 15.2	2.5 – 23.7
% No. of Positive samples	1.6	7.0	16.0	32.3

Sugar beans	N = 89	N = 29	N = 25	No samples available
AFB1	8.6 – 21.8	2.1 – 137.9	2.3	
Total AF	8.6 – 53.5	2.1 – 341.9	4.0	
% No. of Positive samples	3.4	10.3		