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Damage potential of *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae) on cocoa beans: Effect of initial adult population density and post infestation storage time

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ABSTRACT

The effect of different initial adult population densities of *Tribolium castaneum* (Herbst) at several post infestation storage times on the final adult population density, the percentage of damaged beans, the percentage of weight loss, and the weight of insect feeding residues on cocoa beans was investigated in laboratory experiments. Both factors interactively had highly significant ($P < 0.01$) effects on variables assessed. The highest mean final adult population density of 129.7 ± 4.6 was recorded in samples infested with the highest initial adult population density and stored for 150 d, while the least mean adult population density of 10.8 ± 0.54 was recorded on samples infested with the lowest initial adult population density in samples stored for 30 d. The highest percentage damaged cocoa beans 51.0 ± 1.21% was recorded in samples infested with the highest initial adult population density, while the least mean percentage damaged beans of 16.9 ± 1.26% was also recorded on samples infested with the lowest initial adult population density. Similar trends of means were recorded for all the remaining variables. Correlation between factors was significant and positive. Multiple and simple linear regressions analyses were also significant ($P < 0.01$) and all equations fitted the regression models and perfectly described the relationship between the independent and the dependent variables. Our results show that *T. castaneum* can impact negatively on both the quantity and quality of stored cocoa within just 30 days of infestation, with the impact increasing with increasing population density and post infestation storage time.

1. Introduction

Cocoa is one of the important agricultural commodities traded globally (ICCO, 2015). Malaysia currently ranks as the 12th world cocoa producer with an estimated production of 1757 tonnes in 2016. It is the 1st and fifth major cocoa grinder in Asia and worldwide respectively (Lee, 2013), with a total grinding of 203, 093 tonnes in 2016 (MCB, 2017). This gives a production deficit of 201,336 tonnes over the same period. To address this deficit, the Malaysian government through its strategic commodity policy (2011–2020) targets to increase the area under production to 40,000 ha and raise the yields to 1.5 t ha^{-1} by 2020. This step, besides bridging the deficit, is expected to bring an increase of RM6 billion (USD1.5 billion) as export earnings from cocoa by 2020 (MPIC, 2011).

Cocoa is traded as dried cocoa beans in its primary form (Begum et al., 2007; Navarro et al., 2007; Joel et al., 2013), is attacked by many insect pests in storage, retail outlets and transit, especially in humid and warm tropical environments (Sivapragasam, 1990; Begum et al., 2007; Jonfia-Essien, 2012; Asimah et al., 2014) like Malaysia. Insects infestations of cocoa beans and other stored products mainly causes damage due to direct feeding on the commodity (Compton and Sherington, 1999; Lale, 2002; Sallam, 2008; Jonfia-Essien and Navarro, 2010), and indirectly as contaminants due to the presence of live or dead individuals and their waste materials (Obeng-Ofori, 2010; Jonfia-Essien and Navarro, 2010). The direct feeding damage normally results in physical reduction in quantity followed by a corresponding loss in weight and nutritional value; while the presence of contaminants degrades

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the physical aesthetic appearance of the beans (Dharmaputra et al., 1999; Tettey et al., 2014) and the commercial value of the infested commodity (Sivapragasam, 1990; Adarkwah et al., 2016). For this reason, export crops such as cocoa, coffee, and groundnut among others are normally expected to be of high quality (FAO, 1985), and must remain in such state until it is finally processed (Adarkwah et al., 2016). Similarly, infestation of cocoa beans by insect pests is of serious concern (Navarro et al., 2007), as it is part of the factors determining the quality of the beans at the global market (Sivapragasam, 1990; Jonfia-Essien and Navarro, 2010, 2012; Jonfia-Essien, 2012; Tettey et al., 2014; MCO, 2017). In addition, the Malaysian cocoa board regulations on grading cocoa beans demands that it should be free from insect infestations and contain <2.5% of insect damaged beans (MCB, 2017).

Tribolium castaneum is believed to be of Indo-Australian origin (Ridley et al., 2011), but is currently a worldwide insect pest of great economic significance in stored product environments (Haines, 1991; Nenaah, 2014). It is, however, particularly more common in warmer climates in temperate countries (Hill, 2002). It is also one of the most common insect pests found attacking cocoa beans globally (Navarro et al., 2007; Jonfia-Essien and Navarro, 2012; Bateman, 2015). It is a major insect pest infesting cocoa beans in both farm stores and commercial warehouses in Malaysia (Sivapragasam, 1990; Hamid and Lopez, 2000; Asimah et al., 2014). Such infestations are believed to cause a reduction in the biomass, physical integrity and quality of cocoa beans (Tettey et al., 2014; Adarkwah et al., 2016), and may impart off odours due to the quinones secreted from abdominal and prothoracic glands (Hodges et al., 1996). However, published information on the extent of exact damage due to infestation by this major insect pest on cocoa is limited. Little is also known about the effects of the initial population density of adult *T. castaneum* infestation and the length of post-infestation storage period on eventual population densities and their related damage parameters on cocoa beans. There are also no reports on the effect of interaction between these factors on subsequent population densities and their associated damage parameters on cocoa beans. This information is not only vital for planning and implementing *T. castaneum* control strategy for cocoa beans, particularly using the IPM approach; It will also be useful in gauging the benefits of using both novel and existing methods for control of this pest on cocoa beans.

This study was therefore aimed at determining: 1) the effect initial adult population density on potential population growth of *T. castaneum* on cocoa beans over some post-infestation storage periods. 2) The extent of cocoa beans damage, its associated weight loss, and that of the amount of insect feeding residue produced over the same storage time. 3) the effect of interaction between initial infestation density and post-infestation storage time on final adult density, extent of cocoa beans damage, weight loss, and the associated amount of insect feeding residue, 4) and to correlate between these factors and their response variables as well as to develop equations for the description of these relationships.

2. Materials and methods

2.1. Insect culture and rearing

Tribolium castaneum used for the culture was obtained from a laboratory culture at the Entomology Laboratory of the Department of Plant Protection, Universiti Putra Malaysia. The insects were sub cultured and reared in the laboratory on artificial diet made from wheat bran and baker yeast (19:1 w/w) (Haines, 1991; Wijayaratne et al., 2012; Ahmad et al., 2012b) under the prevailing conditions of 29.45 ± 0.43 °C, 66.43 ± 1.65% Relative humidity, and 12:12 D:L photoperiod. Prior to use for rearing, the wheat bran was sterilized by freezing in a refrigerator for three (3) weeks to disinfest it from insects, mites and their immature stages (Jagadeesan et al., 2013) with slight modifications.

2.2. Source of cocoa beans and sterilization

Insect free standard Malaysian cocoa beans grade one (SMC1) used for this experiment was purchased from the Malaysia Cocoa Board Research Centre, Hilir in Perak-Malaysia. SMC1 is normally cocoa beans with <2.5% insect damaged and germinated beans per 100 g (MCB, 2017). The beans were sieved in the laboratory to remove dirt and dust (Jonfia-Essien, 2006; Tefera et al., 2011), and stored in sealed plastic bags under normal room temperature until needed. Prior to being infested for damage assessment experiment, the beans were sterilized at 60 °C for 10 h in a ventilated oven (Memmet Model-D-91126 GmbH + CO.KG, Germany) to disinfest it from any residual infestation (Tuncbilek and Kansu, 1996). The beans were wrapped in papers during the sterilization process. The sterilized beans were left in their wraps to acclimatize to room temperature before being used for experiments.

2.3. Insect infestation bioassay

Two hundred and fifty (250) grams of disinfested cocoa bean were weighed using analytic balance (AND GF- 300, Japan) of 0.01 g precision into each of 120 plastic containers (160 × 110 × 90 mm). The containers were randomly divided into five groups (24 samples for each group). Each group representing a storage time of 30, 60, 90, 120 and 150 d. Within each group, containers were then, randomly allocated to series of infestation levels (0, 10, 20, and 30), and each series was replicated six times. Laboratory reared adult *T. castaneum*, 2–3wks old (Donahaye et al., 1996; Mahroof et al., 2003; Begum et al., 2007) were collected from the colony using an aspirator and introduced onto the cocoa beans in the plastic containers at an infestation level of 0, 10, 20 and 30 unsexed individuals (Mahroof et al., 2003; Boina and Subramanyam, 2004; Jonfia-Essien, 2006; Begum et al., 2007; Jonfia-Essien et al., 2010; Tefera et al., 2011; Jonfia-Essien and Navarro, 2012; Đukić et al., 2016). The tops of the containers were covered with a muslin cloth to provide ample aeration for the insects during the experiment. The original lids of the containers, with their entire tops excised, were used to keep the cloth firmed to the container to prevent the insects from escaping away. The set-ups were left undisturbed (Tefera et al., 2011) in the laboratory at 29.4 ± 0.43 °C, Relative humidity of 66.4 ± 1.65%, and 12:12 D: L photoperiod for experimental storage periods of 30, 60, 90, 120 and 150 d after infestation. The experiment was conducted in a Completely Randomized Design (CRD) with six replications.

2.4. Data collection

After each post infestation storage times (30, 60, 90, 120 and 150 d), the containers were opened and sieved through double staked sieves of different sieve diameter (Jonfia-Essien, 2006; Tettey et al., 2014), underlaid by a sheet of aluminium foil to collect the residues. The sieving method was adopted because it has been reported to be satisfactory for estimating insect numbers on infested cocoa beans (Sivapragasam, 1990). The sieve with larger diameter (6.7 mm) was used to separate the cocoa beans from both the insects and their feeding residues. The sieve of smaller diameter (0.21 mm) separated the insects from their feeding residues. For each container, the number of adult insects (live and dead) was counted and recorded. The residues produced were also weighed and recorded (g), and the cocoa beans were visually inspected for signs of damage. Damaged beans are those with holes and visual defects or