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Integrated Pest Management of the Yam Chip Beetle *Dinoderus porcellus* Lesne (Coleoptera: Bostrichidae): Current Status and Future Prospects

Loko Yêyinou Laura Estelle, Toffa Dèca Mondoukpè Joelle and Orobiyi Azize

Abstract

In West Africa, *Dinoderus porcellus* Lesne (Coleoptera: Bostrichidae) is a pest that attacks and spoils stored yam chips. Despite this fact, very little attention has been given to this pest, which could destroy up to 65% of stocks. In order to prevent any damages, farmers are widely using chemical substances for fighting against this pest despite their negative impacts on human health and environment. This chapter aims at proposing a solution approach and discussing the development of an integrated pest management strategy. The solution approach includes storage bags, varietal resistance, botanicals, and biological control. Further research should be done on the use of hermetic bags, essential oils, entomopathogens, insect growth regulators, pheromones, and their combined effects in the *D. porcellus* control.

Keywords: biological control, botanicals, *Dioscorea* sp., storage bags, varietal resistance

1. Introduction

Yam (*Dioscorea* sp.) is a plant that produces edible tubers that contribute to food security and poverty reduction in West Africa. With a production of 67,312,076 tons in 2017, representing 96.3% of world production, West Africa is rising to first place in the production and consumption of yam (236 kcal) per capita per day [1]. Yam tubers that are used in the preparation of various culinary dishes in West Africa [2] are very rich in carbohydrates, vitamins, and minerals [3]. In addition to the important trade in yams in West Africa [4], it is anchored in the sociocultural life of the populations as evidenced by the many festivals organized for the release of new yams [5].

Unfortunately, because of their high water content [5], fresh yam tubers are highly perishable with postharvest losses of up to 85% [6]. An alternative to the perishability of yam tubers is the transformation into chips, stabilized product by peeling, precooking, and drying in the sun [7]. The manufacture of yam chips,

known in Benin, Nigeria, and Togo, makes it possible to preserve the surplus of the tubers for use during the lean season [8]. However, the yam chips are severely attacked by insects that cause significant losses by reducing them to an inconspicuous powder within a few months [7]. Various insect pests such as *Dinoderus porcellus* Lesne, *Araecerus fasciculatus* DeGeer, *Dinoderus bifoveolatus* Wollaston, *Palorus subdepressus* Wollaston, *Tribolium castaneum* Herbst, *Rhyzopertha dominica* Fabricius, *Lasioderma serricorne* Fabricius, *Sitophilus zeamais* Motschulsky, *Cathartus quadricollis* Guérin-Méneville, *Gnatocerus maxillosus* Fabricius, *Cryptolestes pusillus* Schönherr, *Carpophilus binotatus* Murray, *Carpophilus dimidiatus* Fabricius, and *Psocoptera* spp. were found in stored yam chips [7, 9, 10]. However, *D. porcellus* remains by far the most abundant and most damaging storage pest to yam chips [9–12].

The use of synthetic chemical insecticide is the main method of control used by farmers to protect stored yam chips against *D. porcellus* [7, 10]. However, most of the insecticides used by farmers are not specific for stored yam chips protection, and their misuse has led to numerous cases of food poisoning and deaths of whole families registered [13, 14]. Faced with this deplorable situation, it is important to use alternative methods that respect the environment and the populations' health.

Several alternative methods of *D. porcellus* control have been tested in recent years such as the use of botanicals [15], varietal resistance [16], biological control [17, 18], and physical tools [19]. However, effective protection of stored yam chip from *D. porcellus* requires integration of all these control methods. In this chapter we review the various methods of *D. porcellus* control, highlight the methods to be explored in the future, and discuss an integrated control method against this pest.

2. General description about *Dinoderus porcellus*

2.1 Description

Beetles of the *Dinoderus* genus are the smallest of all bostrichids [20]. According to Schäfer et al. [21], they are characterized by a very short forehead with a fronto-clypeal suture very little distinct; their antennae are composed of 9–11 segments with the second segment shorter than the first segment. *Dinoderus* spp. are also characterized by the last abdominal segment visible and curved; the pronotum having a perforated posterior surface is bordered anteriorly by a row of teeth; the subapical carina is absent in elytra [21]. The adult of *D. porcellus* is reddish-brown with elytra black and hard, shiny, appearing glazed, almost glabrous on their dorsal part (**Figure 1**). *D. porcellus* is different from the other *Dinoderus* by a pronotum without fovea but with a posterolateral carina reaching the first row of marginal teeth and a dorsal punctuation of the elytra consisting of large perforations [21].

2.2 Biology

D. porcellus digs holes on the yam chips in which it reproduces. The female lays her eggs inside the dug holes, which hatches after 6–8 days [19]. It was noted that at a temperature below 10°C and above 40°C, no oviposition was observed in females of *D. porcellus* [19]. The larva development time is an average of 24 days, while the nymphal stage lasts an average of 5.25–6.50 days [19]. According to Nwana [22] the average development time of *D. porcellus* on yam chips is on average 35.9 days at room temperature.

2.3 Pest status

In West Africa, the beetle *D. porcellus* is a serious pest of stored chips of several roots and tubers such as cassava [21], yam [10], and cocoyam [22]. *D. porcellus* digs holes in the yam chips (**Figure 2**), drastically reducing their internal parts into powdery waste, which negatively affects their visual quality and decreases their commercial value. Under laboratory conditions, the weight loss due to this pest in



Figure 1.
Dinoderus porcellus adult (source: Schafer et al. [21]).



Figure 2.
Yam chips infested by *D. porcellus*.

4.5 months was estimated to 29.5% in newly dried yams and 39.2% in stock that had already been in store for 6 months [11]. In addition, when yam chips were infested with *D. porcellus* and stored for 3 months, the reconstituted thick paste (amala or télibo) was unsuitable for human consumption and not accepted by consumers [9].

3. Management of *Dinoderus porcellus* in yam chips

3.1 Physical methods

Physical control of stored product insects involves the manipulation of physical factors (temperature, relative humidity, atmospheric composition, etc.) to eliminate them or reduce their population to a tolerable level [23]. The control of stored product insect such as *D. porcellus* could be done by the use of heating or cooling of storage structures. Traditionally, infested yam chips are sun-dried by farmers [10]. Although sun-drying remains one of the oldest methods of control used in the protection of dried foods, it has several disadvantages such as exposure to waste and deterioration of vitamins [24]. In addition, this method is not very effective against *D. porcellus*, which feeds inside the chips so as not to be exposed to sunlight. Oni and Omoniyi studies [19] show that storage of yam chips at 20–30°C is optimal for the development and reproduction of *D. porcellus*. Lethal temperatures varied significantly with the species of yam used for making chips. In general, it is therefore recommended to store yam chips at temperatures below 20°C and above 35°C to control *D. porcellus* [19]. However, the manipulation of the temperature of storage structures requires infrastructures such as gas-tight containers, which are not accessible to smallholder farmers who are engaged in the processing of yam chips in West Africa. An alternative could be the use of triple-bagging consisting to seal dried food in a series of two heavy-grade polyethylene plastic bags which were expected to be as hermetic [25]. The use of the Purdue Improved Crop Storage (PICS) triple layer bag as an alternative to the use of the common polyethylene bags has been tested by Hell et al. [26] and have proven ineffective in protecting cassava chips against *Dinoderus* spp. and *Prostephanus truncatus*. Nevertheless, further research is needed to fill the knowledge gaps and provide adequate information needed to inform decision-maker for the use of PICS triple layer bag for yam chips protection against *D. porcellus*.

3.2 Botanical insecticides

Botanical insecticides are one of promising alternative to the use of chemical synthetic insecticides in pest control because of their minimal costs and ecological side effects [27]. For the protection of stored yam chips against insect pests, Vernier et al. [7] evaluated the level of protection provided by various biological products derived from neem (*Azadirachta indica* A. Juss.) and *Crotalaria sericea* L. compared with a synthetic pesticide, Sofagrain (1.5% deltamethrin + 0.5% pirimiphos methyl). Among the tested organic products, oil, powdered leaves, and neem seeds gave the best level of protection in terms of reducing the damage caused by pests [7]. Eze et al. [28] had reported the potentials of ethanolic extracts of *A. indica* and *Ocimum gratissimum* L. to protect chips against insect pests. The insecticidal and repellent effects of the powders and extracts of three medicinal plants (*Bridelia ferruginea* Benth., *Blighia sapida* Koenig, and *Khaya senegalensis* (Desr.) A. Juss.) traditionally used in Benin by farmers for the protection of yam chips against *D. porcellus* were tested by Loko et al. [15]. The results showed that the leave powders of the three medicinal plants have strong repellent properties against *D. porcellus*.

and could be a source of novel repellent against this pest. The propanol extract of *B. ferruginea* at 5% proved to be a good fumigant against *D. porcellus*, with 88.89% of pest mortality at 160 $\mu\text{L/L}$ air, while the acetone extract of *K. senegalensis* could be used in the development of a contact insecticide against *D. porcellus* because of having a low LC_{50} of 0.29 $\mu\text{L/insect}$. However, to increase the efficacy of medicinal plants identified, it is important to develop methods such as mixing with some fixative materials. Knowing that plant essential oils are promising alternatives to chemical insecticides [29] and have demonstrated their effectiveness against some Bostrichidae pests of stored products [30, 31], it is important to conduct research on their use on the control of *D. porcellus*.

3.3 Resistant varieties

The use of resistant varieties is the cheapest, effective, and ecologically safe method of protecting stored products against insect pests [32]. In fact, among the solutions proposed by farmers to fight *D. porcellus*, resistant yams chips have been the most plebiscite [10]. To meet the expectations of farmers, a participatory assessment of yam landraces in Benin was conducted in 51 villages through the yam production zone of Benin, and 64 landraces whose chips are resistant to storage insect have been identified [33]. The agro-morphological [33] and molecular characterization [34] of these 64 landraces revealed the existence of many duplicates and classified them in 24 morphotypes [33]. Choosing based on their good agronomic and culinary characteristics, the susceptibility of 5 of the 64 landraces identified as given resistant chips were tested in the laboratory by Onzo et al. [35]. These authors demonstrated the existence of a differential susceptibility between the different tested landraces with respect to *D. porcellus* with Singor and Portchahabim landraces as the least vulnerable to the attacks of this pest. Varietal resistance of yam chips from 24 landraces (corresponding to the 24 morphotypes obtained during morphological characterization) to *D. porcellus* was evaluated by Loko et al. [16] using free-choice tests (antixenosis) and non-choice tests under laboratory conditions. The results showed that basing on the Dobie index of susceptibility five yam landraces (Gaboubaba, Boniwouré, Alahina, Yakanougo, and Wonmangou) were scored as resistant to *D. porcellus*. These five resistant landraces (**Figure 3**) can be used in the integrated management of *D. porcellus*.

3.4 Biological control

Biological control is an important integrated pest management component (IPM), which broadly includes all control types involving living organisms, and represents a good alternative to the use of pesticides. Concerning *D. porcellus*, two predators (*Alloeocranum biannulipes* Montrouzier & Signoret (Hemiptera: Reduviidae) and *Teretrius nigrescens* Lewis (Coleoptera: Histeridae)) have been found in yam chips infested with this pest [10]. The functional responses of *T. nigrescens* and *A. biannulipes* feeding on *D. porcellus* were compared, and the results showed that both predators have a potential as biological control agents of *D. porcellus* [17]. The suppressive effect of *A. biannulipes* on the population dynamics of *D. porcellus* and the yam chip losses caused by this pest was evaluated under laboratory and natural conditions [18]. Results showed that *A. biannulipes* has the potential to be an effective biological agent against *D. porcellus* in stored yam chips (**Figure 4**). In addition, Loko et al. [18] provided detailed information on the biology, behavior, and life history of *A. biannulipes*, which are necessary for the mass rearing and use of this predator to control *D. porcellus*. However, *A. biannulipes* is a generalist predator which can consume several stored product insect pests such



Figure 3.
Pictures of chips from the five resistant landraces to *D. porcellus* identified by Loko et al. [16].



Figure 4.
Predation by *A. biannulipes* adult on nymph of *D. porcellus*.

as *Corcyra cephalonica* (Stainton) (Lepidoptera: Pyralidae), *Tribolium confusum* du Val (Coleoptera: Tenebrionidae), and *Anagasta kuehniella* Zeller (Lepidoptera: Pyralidae) [36]. What could be affected is its effectiveness as a biological agent of *D. porcellus* in farmer storage conditions. Therefore, prior to the use of this predator in an IPM program against *D. porcellus*, it is important to do a molecular gut analysis for determining the part of *D. porcellus* in its diet. Moreover, it is important to evaluate the population dynamics of *A. biannulipes* and *D. porcellus* within multispecies and/or multitrophic systems.

3.5 Synthetic insecticides

Synthetic insecticides are the main control method used by farmers and traders, to protect stored yam chips against insect attacks [7, 10]. In Benin, some recommended synthetic insecticides for storage insect pest control such as Sofagrain (1.5% deltamethrin + 0.5% pirimiphos methyl) and Antouka (permethrin 3 g/kg + pirimiphos 16 g/kg) showed a good level of stored yam chip protection against *D. porcellus* [7, 10]. But in practice, most of the time, farmers use synthetic insecticides focusing other crops such as cotton in Benin [10] and cacao in Nigeria [37] to protect stored yam chips. This misuse of chemical insecticide leads to many cases

of poisoning [13, 14]. Indeed, a study of Sosan et al. [37] revealed the presence of the organochlorine pesticide residues such as Dichloro-diphenyl-trichloro-ethane (DDT) and hexachlorohexane (HCH) at outrageous levels in dried yam chips obtained from Ile-Ife markets, southwestern Nigeria. These two organochlorine pesticide residues classified as dangerous by the World Health Organization [38] could cause serious health and environmental risks. Moreover, the use of aluminum phosphide marketed as Phostoxin, which is a highly toxic pesticide banned in several countries [39], was registered by Adesina et al. [40] as use by traders for yam chip protection. It is therefore important to sensitize farmers and traders to the use of chemical insecticides suitable for the protection of yam chips.

4. Integrated pest management

Integrated pest management (IPM) relies on managing insect populations through the combined use of several control methods in a way, which affords the highest priority to the protection of human health as well as the environment. The promising approaches toward effective IPM for *D. porcellus* are the use of resistant yam landraces combined with botanical powders of three medicinal plants (*B. ferruginea*, *B. sapida*, and *K. senegalensis*) [41]. Based on the few studies carried out in the context of the yam chip protection against *D. porcellus*, we can recommend to smallholder farmers the integration of the different methods in the following way:

- Use resistant landraces (Gaboubaba, Boniwouré, Alahina, Yakanougo, and Wonmangou) for yam chip manufacturing. These five yam landraces have a good agronomic (productivity, number of tubers), culinary (quality of pounded and boiled yam), and technological (quality of yam chips, ease of pounding) characteristics, found in Beninese traditional agriculture [16, 33].
- Peel and cut fresh yam tuber in slice ranging from 2 to 3 cm of thickness for fast drying [16].
- Precook at around 40°C, and soak during minimum 12 h fresh yam tubers before drying for having the best quality yam flour [42], but also protect chips against insect attacks [43]. Indeed, Nwana and Azodeh [44] showed that the intensity of damage by *A. fasciculatus* to yam chips blanched and soaked before drying were low.
- Add plants such as leaves and sorghum straw during the parboiling process for red coloration and its insect repellent properties [10]. Indeed, it is known that color largely affects the acceptability of Amala (thick paste obtained after mixed boil water and yam chips flour) by consumers [45].
- Dry yam chips on clean surface to avoid insect infestation that could inadvertently be carried to storage; yam chip moisture content must be less than 13% to avoid fungi and insect attacks [46].
- Put dried yam chips in polythene-lined jute for lower insect damage and yam chip discoloration [28].
- Add leaf powders of *B. ferruginea*, *B. sapida*, and *K. senegalensis* at a concentration of 5% (weight/weight) in bagged yam chips for a short period of conservation (3 months) because of their high repellent activity against *D.*

porcellus [15]. However, for a long period of yam chip conservation (10 months or more), we recommend the use of neem leaves (100 g per kg) or neem seeds (20 g per kg) powders [7].

- Tightly seal bags and put them in clean and dried place.
- Inspection of stored bags should be done monthly.
- If stored yam chips are attacked by *D. porcellus*, we recommend heating infested yam chips to more than 35°C [19] or adding the predator *A. biannulipes* at a density of one predator for 10 preys [18] or applying the recommended chemical insecticides Antouka or Sofagrain.

5. Scope for future research and development of innovative management strategies

In order to develop a good strategy of integrated pest management for *D. porcellus* in West Africa, further research should be done in the development of alternative control measures and techniques. The alternative methods to be explored that could be adapted to *D. porcellus* control in stored yam chips are as follows:

5.1 Hermetic bags

Hermetic storage bags have proven to be a low-cost solution for preventing storage losses due to insects [47]. Storage systems based on the hermetic principle can be used to maintain stored product quality without the need for pesticide application [48]. Apart from testing the effectiveness of the Purdue Improved Crop Storage (PICS bags™) in *D. porcellus* control, it is important to evaluate the efficacy of other hermetic methods of storage marketed in West Africa such as AgroZ Bag™, and SuperGrain bags™ [49].

5.2 Essential oils

Essential oils can have various effects on stored insect pests (repellence, contact toxicity, antifeedant, growth inhibitory, fumigant, etc.) and can be applied as a part of integrated pest management programs for stored products protection. Indeed, plant essential oils can be used in combination with other control techniques for controlling storage insect pest [50]. Essential oil of plants found in the West African flora such as *Citrus sinensis* [31], *Cymbopogon citratus* [51], *Ocimum basilicum* [52], and *Zingiber officinale* [53] have proven their efficacy on control of several Bostrichidae of stored products such as *P. truncatus* and *R. dominica*. Research on the potential use of essential oils of these plants or other medicinal plants found in West Africa in control of *D. porcellus* in stored yam chips should be prospected.

5.3 Entomopathogens

Entomopathogens have an important place in the biological control because they have a wide host range and are harmless to the environment and human. These include entomopathogenic fungi, nematodes, bacteria, and viruses. These are all widespread in the natural environment and cause infections in many pest species. Entomopathogens contribute to the natural regulation of many populations of arthropods. Much of the research in this area concerns the causal agents of insect

diseases and their exploitation for biological pest control. Many entomopathogens can be mass produced, formulated, and applied to pest populations in an analogous manner to chemical pesticides. Also, they can be used more against stored product pests with the development of new biotechnical methods. Indeed, the effectiveness of the formulation of the entomopathogenic fungi, *Beauveria bassiana* (Bal.) Vuillemin and *Metarhizium anisopliae* (Metch.), against the Bostrichids *P. truncatus* [54, 55] and *R. dominica* [56, 57] has been proven. It would therefore be interesting to evaluate the effect of entomopathogenic fungi in the context of *D. porcellus* control.

5.4 Parasitoids

The parasitoid wasp, *Anisopteromalus calandrae* (Howard) (Hymenoptera: Pteromalidae) found in stored yam chips by Vernier et al. [7], is an important biological agent of several Bostrichidae larvae of stored products such as *R. dominica* [58], and *P. truncatus* [59]. Similarly, *Dinarmus basalis* Rondani (Hymenoptera: Pteromalidae), which is present in all the different regions of West Africa, was also found in stored yam chips [10]. However, *D. basalis* is known as an efficient ectoparasitoid of bruchid pests [60, 61]. Further research must be done to evaluate the potential of these two parasitoids as biological agents for the control of *D. porcellus* in stored yam chips.

5.5 Insect growth regulators

Insect growth regulators are insecticides that mimic hormones in young insects and can be a potential component in integrated pest management against *D. porcellus*. Several features of insect growth regulators make them attractive as alternatives to broad-spectrum insecticides. Indeed, insect growth regulators are more selective; they are less harmful to the environment and more compatible with pest management systems that include biological controls. In addition, insect growth regulators are generally low in toxicity to humans. Kavallieratos et al. [62] have proven the efficacy of insect growth regulators as grain protectants against *P. truncatus* in maize and *R. dominica* in wheat. Therefore, investigations must be done to assess the effects of insect growth regulators on the development of *D. porcellus*.

5.6 Pheromones

Methods for detecting and for monitoring *D. porcellus* are crucial components for the development of an integrated management strategy against this pest. Pheromones which are volatile organic molecules of low molecular weight that elicit a behavioral response from individuals of the same species can serve as a tool to detect infestation at an early stage and to determine the right time for control measures [63]. Thus, Campion et al. [64] and Hodges [65] have shown the efficiency of traps baited with the synthetic aggregation pheromones for detecting and monitoring *P. truncatus* in East and West Africa. Research should develop specific pheromones and attractants of *D. porcellus* to aid in its monitoring and trapping.

6. Conclusions

The pest status of *D. porcellus* is higher in West Africa. This pest causes both quantitative and qualitative damage to stored yam chips. Synthetic insecticides used by farmers and traders for fighting against this insect are very dangerous for human

health and environment. The present chapter has emphasized utilization of resistant varieties, botanicals, parasitoids, and physical methods for *D. porcellus* control. Thus, more emphasis should be placed on the integration of these different methods of *D. porcellus* control. This chapter proposes an integrated pest management combining yam chip processing practices, physical methods, botanical insecticides, biological control, and resistant varieties for fighting *D. porcellus* in stored yam chips. However, detection and monitoring tools should be developed, and it appears that the use of hermetic bags, essential oils, entomopathogens, insect growth regulators, pheromones, and their combined effects should be further investigated in the *D. porcellus* control.

Conflict of interest

The authors declare that they have no competing interests.

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