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THE IMPACT OF POPULATION ORIGIN ON THE TOLERANCE OF WHEAT FLOUR PEST, *Tribolium castaneum* (Herbst) TO TWO BOTANICAL EXTRACTS

E. A. Oyeniyi* and O. E. Ajayi

Department of Biology, Federal University of Technology, P. M. B. 704, Akure, Ondo State, Nigeria.

*Corresponding author's E-mail: eaoyeniyi@futa.edu.ng; oyemmayo@gmail.com

ABSTRACT:
The influence of population origin on the tolerance of *Tribolium castaneum* to oils of *Allium sativum* and *Dennettia tripetala* was investigated in this study. Beetle samples were obtained from four States in South-western Nigeria. Insect samples were collected from four different major towns from each State before being pooled together to have a better representation of insect samples from each State. The main and interactive effects of population location, concentration and exposure time on the tolerance of *T. castaneum* to both botanical extracts were explored. Generally, the nature of botanical insecticide, exposure time and concentration affect the response of beetles to both plant extracts. *A. sativum* was more toxic to Lagos, Ogun and Oyo State biotypes of *T. castaneum* than *D. tripetala*. Lagos State beetle population showed the highest tolerance to both botanical extracts while Ondo and Ogun States biotypes recorded the lowest tolerance to *D. tripetala* and *A. sativum*, respectively. There were significant effects ($p < 0.0001$) of population location (L), concentration (C), exposure time (E) and L×E on the response of beetles to both extracts. This study showed that the geographical location of *T. castaneum* could considerably influence the degree to which other factors; especially exposure time affects beetle's mortality when controlling them using extracts from the two plants extracts.

KEYWORDS: *Allium sativum*, biotypes, *Dennettia tripetala*, geographical location, mortality.

INTRODUCTION

In recent years, the failure of many African nations to produce enough food for her teeming human population remained one of the numerous problems facing their development. In Nigeria, the situation is particularly more worrisome with about 8.1 million people currently estimated to be facing acute food insecurity due to large deficit in national food demand (FAO, 2017). A sharp devaluation of the local currency due to economic downturn occasioned by incessant drop in global oil price has further exacerbated the problem of food insecurity in the country. This has nearly made it nearly impossible for the government to import food grains to meet the deficit in national food demand. Nigerians are therefore being encouraged to go back to farm in order to boost the local food production. Several Agricultural Research Institutes saddled with the responsibilities of developing production and utilization technologies for economically important crops are therefore being established all over the country (Olatunde, 2014).

Triticum aestivum (Linnaeus) commonly known as wheat is one of the notable economically important crops in Nigeria. The crop has been identified to play major nutritional roles in the diet of most Nigerians (Adesina *et al*., 2016). For instance, food items such as bread, biscuits, cake, noodles and pasta prepared from wheat flour have gained acceptance over traditional staples made from commodities such as maize and cassava in the last decade (Proshare, 2018). Consequently, the Nigeria government spent about 1.5 billion U.S dollars, in year 2016 alone, on the importation of wheat to meet the national demand which has been estimated to be about 4 million metric tonnes per annum (Assefa *et al*., 2017). The country has therefore been identified as the third largest importer of wheat in the world (FAO, 2017). This has led to a renewed awareness on the need for the nation to be self-sufficient in wheat production. The production of wheat in the country is however hampered by high levels of severe civil insecurity in many parts of the country. This has led to the destruction and abandonment of many storage facilities in several parts of the country. In adequate and poor storage facilities in many parts of Nigeria have pre-disposed wheat and its flour to insect pest infestation thus, leading to both qualitative and quantitative losses, especially during storage.

Tribolium castaneum (Herbst), commonly known as the red flour beetle has been identified as one of the major pests of wheat flour and other milled cereal products (Adedire, 2011). The destructive activity of this infamous pest of flour has led to deterioration of nutritional quality of stored wheat flour. When infestation is heavy, the infested flour turns yellowish and has pungent, disagreeable odour which makes it unfitted for human consumption (Odeyemi *et al*., 2005). This insect pest has therefore impacted negatively on domestic wheat flour production through their destructive activities in Nigeria. The management of *T. castaneum* infesting wheat flour in the country has been majorly through the use of synthetic insecticides. However, the use of synthetic chemicals for pest management has been associated with many adverse effects on both humans and environmental health and this has led to their ban in many developed nations of the world (Isman, 2006). Most of these chemicals are however still being applied indiscriminately in Nigeria for the management of many stored product pests and this has eventually led to the problem of pest resistance. This has given an impetus to the need to search for a more pertinent insecticide that is eco-friendly and effective against insect pest. Plant based insecticides are being constantly suggested as attractive alternatives to most chemical insecticides in managing insect pests due to their apparently little threat to humans and the environment (Isman, 2006).

Consequently, several scientists have screened many plant materials for their insecticidal potency against stored product insect pests. *Allium sativum* (Linnaeus) and *Dennettia tripetala* (G. Baker) are examples of plants that have been established to be effective against *T. castaneum* which infest wheat flour (Adedire and Akinkurolere, 2005; Ali *et al*., 2014; Mobki *et al*., 2014). In spite of several studies that have been reported on the insecticidal efficacies of both plants against *T. castaneum*; there is still dearth of information on the impact of geographical origin on the response of *T. castaneum* to the insecticidal efficacy of both plants. Cultural and environmental differences occur from one location to another. However, for beetles on wheat flours to survive, they need to adapt to most of the modifications that exist from location to location; thus, new populations (biotypes) are being developed overtime. This study therefore sought to investigate the influence of population origin on the response of biotypes of *T. castaneum*, infesting wheat flour in South-western Nigeria, to the insecticidal efficacies of *D. tripetala* and *A. sativum*.

MATERIALS AND METHODS

This study was conducted in the Laboratory of the Department of Biology, Federal University of Technology, Akure, Ondo state between the month of April and August, 2018.

Collection of insect biotypes

Different populations of *Tribolium castaneum* were originally sourced from either infested semovita or pancake flour from four South-western States in Nigeria. Four States were randomly selected out of the six States in South-western Nigeria as sampling points. The States chosen include Lagos, Ogun, Ondo and Oyo

States. The map showing the four States, where insect samples were collected is shown in Fig. 1. Insect samples were collected from at least four different major towns across each of the States before being pooled together to have a better representation of insect samples from each State.

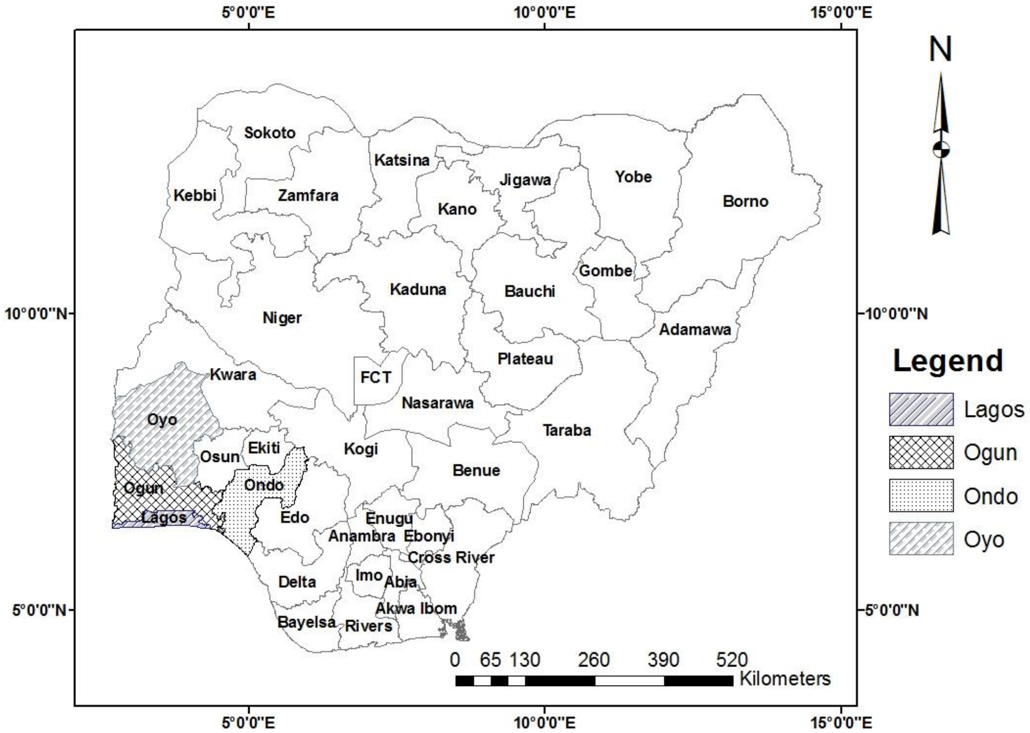


Figure 1. Map of Nigeria showing South-western states where biotypes of *T. castaneum* were collected

Sourcing of wheat grains and preparation of wheat flour

Clean wheat grains were purchased from Oba market in Akure, Ondo State and grinded into flour using electric grinder (model number: AN ISO 90001; 750 watt). The wheat flour was disinfested and sterilized in the oven at 60ºC for 90 min, to kill any microorganism or insect before being stored in a sealed polythene bags. The powders were further sieved through 180 µ perforations before being used.

Insect culture

One hundred and fifty adult *T. castaneum* from Lagos, Ogun, Ondo and Oyo States were separately introduced into disinfested 200 grams of wheat flour in well labelled 1.65 litres plastic containers. Each of the plastic containers serves as the stock culture. The containers were covered with perforated lids and muslin cloth to allow proper aeration and to prevent the insects from escaping. These beetles were allowed to mate and lay eggs before they were removed after 3 days. Each container was maintained in insect cage at ambient temperature (28±2ºC) and relative humidity (75±5%). Beetle biotypes from each State were reared for two generations to eliminate maternally inherited dietary effects. The second filial generations (F_2) of adult *T. castaneum* from each location were then used for contact toxicity bioassay.

Collection of plant materials

Unripe fruits of *Dennettia tripetala* (G. Baker) and dried bulbs of *Allium sativum* (Linnaeus) used for this work were purchased from Oba's Market, Akure, Ondo State. The unripe fruits of *D. tripetala* were air-dried for 14 days at ambient temperature (28±2ºC) and relative humidity (75±5%) under laboratory condition. The dried samples from each botanical were separately grounded with mortar and pestle forming a semi-grounded pepper fruit seeds which was further grounded into powder with an electric blender (model number: QBL-18L40;

350 watt) to obtain fine powder and stored in airtight bottles for further studies. Each plant material was labeled separately.

Preparation of plant extracts

Plant extracts were obtained from *D. tripetala* and *A. sativum* using cold extraction method proposed by Warthen Jr. *et al*. (1984) with little modifications. Three hundred grams (300 g) of the pepper fruit and garlic were separately weighed using Metler beam PB 3002 weighing balance (Search Tech/China) and added into pre-labeled extraction jar containing 1.2 litres of absolute methanol. Each mixture was stirred continuously using a glass rod for 1 hour every 24 h and the extraction was terminated after 72 h. The resulting solution of each botanical mixture was initially filtered through a quadric folded muslin cloth. The filtrate obtained was further sieved through an octa-layer folded muslin cloth and the solvent was separated from the crude extract using a rotary evaporator at 30-40 ºC with rotary speed of 100 rpm for 4 h. Crude extract of *D. tripetala* and *A. sativum* was separately stored in vial bottles.

Tolerance of *T. castaneum* biotypes to botanical extracts

Different concentrations of *D. tripetala* and *A. sativum* were prepared from their crude extract using a micropipette (model number: EN ISO 8655). For each plant extract, concentrations of 5%, 7%, 9%, 11% and 13% were prepared. A 5% concentration was prepared by diluting 500 µl of each plant material with 9500 µl of methanol. Likewise, 7% concentration was prepared by diluting 700 µl of each plant material with 9300 µl of methanol. Also, concentrations of 9%, 11% and 13% were prepared by diluting 900 µl, 1100 µl and 1300 µl of each extract with 9100 µl, 8900 µl and 8700 µl of methanol respectively. Surface film bioassay proposed by Busvine (1971) was adopted in determining the tolerance of each population of *T. castaneum* to *D. tripetala* and *A. sativum* extracts. Aliquots of 0.5 ml (500 µl) of each concentration was applied onto each pre-labeled Petri dish for surface-film coating. The solvent was allowed to escape for 20 minutes and twenty adult *T. castaneum* from each population was introduced into each pre-labeled Petri-dish. Two control treatments were also set up, the first one contained solvent only (solvent control; control A) and the other did not have solvent or extracts (untreated control; control B). Four replicates were set up for each treatment. Adult mortality was assessed at 24, 48, 72 and 96 h post-treatment respectively. Beetles were confirmed dead when they showed no movement when their abdomen were gently prodded with a needle.

Analysis of data

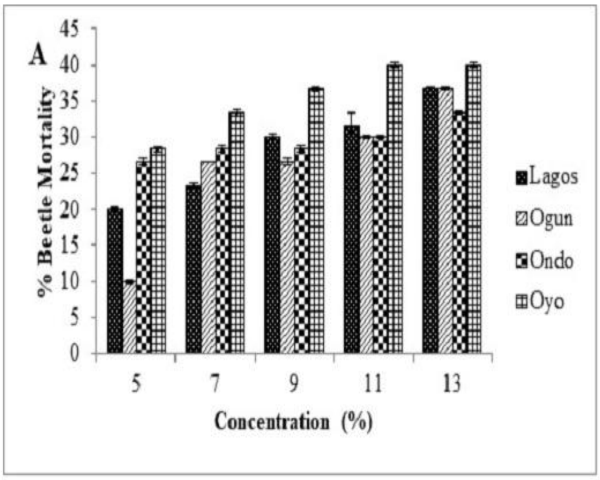
Four States used for beetle biotype collection were randomly selected out of the six States in South-western Nigeria using random sampling analysis. All data were subjected to Analysis of Variance (ANOVA) at $\alpha = 0.05$ and means were separated using Tukey's test. Data on adult mortality were also subjected to probit analysis to determine the lethal concentrations (LC50) of *D. tripetala* and *A. sativum* on *T. castaneum* biotypes (Finney, 1971). General Linear Model (GLM) was also used to determine the main and interactive effects of population location, concentration and exposure time on the tolerance of *T. castaneum* to extracts of *A. sativum* and *D. tripetala*. All analyses were carried out using SPSS 22.0 software package.

RESULTS

Tolerance of *T. castaneum* populations from South-western Nigeria to extracts of *A. sativum* and *D. tripetala*

Figure 2 to 4 show the response of *T. castaneum* biotypes obtained from four States (i.e. Lagos, Ogun, Ondo and Oyo) in South-western Nigeria to *A. sativum* and *D. tripetala* within 24, 48, 72 and 96 h post-treatment respectively. Generally, beetle mortality increased with increasing concentration of each of the botanical extracts regardless of the State from which beetles were collected. Irrespective of the experimental concentration and exposure time, both botanical extracts were however unable to evoke complete (100%) beetle mortality in all the populations of *T. castaneum*.

At 24 h post-treatment, highest mortality was recorded in Oyo and Ondo State biotypes of *T. castaneum* exposed to *A. sativum* and *D. tripetala* respectively at all the experimental concentrations (Fig. 2). Significantly higher ($F_{3,12}$ = 6.36; p = 0.008) mortality was also observed in Oyo biotype of *T. castaneum* exposed to 5% *A. sativum* when compared to their counterpart from Ogun State (Fig. 2A). Significantly lower ($F_{3,12}$ = 5.206; p = 0.016) mortality was also recorded in Ogun and Ondo State population of *T. castaneum* when compared to that of Oyo State population exposed to 11% of *A. sativum* extract. No significant difference (p>0.05) existed in the mortality of beetle populations exposed to all the experimental concentrations of *D. tripetala* (Fig. 2B).



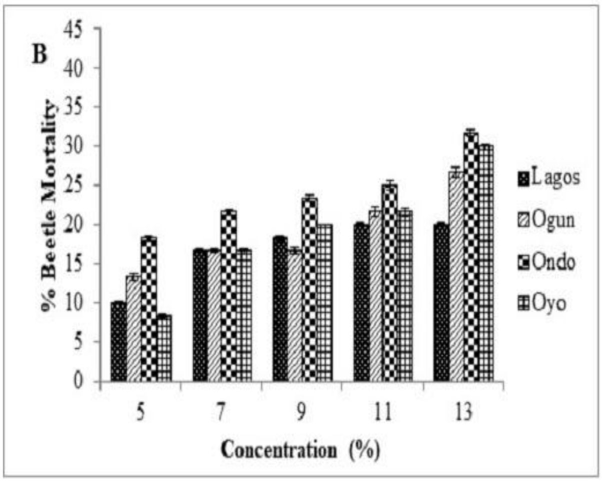
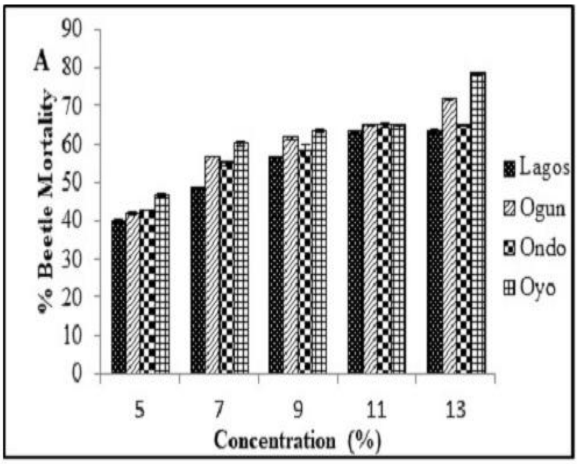


Figure 2. Percentage mortality of *T. castaneum* biotypes exposed to (A) *A. sativum* and (B) *D. tripetala* at 24 hours post-treatment.

At 48 h post-treatment, there was no significant difference (p>0.05) in the mortality of beetle populations exposed to each of the experimental concentrations of *A. sativum* and *D. tripetala* (Fig. 3). Highest and lowest susceptibility was however observed in Oyo and Lagos State biotypes of *T. castaneum* exposed to *A. sativum* at all the experimental concentrations. For beetle populations exposed to extracts of *D. tripetala*, highest susceptibility was only observed in Oyo State biotypes of *T. castaneum* exposed to 9 and 13% of the plant extract (Fig. 3A). Lagos State biotype of *T. castaneum* also showed the least susceptibility to 11 and 13% concentration of *D. tripetala* extract (Fig. 3B).



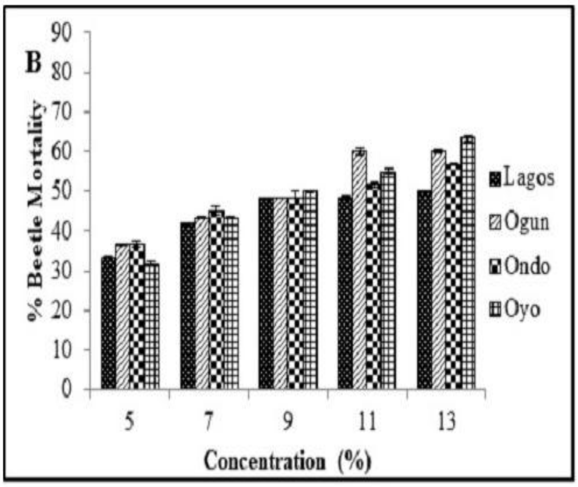


Figure 3. Percentage mortality of *T. castaneum* biotypes exposed to (A) *A. sativum* and (B) *D. tripetala* at 48 hours post-treatment

At 72 and 96 h post-treatment, Ogun State biotype of *T. castaneum* showed the highest susceptibility to *A. sativum* while their counterpart from Lagos State showed the least susceptibility (Fig. 4A and 5A). *A. sativum* was also unable to evoke significant difference ($p>0.05$) in the mortality of beetle populations at all the experimental concentrations at 72 h exposure (Fig. 4A).

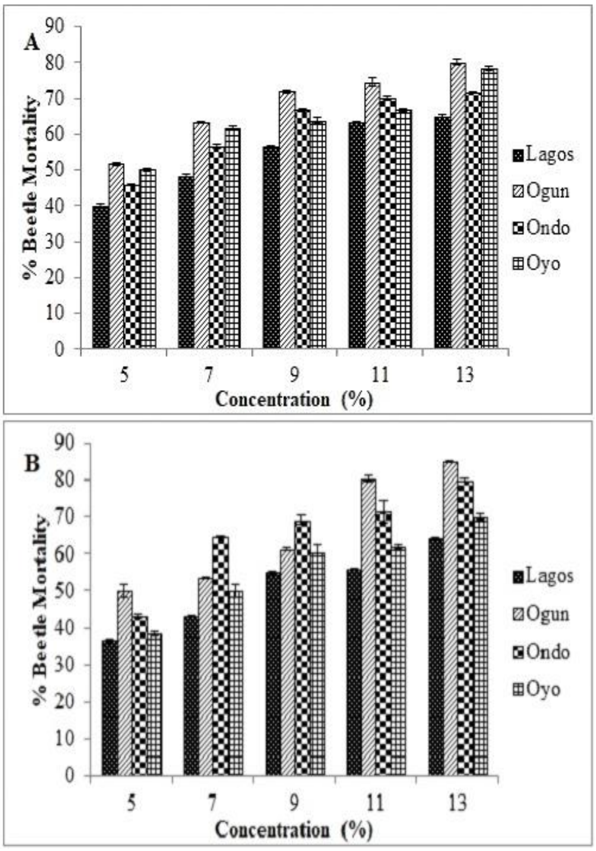


Figure 4. Percentage mortality of *T. castaneum* biotypes exposed to (A) *A. sativum* and (B) *D. tripetala* at 72 hours post-treatment

At 96 h exposure, *A. sativum* was able to elicit significantly higher ($F_{3,12}$ = 8.130; p = 0.003) mortality in Ogun State population of *T. castaneum* than that of Lagos and Oyo biotypes (Fig. 5A). For beetle populations exposed to *D. tripetala*, Lagos State biotype of *T. castaneum* showed the highest tolerance to *D. tripetala* at all the experimental concentrations (Fig. 4B and 5B). Likewise, of all the beetle populations exposed to 5, 11 and 13% of *D. tripetala* extract, only Ogun State biotype of *T. castanuem* showed the highest susceptibility at 72 (50.00, 80.42 and 85.00%) and 96 h (53.51, 83.42 and 88.50%) exposure respectively. There was also significant difference in the mortality values of beetle populations exposed to 7% (72 h: $F_{3,12}$ = 13.893; $p<0.0001$; 96 h: $F_{3,12}$ = 17.454; $p<0.0001$), 11% (72 h: $F_{3,12}$ = 4.961; p = 0.018; 96 h: $F_{3,12}$ = 4.133; p = 0.032) and 13% (72 h: $F_{3,12}$ = 3.935; $p<0.036$; 96 h: $F_{3,12}$ = 5.155; p=0.016) of *D. tripetala* extract.

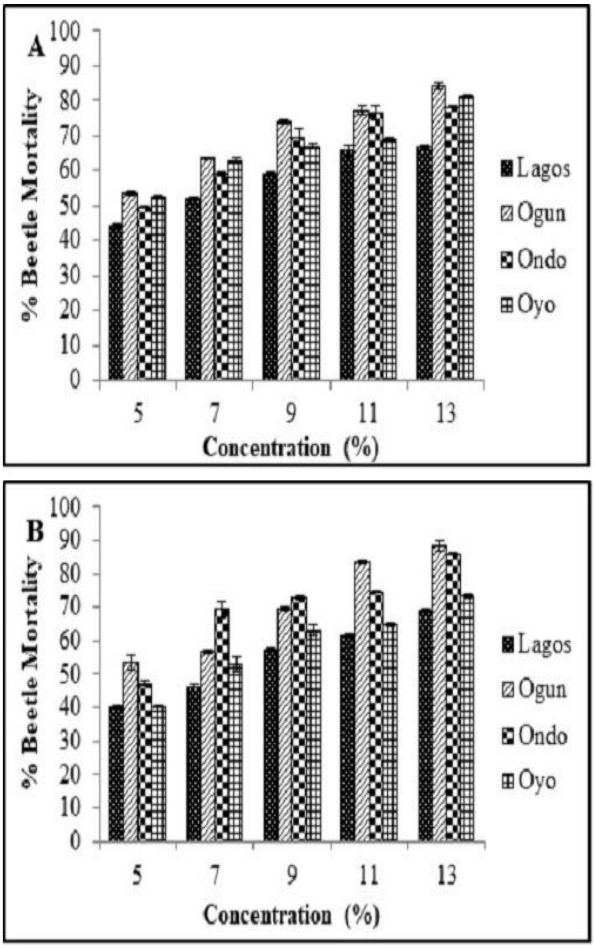


Figure 5. Percentage mortality of *T. castaneum* biotypes exposed to (A) *A. sativum* and (B) *D. tripetala* at 96 h post-treatment

Lethal concentrations (LC_{50}) of both botanical extracts needed to achieve 50% mortality in populations of *T. castanuem* within 72 h of exposure

The concentration of *D. tripetala* and *A. sativum* lethal to 50% of *T. castaneum* population obtained from Lagos, Ogun, Ondo and Oyo State is shown in Table 1. Generally, positive slope of regression irrespective of botanical extract and beetle population shows that mortality increased with increasing concentration of both botanicals within 72 h exposure. Lesser concentrations of *A. sativum* were however required to achieve 50% mortality in South-western populations of *T. castaneum* when compared to the quantity of *D. tripetala* needed to achieve LC_{50}. The only exception was observed in Ondo State biotype of *T. castaneum* where higher amount of *A. sativum* (5.57 mg/ml) extract was needed to achieve 50% mortality than that of *D. tripetala* (5.47 mg/ml). This shows that *A. sativum* is more toxic to Lagos, Ogun and Oyo State populations of *T. castaneum* than *D. tripetala*. Also, of all the insect biotypes used in this study, Lagos State biotype of *T. castaneum* required the highest quantity of *A. sativum* (7.20 mg/ml) and *D. tripetala* (8.23 mg/ml) and this shows that they are the most tolerant biotype. Ogun and Ondo State biotypes of *T. castaneum* however required the lowest quantity of *A. sativum* (4.67 mg/ml) and *D. tripetala* (5.47 mg/ml) respectively to achieve 50% mortality. This shows that they are the most susceptible to both botanical extracts. However, based on the fiducial limit values, there was no significant difference (p>0.05) in the quantity of *A. sativum* and *D. tripetala* needed to achieve 50% mortality in each population of *T. castaneum* within 72 h exposure.

Table 1. Lethal Concentrations (LC) (mg/ml) of *D. tripetala* and *A. sativum* extracts required to achieve 50% mortality in South-western populations of *T. castaneum* within 72 hours exposure

Botanical	Location	Slope (±SE)	Intercept (±SE)	X^2	LC_{50} (95% FL)
A. sativum	Lagos	1.63 (±0.39)	-1.39 (±0.37)	0.20	7.20 (5.60-8.42)
	Ogun	1.88 (±.040)	-1.26 (±0.38)	0.21	4.67 (2.97-5.75)
	Ondo	1.78 (±0.39)	-1.28 (±0.37)	0.57	5.57 (3.78-6.69)
	Oyo	1.60 (±0.40)	-1.11 (±0.37)	1.97	4.99 (2.91-6.21)
D. tripetala	Lagos	1.67 (±0.39)	-1.53 (±0.37)	0.74	8.23 (6.85-9.71)
	Ogun	2.55 (±0.41)	-1.93 (±0.38)	7.01	5.71 (1.40-7.49)
	Ondo	2.20 (±0.40)	-1.62 (±0.37)	2.28	5.47 (4.15-6.38)
	Oyo	1.90 (±0.39)	-1.61 (±0.37)	0.50	7.04 (5.72-8.08)

Note: SE = Standard Error; X^2 = Chi-square; LC = Lethal Concentration; FL = Fiducial limits

Interactive effect of population location, concentration and exposure time on the tolerance of *T. castaneum* to *A. sativum* and *D. tripetala*

There was statistically significant impacts (p<0.0001) of population location (L) (*A. sativum*: $F_{3,\ 240}$ = 19.02; *D. tripetala*: $F_{3,\ 240}$ = 25.78), Concentration (C) (*A. sativum*: $F_{4,\ 240}$ = 94.07; *D. tripetala*: $F_{4,\ 240}$ = 91.03) and Exposure time (E) (*A. sativum*: $F_{3,\ 240}$ = 359.94; *D. tripetala*: $F_{3,\ 240}$ = 440.51) on the response of *T. castaneum* to both botanical extracts. Also, the interaction of L×E had a significant effect (p<0.0001) on the response of *T. castaneum* to both botanical extracts. Likewise, there was significant interaction (p<0.0001) of C×E on the tolerance of *T. castaneum* to *D. tripetala* extract. But, the two-way interactions of L×C ($F_{12,\ 240}$ = 1.04; p=0.41) and C×E ($F_{12,\ 240}$ = 1.68; p=0.08) had no significant effect on the response of *T. castaneum* to *A. sativum*. The three-way interactions of L×C ×E also had no significant effect (p = 1.00) on the response of *T.*

castaneum to *A. sativum* ($F_{36, 240}$ = 0.38) and *D. tripetala* ($F_{36, 240}$ = 0.37) extracts.

DISCUSSION

For epochs, botanicals with insecticidal properties have played key roles in farmers' quest towards ensuring good protection of their agricultural produce from insect pest infestation (Oyeniyi *et al*., 2015b; Oni *et al*., 2018). In order to circumvent the various risk associated with many synthetic chemicals, most farmers in developed and developing countries of the world are now resorting to the use of plant-based insecticides for the management of various insect pest attacking their agricultural produce. *D. tripetala* and *A. sativum* are examples of botanicals that have been established to be highly medicinal and insecticidal (Adedire & Akinkurolere 2005; Egharevba & Idah 2015; Chaubey, 2017).

Both *D. tripetala* and *A. sativum* plant extracts evoked beetle mortality regardless of the location from which the insect biotypes were collected. This confirms the insecticidal potency of both botanical extracts against *T. castaneum* infesting wheat flour in Nigeria. The ability of both botanical extracts to elicit beetle mortality at all the experimental concentrations and duration conforms with the previous findings that *D. tripetala* and *A. sativum* possess insecticidal properties against *T. castaneum* infesting wheat flours (Adedire and Akinkurolere, 2005; Ali *et al*., 2014; Mobki *et al*., 2014).

High mortality observed in biotypes of *T. castaneum* may also be linked to the direct contact toxicity of the extracts. The movement of the beetles on Petri-dishes coated with *D. tripetala* and *A. sativum* extracts may have resulted in the physical abrasion of the cuticle of the insects thus, leading to their death. Similarly, the active ingredients in the extracts might have diffused into the insect spiracles. This might have disrupted the normal respiratory activities of the beetles, and subsequently led to asphyxiation and their eventual death. Similar observation have been reported by several authors for different stored product pests (Ashamo *et al*., 2013; Ogungbite and Oyeniyi, 2014; Oyeniyi *et al*., 2015a, b; Akinneye and Oyeniyi, 2016). However, the efficacy of both botanical extracts varied with the nature of plant extracts, concentrations of the extracts, exposure time and insect population.

A. sativum was able to evoke higher beetle mortality than *D. tripetala* irrespective of the experimental concentration, exposure time and insect location. The higher insecticidal properties of *A. sativum* when compared to *D. tripetala* may be linked to the presence of various insecticidal active compounds like diallyl disulfide, diallyl trisulfide, allyl methyl trisulfide in *A. sativum* which are completely absent in *D. tripetala* (Satyal *et al*., 2017). These compounds are responsible for the characteristic odour of *A. sativum* and its higher fumigant action than *D. tripetala*. The higher pungent smell of the various compounds in *A. sativum* might have led to suffocation of *T. castaneum* biotypes and hence, higher mortality than their counterpart exposed to *D. tripetala*.

The various values of LC_{50} obtained in this study within 72 h exposure revealed that Lagos state biotype of *T. castaneum* required the highest quantity of both plants extracts while Ogun and Ondo state biotype of *T. castaneum* required the lowest quantity of *A. sativum* and *D. tripetala* respectively to achieve 50% mortality. This shows that population of *T. castaneum* obtained from Lagos State were the most tolerant of all the four biotypes while their counterparts obtained from Ondo and Ogun States were the least tolerant to *D. tripetala* and *A. sativum*, respectively. The highest tolerance observed in Lagos State biotype of *T. castaneum* may be linked to the strategic location of the city in Nigeria.

Lagos is arguably the most populated city in Nigeria with an estimated population of over 21 million people in year 2016 (NBC, 2018). Hence, the city is known as the commercial centre of the nation and therefore play host to several markets which are mostly patronized daily from various part of the country. There is therefore massive influx of traders who normally bring in their farm produce and products from different parts of the country. More bulbs of garlic and fruits of pepper fruits might have therefore being on sale due to many large markets in the city. Consequently, flour beetle might have consciously or unconsciously come in contact with both plant materials since diverse products are usually stored together by most residence in Lagos. Hence, high tolerance observed in Lagos State biotype of *T. castaneum* could be linked to possible interaction between both plant materials and beetle population. This might have increased the innate ability of the beetles collected from Lagos State to withstand the botanical extracts more than their counterpart obtained from other locations.

The differences observed in the susceptibility of various populations of *T. castaneum* to both botanical extracts could also be linked to cultural variations. Individuals are known to differ in the way they think and handle food materials due to variations in culture and tradition. New biotypes of insects are usually being developed from time to time as most insects adapt to most of these variations in order to survive. Most of these variations usually lead to increase or decrease in the innate ability of most insects to withstand poisons. Hence, the variations in the susceptibility of Lagos, Ogun, Ondo and Oyo States biotypes of *T. castaneum* to *A. sativum* and *D. tripetala* could be linked to the aforementioned. Oyeniyi *et al.* (2015a) as well as Gbaye and Oyeniyi (2015) had earlier reported similar observation for Osun State biotypes of *Callosobruchus maculatus* (Fabricius) exposed to *Piper guineense* (Schum and Thonn) and *Eugenia aromatica* (Baill), respectively. Similarly, Fragoso *et al.* (2002), Pereira *et al.* (2006) and Odeyemi *et al.* (2010) reported similar observation for various fields to store pests using synthetic insecticides.

Of all the three factors (i.e. population location, concentration and exposure time) considered in this study, the population location had the least significant effect irrespective of the botanical extract. Lower F-value observed in beetles exposed to *A. sativum* when compared to those exposed to *D. tripetala* however showed that the impact of population location was more pronounced in beetle populations exposed to *D. tripetala* than their counterparts exposed to *A. sativum*. This shows that the location from which *T. castaneum* is collected has a substantial impact on the rate of mortality when controlling beetles using *D. tripetala* than when using *A. sativum*. The significant interaction observed between the location from which *T. castaneum* was collected and time of exposure to both plant extracts also indicated that the degree to which the time of exposure affected beetle mortality was considerably influenced by geographical location from which they were collected for both plant extracts.

CONCLUSION

This study has clearly shown that geographical origin could considerably influence the response of *T. castaneum* to both botanical extracts. The response, however, varies with several factors such as the nature of botanical insecticide, exposure time and concentration of toxin. Lagos State biotype showed the highest tolerance to both botanical extracts while Ogun and Ondo State biotypes showed the least tolerance to *A. sativum* and *D. tripetala*, respectively. In summary, botanical insecticides have a big role to play in the management of various insect pests attacking food produce. However, detailed information is still needed on the various factors that could possibly reduce the efficacy of many prospective botanical insecticides against several stored product insect pests. Having comprehensive information on various factors that could affect the efficacy of botanicals could help to possibly guarantee the use of plant-derived insecticides as suitable alternatives to most synthetic insecticides in the management of various insect pests attacking wheat flour in Nigeria.

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