Methyl Bromide Alternatives for Maize Grain Storage in Kenya

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Abstract: ***Among the maize pest complex that occur in both farms and bulk storage systems in Kenya, the weevil (Sitophilus zeamais Motsch.), grain moth (Sitotroga cerealella Olivier) and the larger grain borer (Prostephanus truncatus Horn) are major primary pests compared to the red flour beetle (Tribolium casteneum Herbst) which is a secondary pest of stored produce. Of the methods used to control the above pests, chemical fumigants and grain dusts are the choice options. Methyl bromide, a broad spectrum fumigant will be phased-out in Kenya in 2015 in accordance with the 1985 Vienna Convention and 1987 Montreal's Protocol for article 5 (developing) countries. Apart from phosphine gas, no other alternative is available for use in bulk storage. Though carbon dioxide fumigation is feasible it requires longer exposure period of 15 days. While fumigation ensures 99.9% pest control, there is need to invest in new grain protectants and non-chemical alternatives to compliment phosphine use and to ensure it remains effective.. The available grain dusts address pest problems at small farmer level, but the way farmers use them is of concern. The prospect of insects developing resistance to phosphine and grain dusts is real and poses great danger to the grain storage sector. The strategies that can mitigate against pest resistance need to be identified and demonstrated to all stakeholders. Adoption of hermetic grain storage by smallholder farmers and grain traders would contribute to reduced use of phosphine and grain protectants thus provide untreated 'refuge' from selection as part of resistance management strategies. Kenya needs more capacity building to identify and evaluate new and credible alternatives.***

Keywords: Grain storage, methyl bromide, phosphine, insect resistance, grain protectant

1. Introduction

Maize (Zea mays) is widely grown in sub-Saharan Africa including Kenya as staple food and livelihood income security (McCann, 2005; Gitonga *et al*., 2013). The annual per capita consumption is estimated at 103kg in Kenya, Zimbabwe 168kg and Malawi 181kg (Hassan *et al*., 2001; Pingali, 2001). The annual maize consumption in Kenya range from 30 to 34 million bags (each bag weighing 90kg) while the production average 28 million bags (Kibaara and Kavoi, 2012). The deficit is bridged by imports from the region. Food grain shortage is still a challenge encountered by farmers and other stakeholders. The causes include climate change, low productivity, diseases and pests. Grain damage due to storage insect pests pose a significant threat to food security. Whereas insect pest complex is diverse, maize weevil (*Sitophilus zeamais* Mostch.), grain moth (*Sitotroga cerealella* Olivier), the exotic larger grain borer (*Prostephanus truncatus* Horn) and the red flour beetle (*Tribolium casteneum* Herbst) are the most important.

The two commonly used pest control methods in the grain storage system are fumigation and dilute insecticide dust admixture. Grain fumigation is done at central and medium (grain traders/millers) storage systems where methyl bromide and phosphine are commonly used. Whereas chemical pest control methods are efficient and effective against a wide range of storage pests, studies blame their use on health hazards (Wolansky *et al*., 2007), environmental pollution (Daglish and Wallbank, 2002) and insect resistance development (Benhalima *et al*., 2004; Pereira *et al*., 2009). In addition, the Montreal Protocol identified added methyl bromide as an ozone depleting substance (UNEP, 2002) and recommended its phase out by January 2015. The ozone layer protects the earth from higher levels of ultraviolet - B radiation from the sun. Ultraviolet – B rays have great potential to cause skin cancer, eye cataract and suppressed immunity to humans and damage to crops.

The fumigant is currently used in Kenya predominantly by National Cereals Produce Board (NCPB) for postharvest grain fumigation in their silos and warehouses. Other players in the grain trade enlisted pest control services to well established companies including Rentokil Before grain market liberalization in 1993, NCPB ensured all grains imported into Kenya by the government were fumigated at the port of entry to disinfest exotic pests. It used 300 tons of methyl bromide to fumigate 15 – 20 million bags of 90kg of grain. After liberalization, other grain handlers came into the scene and NCPB now handles only its commercial maize and 4 million bags in strategic reserve for the government. Its use of methyl bromide has also reduced to 0.6 tons annually. Grain fumigation is a professional job but many newly established pest control companies lack personnel with adequate or relevant skills hence there is doubt in their work output. Presently, information on the use of available alternatives and their limitation for grain treatments is scanty.

2. Alternatives to methyl bromide and their limitations

The alternative treatments that have worked elsewhere in the world include but not limited to carbon dioxide (modified atmosphere systems) (EPA, 2010). The alternatives that have continued to work locally are discussed below.

2.1 Pest control at central and trader/miller storage level

2.1.1 Fumigation

Phosphine gas (hydrogen phosphide, PH_3) is the most common fumigant used on stored grain worldwide. It is available in solid form making it very easy to handle even by the inexperienced persons. It is routinely used in Kenya for treatment of bag and bulk stored grain. As an alternative, PH_3 cannot match all aspects of methyl bromide including cost - effectiveness (Fields and white, 2002; Phillips and Throne, 2010). It requires exposure period of more than 7 days to allow complete gas release especially if temperatures are below 15^{o}C. Also, some insects have higher tolerance to PH_3 fumigation. In situations that cannot be made gastight, attempts to fumigate without checking to correct the problem only result into failure, which leads to the build - up of resistance to the fumigant (Chaudhry, 2000; Song *et al.*, 2011) and migration of resistant populations through grain trade (Opit *et al*., 2012; Pimentel *et al*., 2010). Some insects such as *Rhyzopertha dominica* (F.) and *Tribolium* castaneum (Herbst) have developed resistance to phosphine (Opit *et al.*, 2012).

2.1.2 Monitoring of PH3 concentration

Careful monitoring during PH_3 fumigation could safeguard its effectiveness. These pests have cosmopolitan distribution and occur readily in NCPB storage network. For bulk storage, the NCPB has a network of silos in the main urban centres which effectively replaced the old Cyprus bins in Kitale and Nakuru (Plate 1). Grain held in these silos must conform to the safe moisture for storage level of below 12%. Once this is ascertained, pest control using PH_3 is normally done during loading. Bagged grain is normally done in warehouses where polypropylene bags have replaced the jute or sisal ones.

Polypropylene bags, have restrictive weave against insect penetration and reduced air circulation. Poor air circulation could probably lead to discoloured maize by a process commonly referred to as 'internal stackburn' first observed in Zimbabwe, which coincided with change from storing in jute to woven polypropylene bags (Golob *et al*., 2004). Stackburn is a discolouration of the outer layer of the grain and embryo of stored maize when both moisture content and temperature are high. A comparative study on insect response in grain stored in polypropylene and jute bags under PH_3 fumigation could shed more light on whether the bags play any positive or negative role. On-farm simulation of farmer practice where grain damage was assessed in samples from jute and polypropylene bags found reduced impact in the latter confirming the restrictive nature of the weave. Ineffective grain fumigation due to poorly sealed structures (Benhalima *et al*., 2004); lack of PH3 monitoring (Mills and Athie, 2001); reliance on single fumigation and unsupervised grain trade (Ahmedani *et al*., 2007) which allows resistant strains to be exported or imported could be the main factors that contribute to wide spread resistance.. Training remains the best approach in fighting the rise in pest resistance

2.2 Chemical pest control at farm level

Research has continued to play its role in evaluating pest control products before they can be registered for use locally by the Pest Control Products Board (PCPB). The results enable farmers to store their grain for periods of 6 months or more. Of the chemicals commonly used by farmers, the mixture of 1.6% Pirimiphos-methyl and 0.3% Permethrin is the most effective against a wide range of insect pests. However, their success depends on correct timing, use of recommended dose and appropriate method of application. Whenever farmers use chemical dusts, their methods of application often leave untreated pockets where insects could and do survive. Such grain may find its way to cal or central storage depots through trade and the risk of under - treatment spreads. Concerted efforts are therefore required in training farmers on the best ways to handle their grain. Besides methyl bromide and pshosphine, other pest management methods used by NCPB include spray treatment of dunnages onto which bag stacks are built and around the warehouses and the top manhole of the silos after fumigation using Actellic 25% EC or Fendona 6% SC. Private pest control/fumigation companies use phosphine to fumigate and spray treatments routinely for spot disinfestation around warehouses and factories.

To spearhead the search for credible alternatives, KARI in consultation with the Kenya National Ozone Unit held two pioneer workshops covering grain fumigation with PH_3 and farm demonstrations on use of dilute chemical dusts during storage (Ngatia *et al*, 2005). With financial support from the Multilateral Fund through Environment Canada, KARI brought together representative from Ministry of Agriculture, Pesticide companies, NCPB, grain traders, Farmer representatives from different Farmer Field Schools (FFS) and community based organisations. The objectives of the workshops/demonstrations were to sensitize the stakeholders on the impact of methyl bromide phase out by 2015 and the need to effectively use available alternatives. While the workshops revealed that admixing chemical dusts with grain in silos as it moves along the conveyor belt was feasible, the residue could be a problem because of the quantity involved. A shift of focus to supporting the farmer to use chemical dusts on the farm was more prudent. This was supported by the wide distribution network available throughout for the range of chemical dusts. It was recalled that from 1970s and up to 1980s, NCPB used to encourage farmers to use chemical dusts by paying additional one shilling to every treated bag before delivering to their depots. The above was instrumental in reducing frequent grain fumigation at the depots, but the practice was discontinued when unscrupulous people delivered maize with high moisture content. A revisit on the idea with proper checks in place could bring down pest damage to below economic threshold. Other findings were:

- The NCPB remains the main actor in the grain storage sector, but its capacity to handle complex storage issues have been compromised by reduced budgetary allocations, staff mobility and lack of a good training program.
- The country requires bilateral assistance to identify and capacity building to evaluate credible alternatives.
- Though research has played key role under diminishing budgetary allocation, it could not do much better if this was enhanced to help revive the program where KARI staff used to visit NCPB depots countrywide to inspect and sample for quality analysis every six months..

2.3 A case for non- chemical alternatives

2.3.1 Modified atmosphere

Carbon dioxide (CO_2) has been used in Australia and Israel. It is much heavier than air and usually transported under refrigeration. Its suitability and effectiveness as a fumigant was tested in maize silos at NCPB Nakuru silo complex by KARI in 1995 in collaboration with Natural Resources Institute (NRI) of University of Greenwich, UK and a private company, Carbacid, which mines the gas in the country (Brice *et al.*, 1995). Though its use in Kenya is technically feasible, but its effectiveness depends on dosage rate, long exposure time (15 days) and constant pressure testing due to its capacity to diffuse into commodity and concrete structures. The Cost - benefit analysis demonstrated that CO_2 fumigation was more cost effective at ksh.66 per ton compared to phosphine gas at ksh.92 per ton. However, the capital outlay to enable design change over and technical implications are the main constraints. One of the new innovations to fight pest resistance could be to evaluate a cocktail of CO_2 and PH_3 if such a formulation could be made. This calls for a complete change to enable the two to be mixed in the gaseous form. The research question then would be what ratio to use and what benefits to be achieved considering that both require long exposure period.

2.3.2 Diatomaceous earths (DEs)

DEs are fossilised skeletons of diatoms comprising of amorphous or shapeless silicon dioxide (silica) and small amounts of other mineral elements (Stadler *et al.*, 2012). In contrast to synthetic chemicals, DE dusts adsorb the epicuticular lipid layers inducing mortality mainly as a result of excessive water loss through the cuticle of the insects (Athanassiou and Steenberg, 2007). Whereas commercial DEs such as Dryacide®, Insecto®, Protect -It® and SilicoSec® have been found effective against an array of insect pests and registered in many countries (Stathers *et al.*, 2004), the potential of their use in central storage systems has not been carried out. A study recently concluded by KARI showed DE could effectively protect stored maize under mid-altitude high humidity areas as well as in arid and semi-arid low humid zones (Ngatia *et al.*, in press). Although DEs are effective against storage insect pests, several factors, which include target species, life stage, strain, and grain type (Kabir *et al.*, 2011) limit their efficacy. Because DEs are not insecticides, they take time to affect target organism and are ineffective in damp environment.

2.4 Integrated Pest Management (IPM)

IPM is a pest risk management that combines biological, cultural, physical and chemical tools. IPM is information based integrating pest and facility knowledge to achieve satisfactory control while protecting the environment. It includes:

Sanitation: Improved store sanitation reduces frequency of fumigation. Facilities that maintain highest sanitation levels take longer time before re-infestation occurs (rebound time). Good warehouse practices such as inspection of grains reduce the probability of infestation.

2.4.1 Monitoring

Helps to identify the existing and potential pest problem into a storage facility. The records of the infested area and the insect density over time are kept. These records are used as indicators of the effectiveness of a control measure and for pest management decisions to avoid unnecessary or late implementation of control measures. Visual inspections in and around storage facility, examination of grain samples, monitoring changes in temperature and insect trapping are among the methods used.

2.4.2 Physical Control

Creating extreme temperatures such as low or high and combined with modified atmosphere provide effective control of pests. However, increased power efficiency and gas-tightness of the existing facilities need to be determined.

2.4.3 Hermetic Storage

The technology is based on the principle of creating an oxygen-depleted and carbon dioxide-enriched condition in a sealed storage structure. The conditions are created by metabolism of insects, fungi and grain itself (organic hermetic system) which cause death of same insects and microorganism by asphyxiation (Murdock *et al.*, 2012). Based on hermetic storage, NCPB was able to store grains in Cyprus bins for three to five years with recycling for aeration. Such maize was used as strategic reserve and only released to fight famine. Grain losses were minimal estimated at one percent over three years of storage (Baker, 1974). Their use was discontinued in 1992 when the cost of repair and maintenance became unbearable under strict budgetary cuts. To fill up the void, CIMMYT in partnership with KARI and CARITAS of Embu, Homa Bay and Nakuru Catholic dioceses have been promoting metal silos and hermetic bags for use by smallholder farmers. Metal silos of different sizes are fabricated by trained artisans at local village level and farmers order what they can afford. Hermetic bags are made of three plastic bags inserted and sewn into one. Grain is put in the inner bag, entrapped air squeezed out and tied and the others are tied above it. A practical and cheap technology to reduce and maintain oxygen at very low and carbon dioxide at high levels within a short time is required at farm level. However, hermetic storage require involvement of private sector.

3. Challenge posed by imminent methyl bromide phase-out

Restriction on the use of methyl bromide as a fumigant poses a challenge not only to the grain handling industry, but also to the flower and soil treatment sectors. Support to the flower and soils sectors has enabled them to evaluate such alternatives like metam sodium, solarilization and hydroponics. Only the grain storage sector in Kenya appear to be left out though it is a minor user of methyl bromide. The market pressure to supply residue -free grain from end users is on the rise and therefore alternative insect control alternatives need to be identified and/or developed with urgency. At present, PH_3 fumigation remains the only alternative to methyl bromide in grain storage industry in Kenya. PH_3 and grain protectants have become vulnerable to insect resistance leading to control failure. (Chaudhry, 2000; Pimentel *et al.*, 2010; Song *et al.*, 2011). A survey of major insect pests in stored grain across the country to generate data (determine the presence and extent of resistance) on which to base resistance management strategies and to inform and influence policy makers to lobby for support in the search for viable alternatives is urgently required. From the survey data, a strategy to manage resistance not only to PH_3, but to the whole range of storage chemicals should be developed in consultation with researchers and the grain industry to ensure inherent practical constraints in the industry are accommodated without deviating from resistance management objective. KARI and Universities have the capacity to play a lead role in areas of postharvest storage, infestation and resistance level studies while NCPB, KEPHIS and PCPB would provide industry leadership in chemical use, market requirement and regulatory services, respectively. Further, technology transfer through training, workshops and infrastructural investment also need support. With requisite support, research would be in a position to revive and broaden the national pest resistance monitoring and management team. The new team could comprise of representatives from line ministry, grain growers, grain traders, chemical companies, regulators, universities and research institutions. Any data generated by the team would be stored on internet -based database called Kenya Grain Insect Resistance Database (K-GIRD)

Presently, there is no known pre – shipment treatments with similar action and speed as methyl bromide. NCPB is the only institution approved by NEMA to import methyl bromide for critical use such as quarantine and pre-shipment fumigation. However, with credible alternatives and country-to country inspection arrangements in place, there would be no need for continued pre-shipment measures using methyl bromide. In addition, the NCPB will have changed the system that depends entirely on methyl bromide fumigation for pest management and replaced them with evaluated alternatives.

4. Conclusion

The progress made by Kenya towards achievement of methyl bromide phase–out in grain storage subsector is described including credible alternatives, those with potential of being rapidly adopted through technology transfer or further research and capacity building were identified. Methyl bromide fumigation is mainly curative and its phase-out only leaves phosphine and contact insecticide as alternatives that are currently being used for insect pest management in stored grain. Phosphine gas has been widely abused and its effectiveness needs to be safeguarded through careful monitoring and adherent to the principles of good fumigation. Research will play its role to determine the extent of phosphine resistance in different insect species and geographical locations affected. A national pest monitoring and management team supported by all stakeholders and coordinated from KARI is the way forward.

5. Acknowledgement

We are grateful to the agencies that funded the work discussed in this paper. The views expressed herein are the authors' and do not necessarily reflect policies of the respective institutions.

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