



## A mini-review of potential toxicity, efficacy and residues management of actellic-based grain preservatives

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### ARTICLE INFORMATION

#### Article History

Submitted: 01 Oct 2020

Accepted: 12 Nov 2020

First online: 29 Dec 2020

#### Academic Editor

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### ABSTRACT

Actellic Gold and Actellic Super Dusts are the most commonly used pesticide products for grain storage in East Africa. Although no efficacy data is available comparing these two products directly, Actellic Gold and Actellic Super Dusts seems to be similar and within acceptable efficacy ranges. Both the products can give mortality rates above 75% of the targeted pests for at least 4 months of storage. The storage period could be longer under improved storage structures like PICS and metallic silos. However, the widespread use of these two pesticides is causing development of resistance in the region. This would threaten the sustainability and economics of crop production as pests will no longer be controlled. To manage this resistance, researchers should explore alternative pesticides with better efficacy, and safety for rotation. These alternative products should be available at affordable cost to all farmers. Like other pesticides, use of Actellic Gold and Actellic Super Dusts could have health and environmental concerns whenever used improperly. From the research, the active ingredients have relatively low acute oral LD<sub>50</sub> values (938–2,690 mg kg<sup>-1</sup>). Although research has proved that at least 80% of these compounds could be excreted from the body in the short term, the long-term bioaccumulation effects are yet to be well understood. To help minimize potential health risks, farmers should always follow the instructions provided on the product labels like wearing goggles, mask, apron, and rubber boots when making the application. Also, home-based processing methods such as sun and air drying of the grains for at least 3 hours, washing, soaking, and boiling could help reduce the concentration of these compounds in the grains and their products.

**Keywords:** Actellic products, post-harvest grain loss, pesticide residue limit, *Prostephanus truncatus*; *Sitophilus zeamais*, *Acanthoscelides obtectus*



**Cite this article:** Otieno HMO, Alwenge BA. 2020. A mini-review of potential toxicity, efficacy and residues management of actellic-based grain preservatives. Fundamental and Applied Agriculture 5(4): 491–499. doi: 10.5455/faa.3243

## 1 Introduction

Post-harvest maize yield losses are complex and involve quantitative and qualitative losses occurring within the value chain. This type of yield loss is high and is one of the major causes of food insecurity in the Sub-Saharan Africa (SSA) region. According to ECJRC (2014), post-harvest losses are estimated to be about 10-23% in cereals across SSA region. Among cereals, maize is the most affected, with losses of about

16-20% compared to other cereal crops such as wheat (5-15% loss), sorghum (11-12% yield loss), teff (11-12% yield loss), and barley (4-12% yield loss) (Tanya, 2017). In Kenya, for instance, these losses are estimated to be about 12-20% of the national production (Onyango and Kirimi, 2017); with about 20-30% of it occurring immediately within the first 6 months after maize harvesting (Kimondo, 2008). The high post-harvest losses in the region is mainly because

of high incidences of insect pests attacking grains from the fields to stores. The high survival and multiplication rates of these pests are as a result of the favorable tropical climate experienced in the region. The extensive production of maize is also likely to result to high losses compared to other crops in the region. The common and important storage insect pests in the region include maize weevils, larger grain borer, moths and red rust flour beetle. If left uncontrolled, these pests could cause 100% loss of products within a few months of storage. To manage these pests, farmers have adopted traditional and modern methods. Some of the commonly used traditional methods/preservatives include smoking, application of wood ash, pebbles, open fire place, and solarization (Golob et al., 1982; Mobolade et al., 2019; Jean et al., 2015). However, because of inefficiencies of these traditional methods, farmers have shifted their focus and are using synthetic chemical preservatives (Kumar and Kalita, 2017). The commonly used chemical preservatives in the region are Actellic compound-based products- mainly Actellic Super Dust and Actellic Gold Dust. Kimenju and De Groote (2010) reported that over 93% of farmers who use chemical preservatives use these two products for storage of maize. These products could have detrimental impacts on the environment and human if not used properly. In humans, cancer, immune system deficiencies, dose-dependent DNA damage, pulmonary and hematological morbidity are some of the most common effects of using dangerous pesticides (UNEP, 1993; Wang and Lin, 1995). Illiteracy and lack of knowledge and information relating to proper selection, best application procedures, and use of personal protective equipment are the predisposing factors. In the environment, the widespread use of these same products have triggered the development of resistance among insect pest populations. This resistance would render these products ineffective and uneconomical in the long term.

Based on this background, this paper aimed at shedding more light on the use of these Actellic products. Specifically, the research sought to (a) assess the mode of action, efficacy and potential development of resistance among storage pest populations, (b) assess the potential human toxicity caused by Actellic-based products, and (c) assess the potential practices for the management of Actellic compound residues in treated grains and products before consumption.

## 2 Methods and Data Sourcing

The secondary data used were systematically sourced from various scientific publications. We assessed the toxicity based on technical compounds in the products- namely pirimiphos-methyl, thiamethoxam, and permethrin compounds. The short-term toxic-

city was assessed based on oral ( $\text{mg kg}^{-1}$ ) dermal ( $\text{mg kg}^{-1}$ ) and inhalation ( $\text{mg L}^{-1} \text{4h}^{-1}$ ). Under efficacy assessment; we presented pesticide's mode of action as given by IRAC classification ([www.irac-online.org](http://www.irac-online.org)) while potency/mortality of storage pests as reported in by various researchers. Solubility of the compounds were used to evaluate the potential for environment toxicity. Key search terms used to locate the resources were; 'Actellic/ Pirimiphos-methyl/ Thiamethoxam/ Permethrin LD<sub>50</sub>', 'pesticide residual effect', 'pesticide efficacy', 'Pirimiphos-methyl/Thiamethoxam/ Permethrin carcinogenicity', 'pesticide residue levels and management', 'Actellic and human health' and 'short and long-term effects of pesticides'. The sourced materials were downloaded, read and cited as a best practice.

## 3 Mode of action, efficacy and pest resistance

The best approach in pest control is through integrated pest management (IPM). The IPM integrates a range of plant protection methods that limit the development of populations of harmful organisms, while keeping the use of pesticides to levels that are economical and minimize risks to human health and the environment. The IPM primarily emphasizes the prevention and suppression of harmful organisms through crop diversification, planting density, planting timing, variety selection, and various other agroeconomic approaches (Barzman et al., 2015). Under IPM, the use of pesticides should be restricted to under emergency cases and/or when other control methods have failed to prove effective (Otieno, 2019). Proper usage of pesticides begins with, among others, the proper selection of products. When choosing pesticides for use, farmers need to consider the safety, ecological risks, efficacy and economic factors (Sharifzadeh et al., 2018; Otieno, 2019). These pesticides provide an effective method of grain preservation in areas with limited access to effective grains storage systems. However, their efficacy could reduce overtime leading to high grain losses (Nukenine, 2010).

Actellic Gold Dust and Actellic Super Dust products combine the use of two active ingredients; Pirimiphos-methyl ( $16 \text{ g kg}^{-1}$ ) + Permethrin ( $3 \text{ g kg}^{-1}$ ) ([www.twigachemicals.com](http://www.twigachemicals.com)), and Pirimiphos-methyl ( $16 \text{ g kg}^{-1}$ ) + Thiamethoxam ( $3.6 \text{ g kg}^{-1}$ ) ([www.syngenta.co.ke](http://www.syngenta.co.ke)), respectively. Both products have one main AI, pirimiphos-methyl. This combination of two different AIs gives these products two modes of action (MoA); 1B + 3A and 1B + 4A, respectively. The thiamethoxan and permethrin compounds act as fortifiers to the main active ingredient. This fortification of pirimiphos-methyl increases the efficacy of the end product (Huang and Subramanyam, 2003; Athanassiou et al., 2009). Depending on the method

of storage (hermetic versus non-hermetic bags) used, pesticide concentrations, and grain moisture content, mortality as high as 100% of storage pests and up to zero percent weight loss over has been reported. For instance, [Mlambo et al. \(2017\)](#) reported 90-100% and 99.6% reduction in grain damage and grain weight loss, respectively, within 40 weeks of using Actellic Gold Dust under farmer storage conditions with high infestations of *Sitophilus zeamais*, *Prostephanus truncatus* and *Tribolium castaneum*. In a bioassay experiment comparing the efficacy of spinosad dust with Actellic Super Dust against major storage insect pests, [Mutambuki et al. \(2014\)](#) reported 100% mortality of *S. zeamais* and 85-99% mortality of *P. truncatus* within 24 weeks. Other researchers have reported 73-100% mortality of *S. zeamais*, *Callosobruchus maculatus*, *Lepinotus reticulatus*, *Liposcelis entomophila*, *L. bostrychophila*, and *L. paeta* on stored maize, rice and wheat within a period of up to 12 months using other pirimiphos-methyl based pesticides (Actellic 500 CE) ([Abo-Elghar et al., 2003](#); [Sgarbiero et al., 2003](#); [Athanassiou et al., 2009](#); [Denloye et al., 2007](#)). However, other studies have reported poor performance of Actellic Super Dust; over 50% maize grain damage within 24 weeks of storage ([Groote et al., 2013](#); [Mutambuki et al., 2014](#)).

Despite high efficacies, farmers need to be aware of the development of insect resistance among storage pest populations. Pesticide resistance is defined as genetic-based decrease in susceptibility of a population to a toxin caused by exposure of the population to the toxin ([Tabashnik et al., 2009](#)). The widespread usage of these insecticides is likely to induce resistance among members of storage pests. Researchers have noted some levels of resistance to the use of actellic-based products by storage pests. For instance, *Rhyzopertha dominica* and *Sitophilus oryzae* populations in Rwanda ([Dunkel et al., 1990b](#)). The incidences of *S. zeamais* developing resistance to actellic products are widespread and have been reported in Ghana and Zimbabwe ([Dunkel et al., 1990a](#)), Mexico ([Perez-Mendoza, 1999](#)), and Nigeria ([Odeyemi et al., 2010](#)). Therefore, to ensure sustainability in production, farmers should start rotating these products. These pesticides for rotation should be effective and available in the market. Also, other non-chemical based storage technologies like the use of hermetic bags (e.g. Purdue Improved Crop Storage- PICS and Triple layer bags) and metal silos could be explored and applied for safe and sustainable post-harvest loss management. These containers significantly modify the environment inside them leading to a reduction in grain deteriorations caused by these insect pests ([Bailey, 1965](#); [Murdock et al., 2012](#)). Researchers have proved that the PICS technology can reduce insect pest infestation and grain weight loss by up to 98% ([Baoua et al., 2012](#); [Williams et al., 2017](#)).

## 4 Potential toxicity

Actellic Super Dust and Actellic Gold Dust combine the use of two active ingredients (AI) with the major component being pirimiphos-methyl (at 16 g kg<sup>-1</sup> concentration). In these products, the main AI is fortified with thiamethoxan at 3.6 g kg<sup>-1</sup> and permethrin at 3.6 g kg<sup>-1</sup>, respectively ([www.syngenta.co.ke](http://www.syngenta.co.ke); [www.twigachemicals.com](http://www.twigachemicals.com)). The toxicity levels of these products vary. Pirimiphos-methyl compound has acute oral LD<sub>50</sub> value of 1180-2050 mg kg<sup>-1</sup>, dermal LD<sub>50</sub> value >2000 mg kg<sup>-1</sup>, and inhalation greater than 5.04 mg L<sup>-1</sup> 4h<sup>-1</sup> ([Brealey et al., 1980](#); [Ivbijaro, 1981](#); [WHO, 2010](#)) (Table 1). Based on these values, the product is classified under hazard class III ([EPA, 2006](#)). This product could have detrimental effects at higher concentrations in humans, birds, and other mammals ([Ngoula et al., 2007](#); [Lawal and Samuel, 2010](#)). The fortifiers have different toxicity levels based on their LD<sub>50</sub> values. Thiamethoxam has acute oral LD<sub>50</sub> of 1563 mg kg<sup>-1</sup>, dermal LD<sub>50</sub> of >2000 mg kg<sup>-1</sup> and inhalation of >3.72 mg L<sup>-1</sup> 4h<sup>-1</sup> ([Maienfisch et al., 2001](#)) (Table 1). Based on these LD<sub>50</sub> values, the product is classified under hazard class III ([WHO, 2010](#)). Permethrin has acute oral LD<sub>50</sub> of 930-2690 mg kg<sup>-1</sup>, dermal LD<sub>50</sub> greater than 4000 mg kg<sup>-1</sup> and inhalation of 23.5 mg L<sup>-1</sup> 4h<sup>-1</sup> ([Ishmael and Litchfield, 1988](#); [Cantalamesa, 1993](#); [EPA, 2006](#); [Hansen and Khan, 2013](#)) (Table 1). In terms of carcinogenicity, the available data seemed not to present enough and clear evidence to conclude these products are carcinogenic or not. Majority of researchers seemed to conclude that permethrin does not cause or promote growth of tumors or cancer cells- a comprehensive review by [McConnell \(1994\)](#). During the assessment of thiamethoxam-related health effects, [Pastoor et al. \(2005\)](#) concluded that the product does not pose a carcinogenic risk to humans. Other researchers have also assessed and concluded that thiamethoxam is unlikely to pose a danger to humans exposed to this chemical at the low concentrations found in the environment or during its use as an insecticide ([Green et al., 2005](#)). A similar non-carcinogenic claim has been made by researchers on pirimiphos-methyl compound when tested on rats and other animals ([Syngenta, 2015](#); [WHO, 2016](#)). However, other researchers seemed to take a neutral point by concluding that the data is not adequate to determine whether the product is carcinogenic ([Karalliedde et al., 2001](#); [Paranjape et al., 2015](#)). The potential of bioaccumulation of these pesticides in the human body is unclear, and the current research work only exist for animals like rats, birds, fish, and rabbits ([Green et al., 2005](#); [Omoyakhi et al., 2008](#); [Clasen et al., 2018](#)). The extrapolation of these results to humans is yet to be conclusive. In terms of solubility, pirimiphos-methyl is slightly volatile and has low solubility in water, 0.01 g L<sup>-1</sup> (Table 1). Permethrin is nearly insoluble in



water, approximately  $0.0000052 \text{ mg L}^{-1}$  at room temperature. On the other hand, thiamethoxam is highly water soluble ( $4 \text{ g L}^{-1}$ ) (Table 1). This means that thiamethoxam would be transported to greater depths in the soil column in soil pore water leading to high potential of environmental pollution than pirimiphos-methyl and permethrin. This is further supported by the regular occurrence of thiamethoxam in surface water bodies in areas of intensive agriculture (Struger et al., 2017; Main et al., 2014).

## 5 Management of Actellic compound residues

To ensure pesticide free food products, farmers must explore other alternatives that are cheap and safe like adoption of cultural and agronomic practices. Proper sun-drying of grains before storage to moisture levels below the critical 12% improves storage. Another commonly used traditional method of preserving grains is the use of wood ash (Golob et al., 1982; Jean et al., 2015). Wood ash has been found to offer significant protection of grains against insect pests with no reduction in seed viability (Jean et al., 2015). However, the use of chemical compounds is still preferred in the control of these pests because of their high efficacies. But this comes at a cost, possible human and environment toxicity. Since these preservatives are mixed with grains, it is obvious they stick on to the coats/pericarp or even get into the grains. This makes it possible to get into the body when the preserved grains are consumed without proper processing. The residual concentration of these chemicals vary depending on prevailing environmental conditions, the period of storage, grain moisture content at the time of storage, concentrations of the products used and type of crop being stored. On individual grain, the concentrations would vary depending on the part of the grain, with a higher concentration on the outer layer (pericarp/bran) compared to the inner layers of the grain (Hajslova, 2000; Balinova et al., 2006). This implies that whole-meal grains and brans would have a higher concentration levels likely to cause significant health impact compared to polished grain products (FAO-WHO, 2004). Researchers have reported low to high pirimiphos-methyl compound residue concentrations in grains: wheat (Sowunmi and Fetuga, 1983; Sgarbiero et al., 2003; Balinova et al., 2006), corn and popcorn grains (Sgarbiero et al., 2003; Silveira et al., 2009), barley, oat, peanuts, and rice (Bullock, 1973). This means that the preservatives find their way into the human body with potential health hazards. Because of these residual accumulations, various international regulatory bodies have set the Maximum Residue Level (MRL) of pesticide compounds acceptable in any grain and animal products. According to ECJRC (2014) MRL is defined as

the highest level of a pesticide residue that is legally tolerated in or on food or feed when pesticides are applied correctly. The MRL depends on several factors, including the crop type and the age of the consumer. For instance, much lower levels are set for baby foods compared to adults. For cereal-based baby foods, the European Commission Directive established an MRL of  $0.01 \text{ mg pirimiphos-methyl per kg}$  Balinova et al. (2006). The MRL for other crops have been established; cereals (e.g. maize, wheat, barley, millet, sorghum, and rice) at  $5 \text{ mg pirimiphos-methyl per kg}$  and legume (e.g. beans and peanut) at  $0.05 \text{ mg pirimiphos-methyl per kg}$  (ECJRC, 2014).

Other than through consumption of grain products preserved with the pesticides, these compounds could also get into the body through inhalations and dermal contacts if the applicator is not protected during grain treatment. Irrespective of the exposure method, pirimiphos-methyl and thiamethoxam compounds are easily excreted out of the body through urine and fecal matter. According to Bowker et al. (1973), Green et al. (2005), and Bullock et al. (1973), 80-100% of these compounds administered in rats, cows, and hens could be eliminated within 7 days after administration. If the situation presented with the experimental animals is similar to humans, then the products are easily excreted from the body. This is a natural process helping the body to keep toxins level as low as possible.

Apart from the above natural processes, consumers should take extra-precautionary measures to ensure foods eaten are low in concentration of these products. To reduce the concentration of pesticide residues in grains, consumers should adopt practices and processes that have been proved to reduce the concentrations of these compounds. These practices are broadly categorized as preparatory steps, thermal treatments, product manufacturing, and post-harvest handling (Bajwa and Sandhu, 2011). Washing pre-treated products with plenty of water before eating (as salads) or cooking has been found to remove pesticide residues on grains, vegetables, and fruits (Nasr, 2002; Radwan et al., 2004). According to Tejada et al. (1990) the habitual practice of washing rice and maize grains before cooking could reduce pesticide residues by 59–100%. During washing, the water dissolves and hydrolyze the pesticide, which are then drained out. Sometimes salt solution could be used for washing; up to 90% reduction in pesticide residue concentrations has been reported with this method (Kumar et al., 2000). Boiling could also significantly reduce the concentration of water-soluble pesticide compounds. About 50-80% reduction of pesticide residue concentrations upon boiling has been reported by Sharma et al. (1994) and Watanabe et al. (1988). Another important method of processing vegetables is blanching. Wen et al. (1985) and Lee and Jung (2009) found blanching method

**Table 1.** Toxicity summary of main active ingredients in Actellic Gold Dust and Actellic Super Dust products

Active ingredient	Acute oral LD <sub>50</sub> (mg kg <sup>-1</sup> )	Dermal LD <sub>50</sub> (mg kg <sup>-1</sup> )	Inhalation LD <sub>50</sub> (mg L <sup>-1</sup> 4h <sup>-1</sup> )	Solubility in water (g L <sup>-1</sup> )
Pirimiphos-methyl	1,180 to 2,050	1,505 to >2,000	>5.04	0.01
Thiamethoxam	1563	>2,000	>3.72	4.1
Permethrin	938 to 2,690	>4,000	23.5	0.0000052

to reduce pesticide residue concentrations by up to 99% in vegetables. Heating reduces pesticide concentrations through degradation and evaporation. The application of heating method in our daily lives is through solarization of maize grains before using for other household purposes. Roasting of peanuts is also another method that could significantly reduce concentrations of these compounds. If possible, consumers should combine as many strategies as possible to reduce pesticide concentrations in grains and other foodstuffs. For instance, when preparing boiled maize/bean for local dishes, the process should begin with sun-drying followed by soaking and washing before cooking. This combination could provide grains free from pesticide residues.

## 6 Conclusions and Recommendations

Actellic Gold and Actellic Super Dusts are the most commonly used grain storage preservatives in Sub-Saharan Africa. Although there is no side-by-side efficacy data comparing these products, the efficacy data presented seems to be similar and reasonable. High mortality of storage pests could be achieved for at least 5 months during storage. This period is likely to be longer when using improved storage structures like hermetic stores, PICS and Silos. The widespread use of these pesticide products is causing development of a resistant populations. Many other preservatives are available on the market for exploitation; a preliminary review of evidence suggested that at least some of these products may be more effective and safer than Actellic Gold or Actellic Super. Actellic Gold and Actellic Super Dusts pose similar health risks to human health. These products remain in the treated grains and could have health risks if consumed above MRL. Steps should, therefore, be taken to train farmers on how to minimize any health risks associated with these preservatives.

- Farmer should be trained on integrated pest management methods, proper hygiene, and use of personal protective equipment (PPE) when handling pesticides.
- Before using any chemical pesticides, farmers should first explore the use of traditional strategies such as smoking, application of wood ash,

pebbles, open fire place, and solarization. All the traditional methods ensure chemical free foods.

- To reduce chances of developing a resistant population, pesticide rotation should be promoted among farmers. This means that alternatives should be tested in terms of cost, efficacy, and health risks.
- To mitigate any short and long term health risks associated with the use of actellic and other pesticide products, training should cover various home-based processing strategies with the capacity to reduce pesticide residue concentrations. These processes and practices include (i) sun and air drying of the grains preserved using these pesticides for at least 3 hours before processing further, (ii) washing and soaking of beans, cowpea, grams, and maize before boiling, and (iii) processing (e.g. polishing) of grains should be done to remove the outer layer that contain these compounds.

## Abbreviations

AI: Active ingredient; FAO: Food and Agriculture Organization of the United Nations; MRL: Maximum Residue Level; UNEP: United Nations Environment Programme; USEPA: United States Environmental Protection Agency; PICS: Purdue Improved Crop Storage; WHO: World Health Organization.

## Conflict of Interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

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