

Conclusions

Accurate, traceable to compliance and accessible phosphine concentration web monitoring provides immediate actionable data (**Figure 3**) to deliver safeguards that address potential insect resistance. If implemented, these demonstrable advantages allow an expanding global market to reasonably rely on a higher quality, uninterrupted supply chain for stored grain stuffs. Data accuracy, warehousing and easy access of data is key for informed decisions.

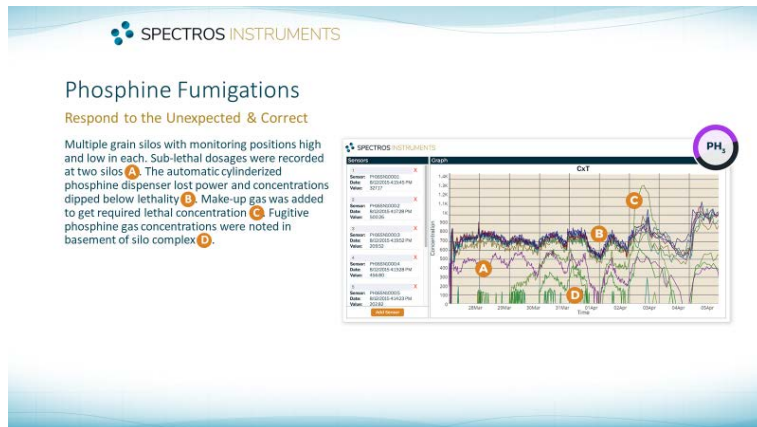


Figure 3: Sixteen-position web-based phosphine fumigation at a grain processing facility. Each line (trace) represents one sampling point of gas concentration vs. time and details proactive corrections avoiding a fumigation failure.

Qualitative Discussion about Reducing Grain Postharvest loss with Mobile storage in Ghana, West Africa

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Abstract

Farming sustainably and protecting gross harvest production correctly provides growers with “health care, school fees and peace-of-mind” (net benefits). Reducing Postharvest and input loss sustains the components of agriculture’s triple-bottom-line which are “accessible nutrition, reduced green-house emissions, and foreign exchange reserves”. Lacking storage that stops grain PHL, agriculture suffers critical problems like the *Aspergillus* fungi that leaves grain contaminated with invisible aflatoxin that growers cannot consume or market. The objective of the Ghana pilot study was to understand why new ideas/findings like, applying biologicals to the soil before harvest, gross production inputs, virtual markets and especially the spread of stationary grain warehouses have failed to improve the net benefits of farming or agricultures’ triple-bottom-line in sub-Saharan Africa. Qualitative comparison methods were used to identify roadblocks to improvement as scientific monitoring and storage eliminate grain Postharvest loss on the drylands in many parts of the world. Observations suggest net benefits are being ignored as reviews and assessments of primitive or council storage exchange scientific rigor for Stationary Warehouse Prejudice. Scientific rigor illuminates how the qualitative cost of aflatoxin, and quantitative expense of pests, recycling plastic, and empty stationary warehouses impact end-user-cost per unit stored per month. We conclude that Postharvest loss is expensive, and that relatively inexpensive mobile metal storage assets would improve net benefits and the triple-bottom-line.

Key words: grain, aflatoxin, storage, postharvest loss, triple-bottom-line.

1. Introduction

Staple, pulse, and legume (grain) farming means harvesting sustainably as much as possible from

production inputs, arable land (ecosystem services), and protecting what is harvested correctly so surplus provides for “health care, school fees and peace-of-mind” (net benefits). Reducing “Postharvest loss sustains the important components of agriculture’s triple-bottom-line which are “accessible nutrition, reduced green-house emissions, and foreign exchange reserves”.

Of course, not all sub-Saharan Africa (SSA) farm production is the same, so it is impossible to lump all Postharvest loss together. Some Postharvest loss is of “fruits, vegetables, and meat” (dense nutrition) and some is dry, high calorie and protein grain. However, grain provides most of the calories that power animal and human hard labor to “plant, grow, harvest, thresh, clean, dry, aggregate, store, monitor and process” grain and densely nutritious food. At the farm level, especially in the field, many biotic pests like fungi, insects, rats, birds, or abiotic groundwater, flooding, wildfire, and theft are difficult or impossible to control without protective storage. Historically Postharvest loss means SSA grains are contaminated by rats, insects, and fungi that cause Postharvest loss like aflatoxin. Aflatoxin “increases morbidity and mortality” (IARC, 2016) and small-scale grain growers’ cannot safely consume or market grain.

Development often confronts Postharvest loss with production packages that temporarily increase gross grain production. For example, guaranteeing a price 10% above market premium for all compliant product. When there is typically a great deal of Postharvest loss, first season sourcing from local growers’ results in 70% out of tolerance product, mostly from aflatoxin. When a lab test determines contamination, grains are simply turned back, and growers must fend for themselves. Some contaminated product goes to animal and fish feed formulators, which take half of the rejected product. Same growers then sell another quarter to mill operators, who do not test or care about quality. The remainder is consumed by growers (Lamb, 2017).

Objectives

Our objectives were to strengthen knowledge about why the spread of inputs and stationary warehouse storage for surplus grain have failed to reduce Postharvest loss. For example, knowing why International Crops Research Institute for the Semi-Arid Tropics (ICRISAT, 2017) says application of biologicals like harmless strains of *Aspergillus* fungi to the soil have had very limited success reducing SSA Postharvest loss in storage, is critical (Kumar, 2017). Exposing this aspect of Postharvest loss would help development experts guide research and outreach by HarvestPlus, International Fertilizer Development Corporation (IFDC), International Institute for Tropical Agriculture (IITA), Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), Ghana’s Social Enterprise Development Foundation (SEND-Ghana), Adventist Development and Relief Agency (ADRA), Mennonite Economic Development Associates (MEDA) and Center for Agricultural Rural Development (CARD) for example.

2. Materials and Methods

The three qualitative comparison methods were:

- evaluate the scientific rigor used to assess storage by organizing, reviewing, and comparing research
- field test mobile storage (Fig. 1) by observing adaptive learning at four of many locations
- identify any potential roadblocks for growers’ rights to reduce Postharvest loss with mobile storage.



Figure 1. Mobile metal storage has utility for storing many crops, monitoring and primary processing surplus grain. Image: Unknown and modified by author.

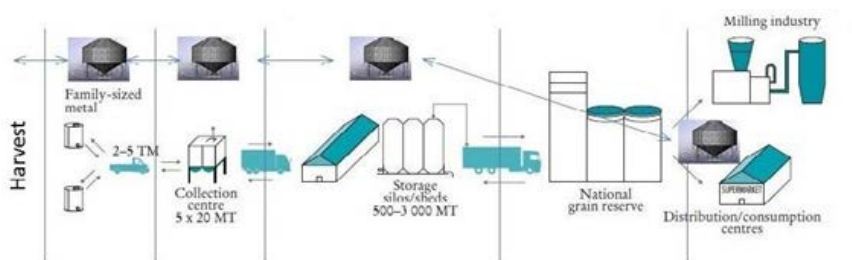


Figure 2. Mobility lets growers optimize storage at many locations. Image: FAO 2015 D. Mejla and modified by author.

3. Results

Qualitative comparison is relevant as scientific improvements (Butler, 1907), research (Proctor, 1999), storage testing (Opit, 2016), and grain moisture content measurement (Armstrong, 2016) etc., permit judicious adjustments to the timing, choice, and intensity of control actions, timely chemical pest control measures, in grain storage. Adjustments that are expedited using “Integrated Pest Management” (IPM) are often not only the cheapest but also the most reliably efficacious of the possible options and reduce Postharvest loss to insignificant levels on the drylands of the world that provide SSA with a staggering 83% of the food it consumes, though SSA holds nearly 50% of the land available worldwide” (Juma, 2016).

The key results suggest that solutions to the aflatoxin challenge that plagues SSA farmers, other agri-entrepreneurs, and governments are ignored. Kaminski, (2014) describes how reviews and life-cycle assessments of African storage, exchange scientific rigor for “Stationary Warehouse Prejudice” (Adjei, 2017). While Kumar (2017), and Ampuko (2018) mention aflatoxin, they ignore innovation storage solutions that their “Archer Daniel Midland Institute for the Prevention of Postharvest Loss” at University of Illinois and “1st All Africa Postharvest Congress and Exhibition”, at University of Nairobi, respective research organizations exposed for peer review in conference proceedings. These and other reviews also ignore how sealed storage requires additional stationary infrastructure (Fig. 1) to mitigate condensation, handling to monitor for grain damaging insects that bore into plastic bags, and that rodenticides are not chemical free and soft plastic needs to be recycled. Examples of life-cycle assessments are the World Food Program (WFP) Global Postharvest Knowledge Center (Rierson, 2017) which ignores that that growers and refugees are often tenure-insecure. Michigan Institute of Technology (MIT) Comprehensive Initiative on Technology (2016)

merely evaluates the end-user-cost per unit stored annually, assuming all storage is full for the same number of months, instead of a per unit per number of months perspective that illuminates the cost-effectiveness of storage that is full for longer periods.

During pilot study field tests, we observed Ghana's agricultural business environment and witnessed adaptive learning that suggested mobile storage addresses the needs of tenure-insecure growers. While field testing at four locations we observed that rights to storage shifted benefits to growers and away from patriarchs wielding land-tenure, opportunistic traders setting prices or councils that are unresponsive (Easterly, 2015).

Roadblocks that the pilot study identified were Stationary Warehouse Prejudice, Development Packages, and Purchase Price of mobile storage.

Stationary Warehouse Prejudice Roadblock

University of Ghana's Egyir (2017) questions the competence of most of the current stationary warehouse management to source working capital, or network to accomplish IPM. Lack of management means Postharvest loss increases with storage period and capacity. However, empty, or full, with or without market access, prejudice for stationary warehouses provide protocol fees or services that facilitate cooperation by grain councils in East Africa or Ghana. This kind of cooperation makes implementation of production package blueprints easy for any "non-Governmental Organization" (NGO), even though NGO cultural advisors know that Postharvest loss will continue to impact advisor extended families in rural communities.

Agribusiness lobbies globally to set the agricultural research and education agenda to facilitate profits through the sale of inputs like mechanization, seeds, fertilizers, and pesticides (gross production technologies). Input agribusiness sees little profit in the preservation of food once it is produced. In fact, SSA agribusiness profits from Postharvest loss in warehouses as this loss reduces the food supply thus creating the perception that inputs to plow new land (extensification) and/or for irrigation (intensification) are needed to produce more food (Wilson, 2016). SSA agribusiness ignores that when Postharvest loss drives intensification or extensification, ecosystems are degraded and soon limit net benefits and the triple-bottom-line.

SSA research and outreach assess grower-controlled storage with wheels, as disruptive and suggest already proven off-the-shelf "Mobile storage needs basic research and testing if we are to share/promote [for growers to evaluate] it widely" (Essegby, 2017). Agribusiness and councils lobby so research and outreach delay Postharvest loss solutions and so annual grain summits and USAID's ADVANCE Preharvest events or forums exclude innovation from local agendas. Excluding innovation from local agendas discourages grower evaluation of inputs and protocol.

Development Package Roadblock

Development often confronts PHL with gross production packages and support councils to blueprint stationary warehouses for average local production. As averages are rare, council managed warehouses are either almost empty or overflowing and often far away from Postharvest loss control locations. On the other hand, the dynamic nature of farming and chronic Postharvest loss it is risky for tenure-insecure growers to build and maintain warehouses at optimal locations.

Many development packages attempt to move growers up by implementing warehouse receipt systems (WRS). However, if the receipt system warehouse is "too far away or does not scale to production for cost-effective IPM" (unresponsive), WRS are soon "rusting" monuments to Postharvest loss (Armah, 2006). Kula (2017) suggests development experts should learn the lesson that WRS based on stationary warehouses do not even out supply or help growers (World Bank, 2013).

"Tackling [stationary] WRS Challenges" by Mugano (2017) explains precisely, the familiar lack of suitable infrastructure or requisite skills, legal and regulatory issues, missing or weak complementary market institutions, disabling elements in the policy environment that discourage key stakeholders especially bankers from financing agriculture in SSA.

An example of a Development package is Financing Ghanaian Agriculture Project (FinGAP) Incentive grants. FinGAP assists "Financial Organizations" (FO) to focus on areas that will never support commercialized farming where the "most vulnerable growers are" (World Vision). One of these FOs is the Center for Agricultural and Rural Development (CARD). Incentive grants allow CARD to provide credit-in-kind for inputs to approximately 10,000 vulnerable growers in exchange for bags of "maize, rice and soy" (produce). The credit-in-kind is more likely put to good use by growers for approved production practices than cash which could be diverted to unapproved uses. Middlemen from target districts assist CARD activities by delivering approximately 500 MT of loan repayment produce which is then aggregated, stacked on pallets and covered by tarps anticipating price appreciation. FinGAP reports that supporting FOs activities leads to increased gross production and 100% loan repayment.

Although easy to move pallets and tarpaulins are at first attractive option to stationary warehouses, they do not stop Postharvest loss from flourishing throughout the stack during the 6-8 months the repayment produce anticipates price appreciation. Ground water and termites weaken pallets and allow sacks to contact fungi in the soil. Manually removing/replacing the tarpaulins daily is needed to prevent condensation that allows fungi, insects, rats, and birds to feast. CARD's capacity to move up above grants and sustain the triple-bottom-line is limited by Postharvest loss (Shukla, 2017).

The surplus grain that remains with CARD growers at the farm level or council district warehouses will likely be rewetted (Trenk, 1970) and allow Postharvest loss like aflatoxin to impact the most vulnerable children (Cardwell, 2014). Postharvest loss is not approved production practice as the net benefits of credit-in-kind inputs are diverted to pests, middlemen and councils.

Development packages that use gross production to ignore the impact of Postharvest loss, miss an opportunity to approve storage practices so that net benefits drive the triple-bottom-line without further use of land, water, and other agricultural inputs (APHLIS, 2015).

Purchase Price Roadblock

Even though the cost of any metal grain storage decreases with increases in capacity and the number of months that capacity is full, the up-front purchase price of metal storage is a roadblock for grower storage rights that reduce Postharvest loss.

4. Discussion

Rights that secure access to land or tenure, reduce the risk to resources invested to build and maintain stationary storage like warehouses. However, SSA growers are often tenure-insecure. Lacking storage that meets their needs, growers are forced to sell quality surplus early or suffer significant Postharvest loss (Lipinsky, 2013).

North Carolina State University (NCSU, 2018) focus group discussion suggests crops are not stored in the field for fear of theft. As a result, farmers only harvest volumes that they can carry in any one day. Considering that the main means of transportation was by head, the amounts that can be transported within a given period is limited. As a result, the produce may be exposed to rewetting in case of rains. These findings seem to imply that a transport intervention that parks cost-effectively to store aggregated quality while heads, wagons or trailers haul heavy loads may go a long way in reducing the losses that occur at harvest before or as crops leave the fields.

Opportunistic traders or middlemen know growers lack storage and set low prices. Low prices reduce the net benefits of inputs like hard labor, ecosystem services, and especially gross production inputs like "FarmerLine (sms information), Tuluu (virtual market), AgriCorp (education), Oikocredit (micro-finance), Area Yield Index Crop (insurance), Hello Tractors and Solar powered irrigation (mechanization), HarvestPlus Biofortification (improved crop varieties), IFDC (fertilizers), IITA's AflaSafe fungi (biologicals)" and other process improvements like commodity marketing. The result is the tenure-insecure grower may experience "market failure" (Jones, 2011) after investing inputs, selling grain low, and then buying similar grain back at a higher price. Or, if the grower attempts to

gain the advantage by controlling assets that store grain in bulk, sack, or airtight metal can, hard plastic drum or soft plastic bag, they may “challenge the tradition” of patriarchs (Bott, 2005). In SSA the grower invests the important inputs and gets just enough to survive but not enough to move up, as “Postharvest and input loss” (PHL), middlemen and councils divert significant net benefits.

Simply, harvesting grain without storage means PHL is chronic and invisible aflatoxin stops growers from setting, or modifying, their own goals, so two farms with identical climates and soils may be managed with different aims to achieve the diversity needed to sustain the triple-bottom-line (FAO, 2015).

If SSA development experts realized that grain PHL is an integral part of the SSA agricultural system (Boa, 2016), innovative grain storage would initiate the ‘golden age’ of SSA agriculture (Pearce, 2016). The Great Grain Bin Adventure (Butler, 1907) is an example which justifies many calls for proposals that specify food chain policy innovations, as there are few positive outcomes if aflatoxin means small-scale grain growers cannot safely consume or market grain (Mendoza, 2016).

Solutions to the Roadblocks and PHL

When scientific rigor quantifies the role PHL played during “decades of grain net yield increases in other parts of the world, to keep SSA grain agriculture less mechanized, low-yielding, and insecure” (Juma, 2016), accountable development packages will finance agendas that are responsive to grower net benefit and improve SSAs’ triple-bottom-line.

On the drylands of SSA, output agribusiness like Cimbria and African Grain Care etc., have built, validated, tested, sold and maintained 1000s of stationary metal vented, raised sloping floor silos for utility storage. If the storage was mobile the same storage could be relocated at any PHL control point and provide the practical utility needed to support IPM practices. So, should be easy for research and outreach to understand how storage with wheels, just like just like agricultural wagons and trailers will likely improve tenure-insecure growers’ net benefits. Storage with wheels can be leased. Leased and/or purchased mobile storage can be parked cost-effectively at dynamic PHL control points so utility like vents will cost effectively mitigate condensation; wide-opening roofs reduce the labor needed to aggregate quality and monitor insects while also stopping rewetting; sloping floors reduce cleaning requirements and rise above groundwater and rats secure net benefits. Incentives for FOs to address the purchase price of an approved practice like storing and marketing safe surplus will move growers up to economies of scale and attract the working capital of local banks that will sustain agricultures’ triple-bottom-line (Mugano, 2017).

To help focus the qualitative discussion we wanted to assess options like the airtight metal can (Fig. 3) versus mobile utility using the Granary Selector ‘app’ developed by the Natural Resources Institute at University of Greenwich under a contract with the Swiss Development Agency (Tran, 2016). However, the app does not allow users to organize, review and compare storage factors like lease or mobile types. We addressed this roadblock to financing by organizing a comparison based on practical field handling (Text Box 1.), storage (Text Box 2.), and marketing (Text Box 3.).

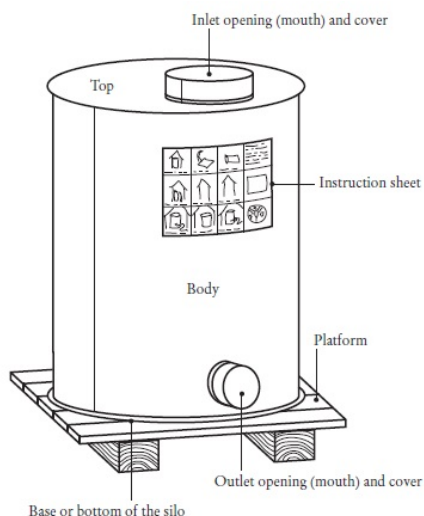


Figure 3. Airtight metal can capacities larger than 1.8 MT “become hard to operate” (George, 2011). Image: FAO 2015.

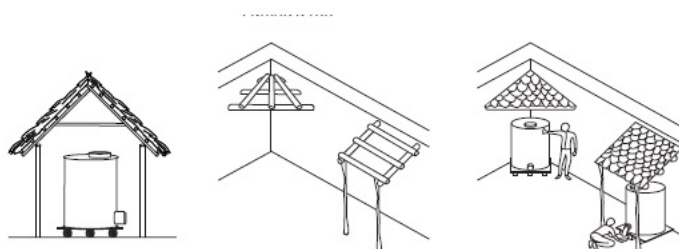


Figure 4. Airtight metal cans require additional infrastructure like floors, stationary platforms and roofs. Image: FAO 2015.

Text Box 1. Summary practical comparison of field handling to storage environments when significant PHL occurs (Lipinski, 2013). See Appendices A for detail.

Can (artisan, airtight, not for paddy rice)

Field handling with cans prevents rodents, birds, insects, rain, and theft without walls. Cans do require platforms to exclude ground water and a roof to mitigate condensation caused by temperature fluctuations (day vs night). Cans do not allow air exchange and so condensation caused by temperature fluctuations can encourage fungi and insects and in turn lead to major losses in grain quality and volume. A hermetic or airtight seal is used to prevent fungi and insects. At first the cost of airtight insect and fungi control is low. However, the longer the grain is stored in airtight cans, the longer it will take for any metabolism to reduce the atmosphere. If the can is not filled, then the excess atmosphere may

Bin (mobile utility)

Field handling mobile bins excludes rodents, groundwater, birds, rain, wild fire, theft and vents allow air exchange to mitigate condensation caused by temperature fluctuations (day vs night). Handling or “process solutions” (Rockefeller, 2015) have high utility when they mitigate fungi and insects by moving IPM into cropping systems for excellent value loss prevention/month/unit stored.

encourage any metabolism. Without the low oxygen atmosphere environment cans are less effective at suppressing insects and fungi.

Text Box 2. Summary of storage where significant PHL impacts (Lipinski, 2013) the value of stored gross yield. A market-oriented growers' net benefits are a function of price seasonality, value loss prevention, and their opportunity cost of capital invested (Jones, 2011). See Appendices B for detailed practical comparison.

Can (in warehouse to stop condensation)

Storage will capture seasonality as IPM for value loss prevention/month/unit stored is good. However, artisan constructed cans with capacities larger than 1.8 MT "become hard to operate so this is the largest practical size" (George, 2011) and limits scaling for growers' cooperative storage.

Bin (self-contained)

Bins capture seasonality as leased capacity is a business expense and reduce the need for capital, transport, and tenure. Mobile storage is a value adding process solution, since utility with wide-opening-roofs mitigates abiotic and biotic problems with excellent IPM/month/unit stored.

Text Box 3. Summary estimation of the marketing incentives for optimal production as can or mobile bin utility counter act the "yield gap that may exist as the high costs of inputs or the low returns from intensification and/or extensification make it economically suboptimal to raise production to the maximum technically attainable" (Godfray, 2010). See Appendices C for detail.

Cans (in warehouses for primary processing)

Primary processing out to bowls, sacks, back to bulk and cleaning is assisted by gravity if the loaded cans are set up on platforms. Building and maintaining strategic roofs and platforms is capital that must be risked in anticipation of price appreciation and to ease primary processing. Maintenance of redundant roofs and platforms close to dynamic aggregation and marketing locations may limit surplus production.

Bin (primary processing)

Primary processing out by gravity matches demand for bowl, sack, bulk anywhere roads go. Leasing process solutions keeps maintenance costs per unit stored per month low, and reduce the scale needed to be economical. This primary processing utility is economical as units move when empty, and park cost effectively where storage is needed.

Conclusion and recommendations

PHL limits the net benefits that storage should provide grain growers and SSA agriculture is therefore insecure and production sub-optimal.

SSA research or outreach should conclude that PHL is expensive and recommend that relatively inexpensive storage assets should meet growers' needs, as well as democratize food supply decisions.

The pilot study recommends mobile utility be reviewed objectively and compared with roadblocks so

- growers have many IPM alternatives
- abiotic and biotic PHL becomes insignificant
- agricultures' triple-bottom-line benefits growers in an inclusive manner.

Acknowledgement

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Appendices

Appendices A.

Detail practical comparison during field handling to storage environments when significant PHL occurs (Lipinski, 2013) detail.

Can (artisan, airtight, not for paddy rice)

Field handling with cans prevents rodents, birds, insects, rain, and theft without walls. Cans do require platforms to exclude ground water and a roof to mitigate condensation caused by temperature fluctuations (day vs night). Cans do not allow air exchange and so condensation caused by temperature fluctuations can encourage fungi and insects and in turn lead to major losses in grain quality and volume. A hermetic or airtight seal is used to prevent fungi and insects. At first the cost of airtight insect and fungi control is low. However, the longer the grain is stored in airtight cans, the longer it will take for any metabolism to reduce the atmosphere. If the can is not filled, then the excess atmosphere may encourage any metabolism. Without the low oxygen atmosphere environment cans are less effective at suppressing insects and fungi. If necessary, grain in the cans can be fumigated, with a caution that fumigation should never be done in cans that are located inside of living spaces. Flexible capacity for field handling to storage is poor because cans do not store cobs, groundnuts in the shell or sacks. There are mechanical options to the manual labor typically used to load, but flat-bottomed cans require manual cleaning. Cans are suited to smallholder field handling to storage because scaling to harvest is only limited by the roofs and raised platform on floors growers are willing to invest. However, relative to the surplus storage at dynamic PHL control locations needed to impact foreign exchange, cans will soon limit growers' benefits.

Bin (mobile utility)

Field handling mobile bins excludes rodents, groundwater, birds, rain, wild fire, theft and vents allow air exchange to mitigate condensation caused by temperature fluctuations (day vs night). Handling or "process solutions" (Rockefeller, 2015) have high utility when they mitigate fungi and insects by moving IPM into cropping systems for excellent value loss prevention/month/unit stored. Leases effectively scale without warehouses, so "Growers whose scale of operation is too small to be able to produce SAFE FOOD" (Cardwell, 2015) can move up by participating in cooperative storage. Field handling to storage is excellent because bins with utility also store cobs, groundnuts in the shell or sacks and combinations of sacks and bags by multiple growers. Loading utility can be either manual or mechanical and sloping floors reduce manual cleaning. Mobile utility bins are very well suited to field handling to storage because leases effectively scale (location and capacity) to prevent PHL and secure harvest regardless of transport or land rights. If the bins are purchased, they become "mobile assets" (Growing Africa, 2013). 15+ year life cycle assessments must consider assets with the utility to store inputs (seed and fertilizer) at planting, optimal aggregation locations, proximity for monitoring, primary processing, and self-cleaning features.

Appendices B.

Detailed comparison of storage where significant PHL impacts (Lipinski, 2013) the value of stored gross yield. A market-oriented growers' net benefits are a function of price seasonality, value loss prevention, and their opportunity cost of capital invested (Jones, 2011).

Can (in warehouse to stop condensation)

Storage will capture seasonality if local water tank artisans build cans so capital requirements are medium. However, if airtight cans are opened for monitoring or to add or remove portions, the hermetic atmosphere that prevents fungi and insects, must be restored by metabolism. The longer the grain is stored in hermetic cans, the longer it will take for metabolism to restore and maintain the hermetic atmosphere. If a can is not filled, then the excess atmosphere may prevent the creation of hermetic environment. Without the hermetic environment cans are less effective at suppressing for example, residual fungi. If necessary, grain in the cans can be fumigated, with a caution. Due to the limits of artisan construction, fumigation should never be done in cans that are located inside of living spaces. IPM for value loss prevention/month/unit stored is good. However, artisan constructed cans with capacities larger than 1.8 MT “become hard to operate so this is the largest practical size” (George, 2011) and limits scaling for growers’ cooperative storage. Investment is required to maintain and monitor a low atmosphere environment, roofs and the raised platform needed for gravity assisted processing and cleaning. Infrastructure for can storage is fixed relative to where large and small harvests or floods may occur, and tenure-insecure growers are less likely to invest if they consider surplus storage too risky.

Bin (self-contained)

Bins capture seasonality as leases are a business expense and reduce the need for capital, transport, and tenure. Mobile storage is a value adding process solution, since utility with wide-opening-roofs mitigates abiotic and biotic problems with excellent IPM/month/unit stored as, if necessary utility can be easily fumigated. Purchasing storage, a “process solutions” like mobile utility “are innovative ways of providing collateral” (Growing Africa, 2013) because asset with mobile utility make sense for on-site storage, security and proximity that replaces PHL with marketing for growers’ net benefits. 15+ year life cycle assessments must consider the protocol fees and services for storage rights that impacts foreign exchange.

Appendices C.

Detailed estimation of the marketing incentives for optimal production as can or mobile bin utility counter act the “yield gap that may exist as the high costs of inputs or the low returns from intensification and/or extensification make it economically suboptimal to raise production to the maximum technically attainable” (Godfray, 2010).

Cans (warehouses for primary processing)

Secure warehouses at markets offer good return even though cans are fragile and difficult to transport and require building and maintaining redundant stationary roofs and platforms. Roofs must allow access by ladder to the lid for aggregating in. Processing out to bowls, sacks, back to bulk and cleaning is assisted by gravity if the loaded cans are set up on platforms. However, if opened for monitoring, growers must restore the hermetic atmosphere and

Bin (primary processing)

Mobile bin marketing offers optimal returns. When mobile utility secures the hard labor required to aggregate harvest quality and control abiotic and biotic problems, moisture testing and using the Sun to cook insect pests (solarization) prior to storing become relevant. On the drylands at aggregation, humidity is low enough for applications of Diatomaceous Earth. After grain is stored, utility means aeration to condition, and wide-opening-roof features that ease monitoring and secure collateral. Utility nearby means aggregation, monitoring fumigation or marketing decisions become judicious and will reduce PHL, especially insects. SSA temperatures are consistent, and so endemic parasitic wasps are likely effective in a vented bin to control moths and beetles (biocontrol). Since the vented storage is located nearby, the labor required to monitor biocontrol is reduced. Primary processing out by gravity matches demand for

maintain platforms and roofs against termites and rotting. Building and maintaining strategic roofs and platforms is capital that must be risked in anticipation of price appreciation and to ease primary processing. Maintenance of redundant roofs and platforms close to dynamic aggregation and marketing locations may limit surplus production.

bowl, sack, bulk. In other words, mobile utility means capacity for growers' and their cooperatives can be adding value adding anywhere roads go. Leasing process solutions keeps maintenance costs per unit stored per month low, reduce the scale needed to be economical and enable access at any temporal or spatial link in the value chain. Self-contained primary processing utility is economical as units that move when empty, will park cost effectively where storage is needed. Mixing leases and purchases scale capacity to growers' requirements at harvest, aggregation, storing and processing at markets. 15+ year life-cycle assessments should consider how bins move to where storage is optimal, so capital investment provides the triple-bottom-line.

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Utility of biotechnology based decision making tools in postharvest grain pest management: An Australian case study

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Abstract

A major concern for the Australian grain industry in recent years is the constant threat of resistance to the key disinfestant phosphine in a range of stored grain pests. The need to maintain the usefulness of phosphine and to contain the development of resistance are critical to international market access for Australian grain. Strong levels of resistance have already been established in major pests including the lesser grain borer, *Rhyzopertha dominica* (F.), the red flour beetle, *Tribolium castaneum* (Herbst), and most recently in the rusty grain beetle *Cryptolestes ferrugineus* (Stephens). As a proactive integrated resistance management strategy, new fumigation protocols are being developed in the laboratory and verified in large-scale field trials in collaboration with industry partners. To aid this development, we have deployed advanced molecular diagnostic tools to accurately determine the strength and frequency of key phosphine resistant insect pests and their movement within a typical Australian grain value chain. For example, two major bulk storage facilities based at Brookstead and Millmerran in southeast Queensland, Australia, were selected as main nodes and several farms and feed mills located in and around these two sites at a scale of 25 to 100 km radius were selected and surveyed. We determined the type, pattern, frequency as well as the distribution of resistance alleles accurately for two major pests, *R. dominica* and *T. castaneum*. Overall, this information along with the phenotypic data, provide a basis for designing key intervention strategies in managing resistance problems in the study area.

Keywords: phosphine, molecular platform, grain value chain, resistance management

1. Introduction

Protecting harvested grain from insect infestations is essential for facilitating domestic and international trade. In Australia, for example, the industry strictly adheres to a 'nil tolerance' principle for live insects to gain competitive advantage in international trade. Over the last decade, there has been significant progress in pest and resistance management in Australia in response to the development of high level of resistance to phosphine in key pest species, the primary fumigant used to disinfest stored grain (Nayak et al., 2013; Kaur and Nayak, 2015). While the alternative fumigants sulfuryl fluoride is being evaluated as a 'resistance breaker' to alleviate phosphine resistance problems (Nayak et al., 2016), efforts are ongoing to extend the usefulness of phosphine through development of higher application rates to control strongly resistant populations (Nayak et al., 2013; Kaur and Nayak, 2015).

In any resistance management program, key components include proper determination of strength of resistance and its distribution along the value chain, and appropriate and timely control of resistant populations. Researchers in Australia and India are collaboratively engaged in the