Online ISSN: 2299-9884
Polish Journal of Entomology 90(3): 119–129 (2021) DOI: 10.5604/01.3001.0015.0629

Abundance and diversity of insects associated with stored grains and tamarind in Nigeria

James Adebayo Ojo[1*], Adebayo Amos Omoloye[2]

[1] Department of Crop Production, Kwara State University, Malete, Kwara State, Nigeria.

[2] Department of Crop Protection and Environmental Biology, University of Ibadan, Ibadan, Nigeria.

* Corresponding author: jamesadebayoojo@gmail.com

Abstract: Detailed information on insect pests of stored grains in Nigeria is lacking. A two-year survey was conducted to determine the species composition and abundance of insects associated with maize, millet, rice, sorghum and tamarind in eighteen locations across five agro-ecological zones in Nigeria. Sixteen coleopteran, lepidopteran and hymenopteran species were associated with stored products, with high species richness on cereal grains but low species richness on tamarind. Most of these insects are polyphagous on cereal grains, whereas the tamarind weevil *Sitophilus linearis* (Herbst, 1797) (Curculionidae), and *Caryedon serratus* (Oliver, 1790) (Chrysomelidae) were found only on tamarind in this study. The maize weevil *Sitophilus zeamais* (Motschulsky, 1758)*,* rice weevil *Sitophilus oryzae* (Linneaus, 1763)*,* lesser grain borer *Rhyzopertha dominica* (Fabricius, 1792) (Bostrichidae), rusty grain beetle *Cryptolestes ferrugineus* (Stephens, 1831) (Laemophloeidae) and red flour beetle *Tribolium castaneum* (Herbst, 1797) (Tenebrionidae) were most abundant on stored grains. The tamarind weevil, *C. serratus* and the sawtoothed grain beetle *Oryzaephilus surinamensis* (Linneaus, 1758) (Silvanidae) were most abundant on tamarind. The hymenopterans *Theocolax elegans* (Westwood, 1874) (Pteromalidae)*, Anisopteromalus calandrae* (Howard, 1881) (Pteromalidae) and *Cephalonomia waterstoni* (Gahan, 1931) (Bethylidae) were the dominant parasitoids of larvae and pupae of the storage pests. Simpson index of diversity of insect species across locations ranged from low (0.63) to high (0.89).

Key words: storage insects, species richness, Coleoptera, polyphagous, Lepidoptera

Introduction

Cereals are the most important crops, as well as the main sources of calories, in Nigeria and many developing countries (Cordain 1999, Lale & Ofuya 2001). Sources of dietary energy are 3% from animal proteins, 11% from roots and tubers, 6% from pulses, and the remaining mainly from cereals (Cordain 1999, Schönfeldt & Hall 2012, Galati *et al.* 2014). The four most widely cultivated cereal crops in Nigeria and in sub-Saharan Africa are maize (*Zea mays* Linnaeus, 1753), rice (*Oryza sativa* Linnaeus, 1753), sorghum (*Sorghum bicolor* Linaeus, 1753) and millet (*Pennisetum glaucum* Linnaeus, 1753) (all Poaceae) (Edmonds *et al.* 2009, FAO 2017). In Nigeria, maize, sorghum, rice and millet are main staple food crops in terms of production (10.42, 6.94, 9.86 and 1.50 million tons, respectively) and area harvested (6.54, 5.82, 4.91 and 2.21 million hectares, respectively) (FAO 2017), whereas there is no statistical record for tamarind (*Tamarindus indica* Linnaeus, 1753) (Fabaceae). It is a leguminous tree crop grown mainly in the savanna regions of Nigeria and valuable for medicinal, confectionary and livestock feed purposes.

Despite this high level of production of cereals, the nutritional demand of the rapidly growing population cannot be met due to their inadequate supply (Edmonds *et al.* 2009). This production-supply shortage is caused by interactions of socioeconomic, technological, policy, biotic and abiotic factors (Odeyemi & Daramola 2000, Oscar 2009, Ojo

& Omoloye 2012, Elliott *et al.* 2014, Ojo *et al.* 2016a). Inadequate and high cost of farm inputs, poor infrastructure, poor access to quality seeds and growing population pressure are some of the socioeconomic and technological constraints to cereals production (De Groote *et al.* 2004, Oscar 2009, Galati *et al.* 2014). Degraded soil and climate change are part of the abiotic constraints to cereal production (Galati *et al.* 2014).

A significant proportion of harvested grains are lost in the field, in transit or in storage (Lale & Ofuya 2001, Ojo *et al.* 2016a, b).

Table 1. Agro-ecological zones and storage pest sampling locations in Nigeria.

Agro-ecological zones	**Municipalities**	**Crops sampled at each farmer's store**
Northern Guinea Savanna	Birni Gwari, Ningi, Dukku, Mubi	maize, rice, sorghum, millet, tamarind
Southern Guinea Savanna	Bida, Akwanga	maize, rice, sorghum, millet, tamarind
Semi-Arid Sudan Savanna	Kangiwa, Dange, Bichi, Miga, Potiskum, Biu	maize, rice, sorghum, millet, tamarind
Derived Savanna	Kishi, Pategi, Isanlu, Otukpo	maize, rice, sorghum, millet, tamarind
Humid Forest	Ondo, Uromi	maize, rice, sorghum, millet

Table 2. Insect species recovered from samples of stored maize, millet, rice, sorghum and tamarind in Nigeria.

Species	**Order**	**Family**	**Host**	**Pest Status**
Sitophilus zeamais (Motschulsky, 1758)	Coleoptera	Curculionidae	Maize, Sorghum, Rice, Millet	Primary
Sitophilus oryzae (Linneaus, 1763)	Coleoptera	Curculionidae	Maize, Sorghum, Rice, Millet	Primary
Rhyzopertha dominica (Fabricius, 1792)	Coleoptera	Bostrichidae	Maize, Sorghum, Rice, Millet	Primary
Sitophilus linearis (Herbst, 1797)	Coleoptera	Curculionidae	Tamarind	Primary
Caryedon serratus (Olivier, 1790)	Coleoptera	Chrysomelidae	Tamarind	Primary
Tribolium castaneum (Herbst, 1797)	Coleoptera	Tenebrionidae	Maize, Sorghum, Rice, Millet, Tamarind	Secondary
Lasioderma serricorne (Fabricius, 1792)	Coleoptera	Anobiidae	Maize, Sorghum, Millet, Tamarind	Secondary
Cryptolestes ferrugineus (Stephens, 1831)	Coleoptera	Laemophloeidae	Maize, Sorghum, Rice, Millet	Secondary
Oryzaephilus surinamensis (Linneaus, 1758)	Coleoptera	Silvanidae	Maize, Sorghum, Rice, Millet, Tamarind	Secondary
Plodia interpunctella (Hubner, 1813)	Lepidoptera	Pyralidae	Maize, Rice	Secondary
Sitotroga cerealella (Olivier, 1789)	Lepidoptera	Gelechiidae	Maize, Sorghum, Rice, Millet	Primary
Corcyra cephalonica (Stainton, 1865)	Lepidoptera	Pyralidae	Maize, Sorghum, Rice, Millet	Secondary
Ephestia cautella (Walker, 1863)	Lepidoptera	Pyralidae	Sorghum, Millet	Secondary
Anisopteromalus calandrae (Howard, 1881)	Hymenoptera	Pteromalidae	Maize, Sorghum, Rice, Millet, Tamarind	Natural enemy
Theocolax elegans (Westwood, 1874)	Hymenoptera	Pteromalidae	Maize, Sorghum, Rice, Millet	Natural enemy
Cephalonomia waterstoni (Gahan, 1931)	Hymenoptera	Bethylidae	Maize, Sorghum, Rice, Millet	Natural enemy

Stored grains are infested by several insect pests, causing economic damage that cannot be easily ameliorated. These insect pests bore into the intact outer coats of wholesome or undamaged seeds (primary pests) or penetrate seeds damaged by the primary pests or during harvest and post-harvest operations (secondary pests). The loss and damage caused by these insect pests varied, and depend on the species involved, type and nature of food materials, and storage duration, structure and condition. Any loss above 5% is considered an economic loss (Lale & Ofuya 2001).

The knowledge of pest diversity, distribution and abundance is important in developing and implementing pest management strategies against storage pests (Lale 2002). There is paucity of information on insect spectrum associated with stored grains across different locations in Nigeria. Post-harvest losses threaten farmers' livelihood and income, and food security in different regions of Nigeria. Each region has peculiar combinations of ecological and socioeconomic conditions, which contribute to difference in pest diversity and abundance. This study was conducted to survey for abundance and diversity of insect species associated with selected stored grains and tamarind across the main agro-ecological zones in Nigeria.

Materials and methods

Samples of maize, sorghum, rice, millet and tamarind were collected from farmers' stores from eighteen locations in five agro-ecological zones of Nigeria (Table 1) during the dry seasons (November to December) in 2013 and 2014. The four cereals were selected because they are the most widely grown cereals in Nigeria. Tamarind is not grown in the humid forest zone, limiting insect collections on this product only to the savannas. Three farmers' stores were randomly selected in each location, and the same stores were sampled in both years. The grains were bagged in 100-kg bags, stacked on pallets, and stored either in woven straw granaries or mud storage facilities in the farmers' houses. Most farmers fumigate their grains with aluminum phosphide tablets while bagging in preparation for storage, whereas no fumigation was done on tamarind due to its medicinal value and usefulness of its pulp as laxative. Four bags of each crop were surveyed at each farmer's location. A 167-g sample of each grain type and tamarind (approximately one-month-old since harvest) was collected from the top, middle and bottom of a bag, and thoroughly mixed. Samples collected from all three farmers at the same location were combined, given a 2-kg combined sample of each crop per location. They were put in individual sacks and transported to the Entomology Research Laboratory, Department of Crop Protection and Environmental Biology, University of Ibadan, Ibadan, Nigeria.

Each grain sample was put in a cylindrical plastic rearing container (16 cm high and 6 cm in diameter). Three subsamples (each 300 g) were taken from each 2kg sample, then put in individual rearing containers. The containers were arranged in randomized complete block design (RCBD) with ecozone as the main factor and type of grain as the blocking factor, and kept for 6 weeks in a laboratory maintained at 26±2°C, 63±7% RH and a 12-hour photophase. The containers were observed daily, and emerging insects were collected after the six-week storage period. The insect species were identified at the Insect Reference Museum of the Department of Crop Protection and Environmental Biology, University of Ibadan, Nigeria.

A preliminary analysis indicated that the insect diversity and abundance were similar between the two sampling years. Therefore, proportions of insect species and diversity data from both years were pooled. In order to stabilize the variance, proportion of insect population in grains and tamarind was arcsine-transformed before analysis of variance (ANOVA) using DSAASTAT (Onofri 2007). Simpson's index of diversity was calculated according to Magurran (2004) and Samways *et al.* (2010) using Paleontological Statistics (Hammer *et al.* 2001), and averaged across locations and zones. In order to assess the expected species richness, the 'Chao and Boot' and the Jackknife 1 indices were used to estimate species composition and abundance (Longino 1994).

Results and discussion

Sixteen species of Coleoptera, Lepidoptera and Hymenoptera were associated with maize, sorghum, rice, millet and tamarind obtained from five agro-ecological zones of Nigeria (Table 2). The coleopterans (nine species) and lepidopterans (four species) were grain pests, whereas the hymenopterans (three species) were parasitoids of the pests. Seven coleopteran species and all lepidopteran species were polyphagous. On tamarind, the major insect pests included the coleopterans *Sitophilus linearis* Herbst, 1797 (Curculionidae), *Caryedon serratus* Olivier, 1790 (Chrysomelidae), *Oryzaephilus surinamensis* Linneaus, 1758 (Silvanidae), *Tribolium castaneum* Herbst, 1797 (Tenebrionidae) and *Lasioderma serricorne* Fabricius, 1792 (Anobiidae). Three coleopteran and one lepidopteran species were primary pests of maize, rice, millet and sorghum, and two coleopteran species were primary pests of tamarind seeds. A total of seven coleopteran and lepidopteran species were considered secondary pests. The hymenopterans *Anisopteromalus calandrae* Howard, 1881 (Pteromalidae) were found in both tamarind and grains, whereas *Cephalonomia waterstoni* Gahan, 1931 (Bethylidae) and *Theocolax elegans* Westwood, 1874 (Pteromalidae) only in grains.

This study showed that coleopteran and lepidopteran pests are the prevailing orders of insects found on stored maize, sorghum, rice, millet and tamarind across the agro-ecological zones of Nigeria. Similar findings have been reported in Burkina Faso where twelve coleopteran species and two lepidopteran species colonized stored sorghum (Waongo *et al.* 2015). In warehouses in Ghana, four coleopteran and two lepidopteran species were found (Manu *et al.* 2018). However, five coleopteran species colonized stored maize, rice, millet and sorghum in Maiduguri, Northern Guinea Savanna, Nigeria (Chimoya & Abdullahi, 2011). Similarly, six coleopteran species was found on stored grains in Maiduguri (Mailafiya et al 2014). Contrastingly, Ukeh & Udo (2008) found three coleopteran and one lepidopteran species as the prevailing groups colonizing maize in Obudu, Humid Forest zone, Nigeria. The three pyralid and nine coleopteran species found in this study made them the most diverse pest families and orders of stored products in Nigeria. *Sitophilus*, *Rhyzopertha*, *Tribolium*, *Cryptolestes* and *Oryzaephilus* were the predominant coleopteran genera of storage insect pests. This observation is similar to those reported by Waongo *et al.* (2015) in which the genus *Rhyzopertha, Oryzaephilus*, *Cryptolestes* and *Sitophilus* were the predominant coleopteran pests on stored sorghum in Burkina Faso. Manu *et al.* (2018) reported the genus *Sitophilus* and *Prostephanus* as the predominant coleopteran pests on stored maize in Ghana. Chimoya & Abdullahi (2011) reported *Sitophilus*, *Tribolium* and *Rhyzopertha* as the predominant coleopteran genera on stored cereal grains – maize, sorghum, millet and rice in Nigeria. The pyralids (*Plodia*, *Ephestia* and *Corcyra*) and gelechiid (*Sitotroga*) were the dominant lepidopteran storage insect pests in this study. This finding is similar to the reports by Waongo *et al.* (2015) and Manu *et al.* (2018), who observed *Plodia*, *Sitotroga* and *Corcyra* as the common lepidopteran storage pests. The three hymenopterans were natural enemies associated with storage insect pests, similar to the reports by Van Huis (1991), Rees

(2004) and Ukeh & Udo (2008). They reported *Anisopteromalus*, *Cephalonomia*, *Theocolax* and *Dinarmus* as ectoparasitoids of larvae and pupae of storage insect pests. Benkhellat *et al.* (2015) also reported *A. calandrae* parasitizing the larvae of *Callosobruchus maculatus* Fabricius (Chrysomelidae).

The proportion of insect species associated with sorghum varied significantly across the agro-ecological zones ($F_{4,13}$=5.86, P<0.001) (Fig. 1). The beetles *Sitophilus oryzae* Linneaus, 1763 (Curculionidae) and *Rhyzopertha dominica* Fabricius, 1792 (Bostrichidae) were the most abundant insects on sorghum across the zones. The proportion of insect species associated with maize across the zones varied significantly ($F_{4,13}$=5.52, P<0.001) (Fig. 2). The proportion of *Sitophilus* was low in the Derived Savanna (DS) and Humid Forest (HF) zones, but high in the other three zones. The three most abundant insect species on maize were *Sitophilus zeamais* Motschulsky, 1758, *R. dominica* and *O. surinamensis*. The proportion of *R. dominica* was higher ($F_{4,13}$=5.32, P<0.001) in Semi-Arid Sudan Savanna (SASS) than in all other zones. The abundance of *Cryptolestes ferrugineus* Stephens, 1831 and *Tribolium castaneum* were higher in HF ($F_{4,13}$=6.01, P<0.001) and Northern Guinea Savanna (NGS) ($F_{4,13}$=5.82, P<0.001), respectively.

Rhyzopertha dominica, S. oryzae and *T. castaneum* were the most abundant insect species on rice and millet (Figs. 3, 4). *Rhyzopertha dominica* population was higher in HF on millet and in SASS on rice. *Sitophilus oryzae* population was higher on rice in SASS and NGS than in all other zones. The abundance of these three species were not significantly different from the population of other species in rice ($F_{4,13}$=1.11, P=0.26) and millet ($F_{4,13}$=2.42, P=0.31). On tamarind, the abundance of *S. linearis* was significantly higher ($F_{4,10}$=6.17, P<0.001) than those of other species (Fig. 5). The abundance of *S. zeamais*, *E. cautella*, *C. waterstoni*, *A. calandrae*, *T. elegans* and *L. serricorne* were significantly lower than those of other species on millet ($F_{4,10}$=6.05, P<0.0001) (Fig. 4).

This study has identified the primary pests of stored grains and tamarind across agro-ecological zones in Nigeria to be *S. zeamais, S. oryzae, R. dominica* and *S. cerealella, S. linearis* and *C. serratus*. Richards & Davies (1977) observed the larvae of *S. cerealella* to form webbing on the grains. The secondary pests associated with the cereals in this study include *L. serricorne, P. interpunctella, T. castaneum, C. cephalonica, O. surinamensis* and *E. cautella.* Raoul & Leonard (2013) reported the same group of insects as storage pests associated with grains in Cameroon. In this study, *S. linearis*, *C. serratus* and *O. surinamensis* were the most prevalent and destructive species on tamarind, corroborating observations by Jacob (1995) and Parameswari *et al.* (2002). Jacob (1995) reported *C. serratus*, *S. linearis*, *L. serricorne* and *R. dominica*, whereas Parameswari *et al.* (2002) observed *S. caryedon*, *S. linearis* and *T. castaneum* as the main pests of tamarind. *Sitophilus zeamais* was the most prevalent pest species on maize, *S. oryzae* was the most abundant species on rice, sorghum and millet, and *R. dominica* were more dominant in all the four grains. *Sitophilus linearis* and *C. serratus* were prevalent on tamarind. These observations were similar to Haines (1991), Throne (1994), Lale & Ofuya (2001) and (Chimoya & Abdullahi (2011) who reported that these pests are among the most serious cosmopolitan pests of stored grains in the tropics and sub-tropic regions.

The presence of *T. elegans, A. calandrae* and *C. waterstoni* on these stored products attest to the behaviour of parasitoids which naturally attack the larvae and pupae of many of these pests. Van den Assem & Kuenen (1958), Sharifi (1972), Haines (1991), Rees (2004) and Benkhellat *et al.* (2015) reported that these wasps parasitize larvae and pupae of *Sitophilus*, *Rhyzopertha*, *Callosobruchus*. It is known that these parasitoids possess the

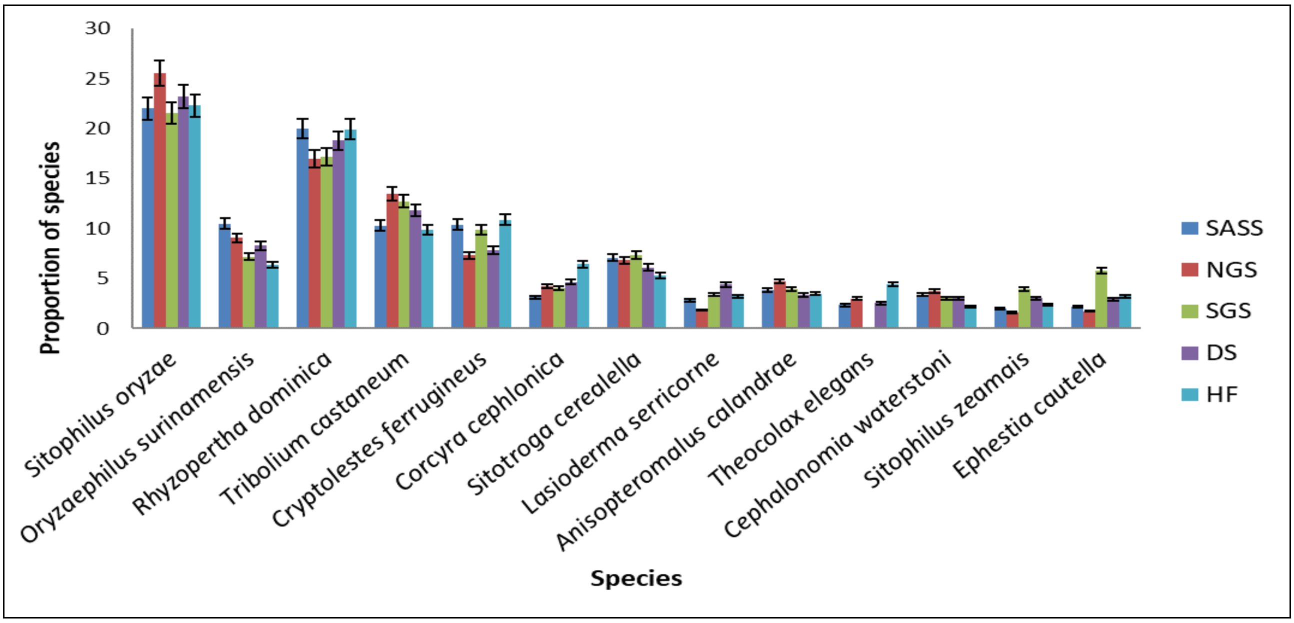

Fig. 1. Proportion of species associated with sorghum from different agro-ecological zones of Nigeria. DS = Derived Savanna; NGS = Northern Guinea Savanna; SASS = Semi-arid Sudan Savanna; SGS = Southern Guinea Savanna; and HF = Humid Forest.

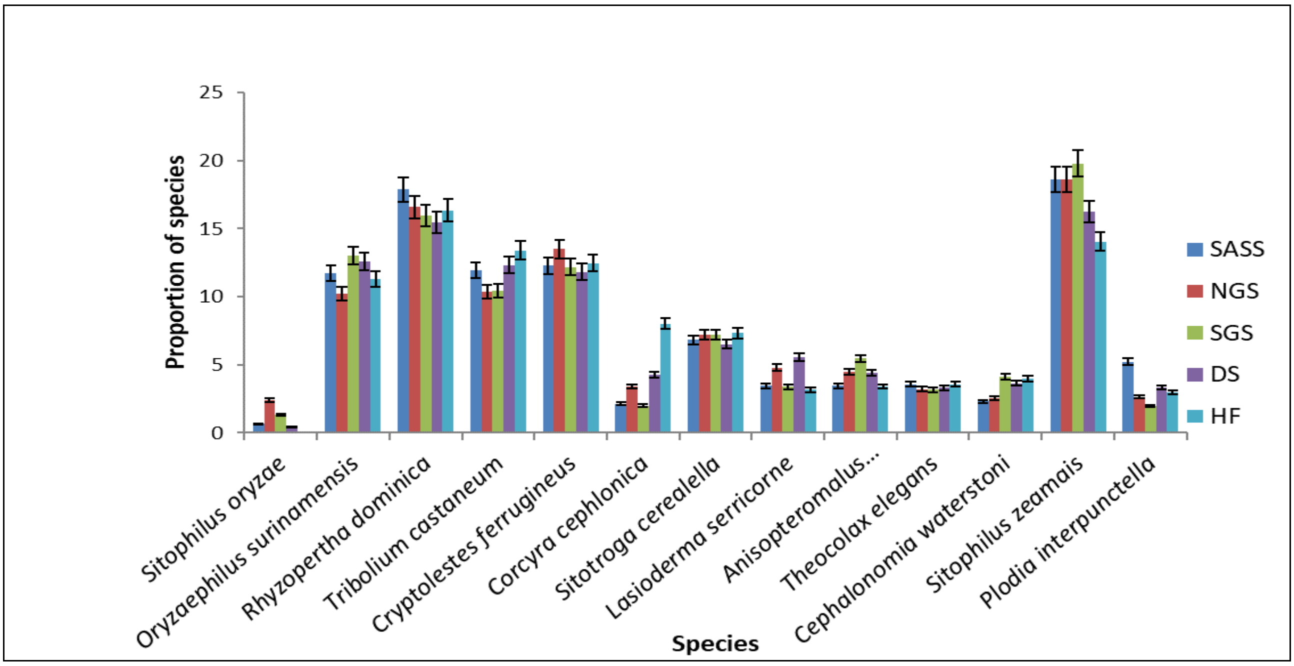

Fig. 2. Proportion of species associated with maize from different agro-ecological zones of Nigeria. DS = Derived Savanna; NGS = Northern Guinea Savanna; SASS = Semi-arid Sudan Savanna; SGS = Southern Guinea Savanna; and HF = Humid Forest.

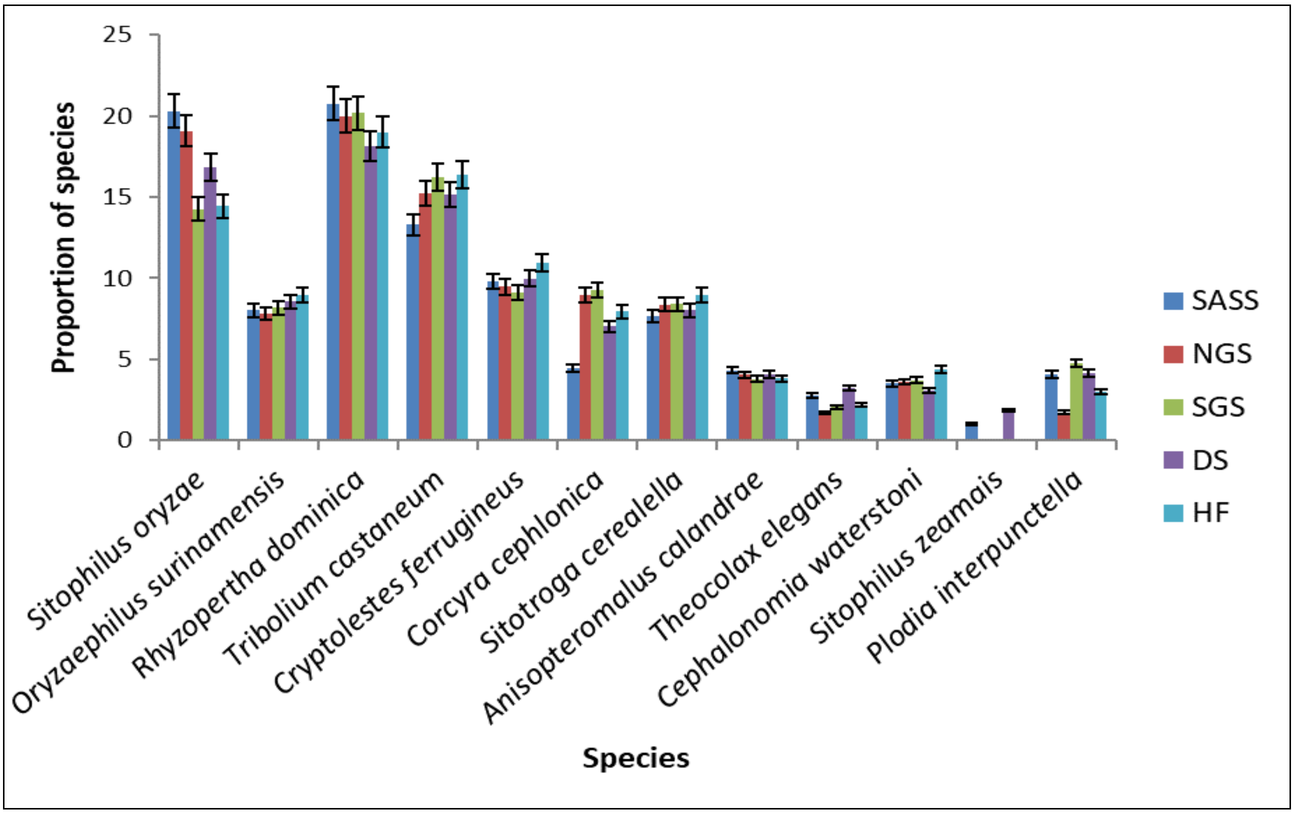

Fig. 3. Proportion of species associated with rice from different agro-ecological zones of Nigeria. DS = Derived Savanna; NGS = Northern Guinea Savanna; SASS = Semi-arid Sudan Savanna; SGS = Southern Guinea Savanna; and HF = Humid Forest.

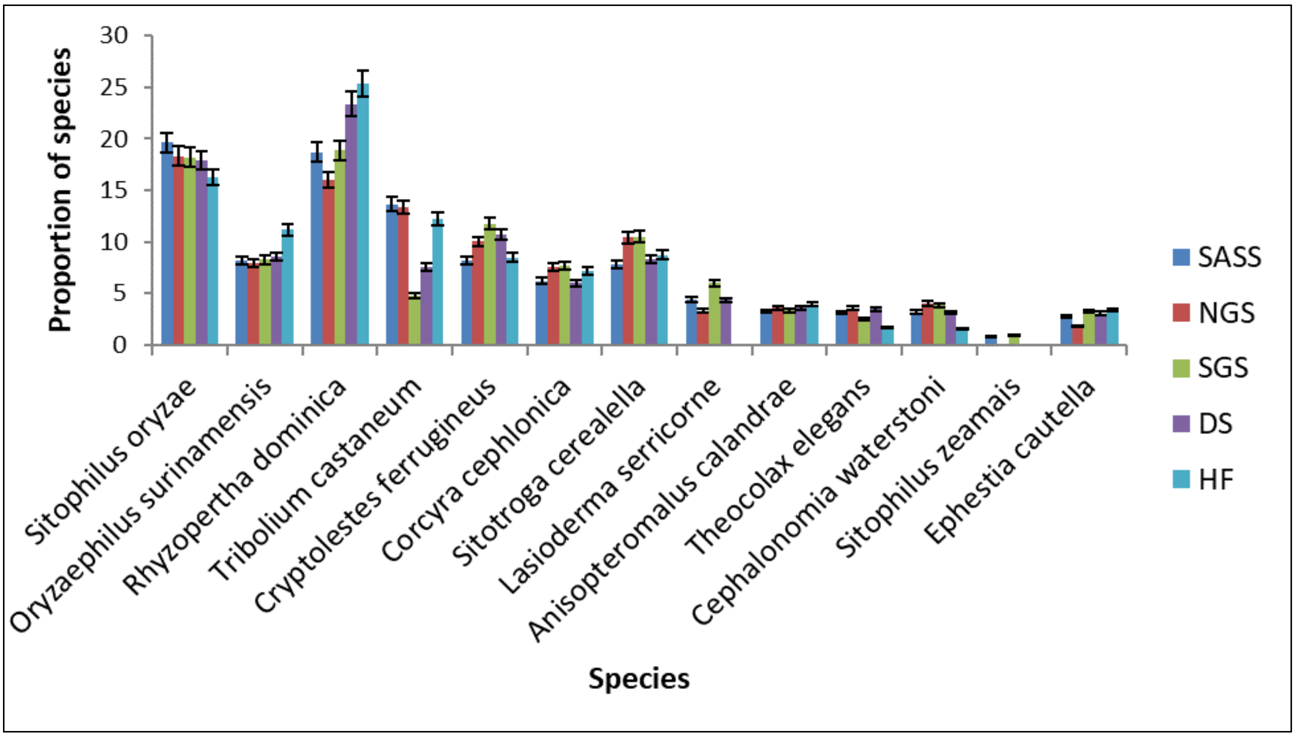

Fig. 4. Proportion of species associated with millet from different agro-ecological zones of Nigeria. DS = Derived Savanna; NGS = Northern Guinea Savanna; SASS = Semi-arid Sudan Savanna; SGS = Southern Guinea Savanna; and HF = Humid Forest.

Table 3. Diversity indices of insect associated with stored grains and tamarind in different agro-ecological zones of Nigeria.

	Derived Savanna	Northern Guinea Savanna	Semi-Arid Sudan Savanna	Southern Guinea Savanna	Humid Forest
			Sorghum		
No. of species	13	12	13	12	11
Simpson index	0.8532 ± 0.18	0.8435 ± 0.19	0.8507 ± 0.18	0.8554 ± 0.16	0.8480 ± 0.17
			Maize		
No. of species	13	13	13	13	11
Simpson index	0.8658 ± 0.19	0.8678 ± 0.16	0.8807 ± 0.13	0.8703 ± 0.15	0.8591 ± 0.18
			Rice		
No. of species	12	10	12	11	10
Simpson index	0.8773 ± 0.09	0.8674 ± 0.07	0.8716 ± 0.11	0.8805 ± 0.10	0.8718 ± 0.06
			Millet		
No. of species	12	11	13	13	10
Simpson index	0.8711 ± 0.12	0.8839 ± 0.09	0.8766 ± 0.06	0.8851 ± 0.08	0.8569 ± 0.11
			Tamarind		
No. of species	6	5	6	5	-
Simpson index	0.6434 ± 0.17	0.6464± 0.26	0.6346 ± 0.18	0.6425 ± 0.21	-

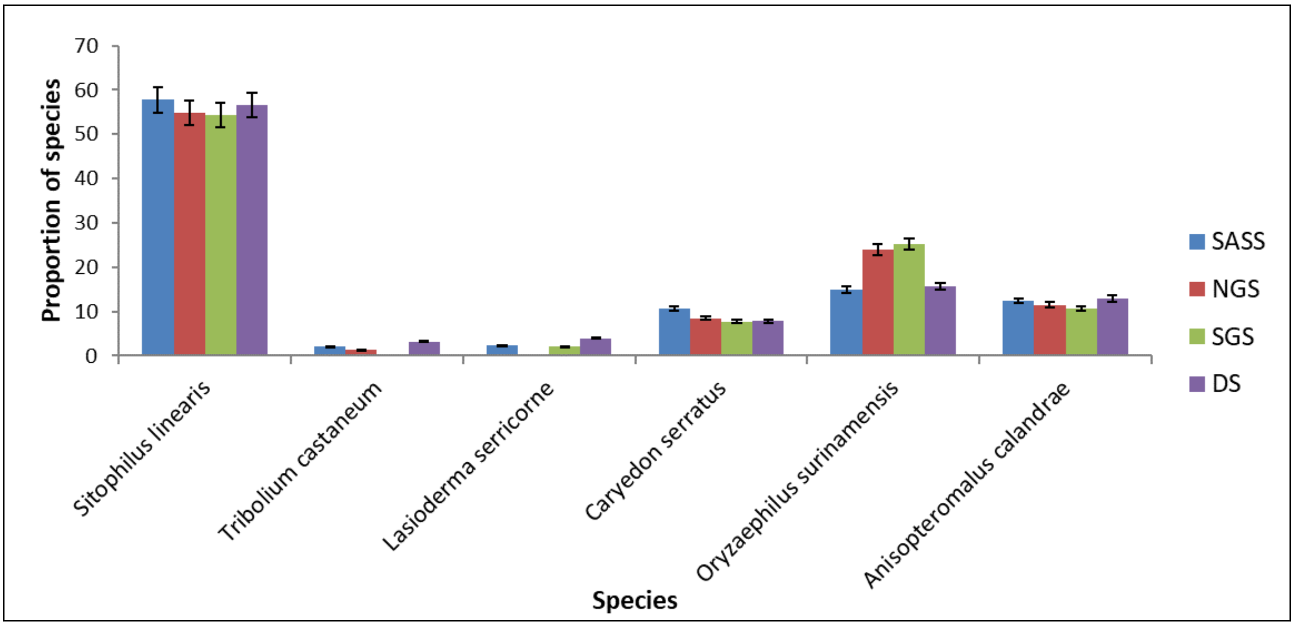

Fig. 5. Proportion of species associated with tamarind from different agro-ecological zones of Nigeria. DS = Derived Savanna; NGS = Northern Guinea Savanna; SASS = Semi-arid Sudan Savanna; and SGS = Southern Guinea Savanna.

ability to discriminate between parasitized and unparasitized hosts in a pest complex environment (Lale & Ofuya 2001, Rees 2004). Unparasitized hosts are being parasitized fast as more eggs are laid on them (Benkhellat *et al.* 2015). This ability to parasitize storage insect pests are harnessed biological control tactics in integrated pest management (IPM) program (Lale, 2002, Amevoin *et al.* 2007).

Tamarind had the lowest species richness, ranging from 5 to 6 species, whereas other grains have higher richness ranging from 10 to 13 species (Table 3). The average Simpson diversity indices ranged from 0.6346 to

0.8851 (Table 3). Sampling effort analysis revealed a potential species richness of 13 (in sorghum, maize and millet), 12 (in rice) and 6 (in tamarind) based on rarefaction curve obtained from accumulated data in the sampling study. These species richness' values were validated by Jackknife 1 and Chao indices. The estimated numbers of species obtained from Jackknife 1 analysis were 13.0 for sorghum, 13.0 for maize, 12.1 for rice, 13.1 for millet and 6.1 for tamarind, whereas those by Chao analysis were 13.0 for sorghum, 13.0 for maize, 11.9 for rice, 12.9 for millet and 5.9 species for tamarind. Results indicate that the possible numbers of species in the cereals and tamarind were realized. Cereal grains were dominated with more insects because they provided the most appropriate environments and food resources for the survival and abundance of insects associated with them.

Results from this survey suggested that grains, such as rice, maize, millet and sorghum, should not be stored together because they are attacked by similar insect pests. Co-storage of large quantity of cereal grains will only serve to provide more suitable food and increase pest population. Management of these pests is important in order to improve the livelihood of farmers and consumers. The survey results also suggested that *A. calandrae*, *T. elegans* and *C. waterstoni*, which are natural enemies of several storage grain pests, are common in grain storage in Nigeria and should be explored as biocontrol agents of storage pests.

References

Amevoin K, Sanon A, Apossaba M, Glitho IA. 2007. Biological control of bruchus infesting cowpea by the introduction of *Dinarmus basalis* (Rondani) (Hymenoptera: Pteromalidae) adults into farmers' stores in West Africa. *Journal of Stored Products Research*, 43: 240–247.

Benkhellat O, Jaloux B, Moali A, Chevrier, C, Monge, JP. 2015. Host discrimination and egg laying in *Anisopteromalus calandrae* (Hymenoptera: Pteromalidae) ectopara-sitoid of *Callosobruchus maculatus* (Coleoptera: Chrysomelidae). *Journal of Stored Products Research*, 61: 48–53.

Chimoya IA, Abdullahi G. 2011. Species compositions and relative abundance of insect pest associated with some stored cereal grains in selected markets of Maiduguri metropolitan. *Journal of American Science*, 7: 355–358.

Cordain L. 1999. Cereal grains: humanity's double-edged sword. *World review of nutrition and dietetics*, 84: 19.

De Groote H, Bett C, Okuro JO, Odendo M, Mose M, Wekesa E. 2004. Integrated approaches to higher maize productivity in the new millennium: Direct estimation of maize crop losses due to stemborers in Kenya, preliminary results from 2000 and 2001. *Proceedings of the 7th Eastern and Southern Africa Regional Maize Conference*. CIMMYT, Mexico, pp. 401–406.

Edmonds DE, Abreu SL, West A, Caasi DR, Conley TO, Daft MO, Desta B, England BB, Farris CD, Nobles TJ, Patel NK. 2009. Cereal nitrogen use efficiency in sub-Saharan Africa. *Journal of Plant Nutrition*, 32: 2107–2122.

Elliott J, Deryng D, Müller D, Frieler K, Konzmann M, Gerten D, Glotter M, Flörke M, Wada Y, Best N, Eisner S. 2014. Constraints and potentials of future irrigation water availability on agricultural production under climate change. *Proceedings of National. Academic of Sciences,* 111: 3239–3244.

FAO, Food and Agriculture Organization. 2017. Crops. http://www.fao.org/faostat/en/#data/QCA ccessed 17 August 2019.

Galati A, Oguntoyinbo FA, Moschetti G, Crescimanno M, Settanni L. 2014. The cereal market and the role of fermentation in cereal-based food production in Africa. *Food*

Reviews International, 30(4): 317–337.
Haines CP. 1991. Insects and arachnids of tropical stored products: Their biology and identification: A training manual. Natural Research Institute. Kent, UK, 246 pp.
Hammer Ø, Harper DAT, Ryan PD. 2001. Paleontological statistics software package for education and data analysis. *Palaeontologia electronica*, 4: 1–9.
Jacob S. 1995. Pests in stored tamarind. *Spice India* 8: 9–10.
Lale NES. 2002. Stored product entomology and acarology in tropical Africa, 1st ed. MNoce Publication Limited, Maiduguri, Nigeria, 213 pp.
Lale NES, Ofuya TI. 2001. Overview of pest problems and control in the tropical storage environment, pp. 1-23. In: Ofuya TI, Lale NES. (Eds.) *Pest of stored cereals and pulses in Nigeria – biology, ecology and control.* Dave Collins Publications, Akure, Ondo State, Nigeria, 174 pp.
Longino J. 1994. How to measure arthropod diversity in a tropical rainforest. *Biology International*, 28: 3–13.
Magurran AE. 2004. *Measuring biological diversity,* 2nd ed. Blackwell Science Ltd, Oxford, UK, 105 pp.
Mailafiya DM, Maina TY, Degri MM, Gadzama UN. 2014. Traders' perception of food grain storage and pest management in Dalwa market, Borno State. *Journal of Agricultural and Crop Research*, 2(4): 62–70.
Manu NE, Osekre A, Opit GP, Campbell JF, Arthur FH, Mbata G, Armstrong PR, Danso JK. 2018. Population dynamics of stored maize insect pests in warehouses in two districts of Ghana. *Journal of Stored Products Research*, 76: 102–110.
Odeyemi OO, Daramola AM. 2000. *Storage practices in the tropics*. Dave Collins Publication, Akure, Ondo State, Nigeria, 235 pp.
Ojo JA, Omoloye AA. 2012. Rearing the maize weevil, *Sitophilus zeamais*, on an artificial maize–cassava diet. *Journal of Insect Science*, 12(69): 1–9.
Ojo JA, Osunlola OS, Longe OO. 2016a. Comparative efficacy of three botanicals against *Callosobruchus maculatus* Fabricius (Coleoptera: Chrysomelidae: Bruchinae) in stored cowpea seeds. *Egyptian Journal of Biological Pest Control* 26: 637–642.
Ojo JA, Valero MC, Sun W, Coates BS, Omoloye AA, Pittendrigh BR. 2016b. Comparison of full mitochondrial genomes for the rice weevil, *Sitophilus oryzae* and the maize weevil, *Sitophilus zeamais* (Coleoptera: Curculionidae). *Agri Gene*, 2: 29–37.
Onofri A. 2007. *Routine statistical analyses of field experiments by using an Excel extension.* In: Proceedings of the 6th National Conference Italian Biometric Society: "La statistica nelle scienze della vita e dell'ambiente", Pisa, Italy. pp. 93–96.
Oscar R. 2009. *Crop monitoring in Kenya*. Joint Research Centre of the European Commission, IPSC Institute, MARS Unit. FOOD-SEC, Ispra (VA), Italy, 6 pp.
Parameswari K, Srimathi P, Vanangamudi K, Sasthri G. 2002. Storability of scarified and nonscarified seeds of tamarind (*Tamarindus indica* L.). *Madras Journal of Agriculture*, 89: 52–55.
Raoul TB, Leonard NTS. 2013. Diversity of stored grain insect pests in the Logone Valley, from Northern Cameroon to Western Chad Republic in Central Africa. *Journal of Agricultural Science and Technology* 3: 724–731.
Rees DP. 2004. *Insects of stored products*. CSIRO Publishing, Clayton, South Victoria, Australia, 181 pp.
Richards OW, Davies RG. 1977. *Imms' general textbook of entomology. Volume I: Structure, physiology and development*, 19th ed. Chapman and Hall, London, UK, 418 pp.
Samways MJ, McGeoch MA, New TR. 2010. *Insect conservation: a handbook of approaches and methods.* Oxford University Press, New York, NY, 441 pp.
Schönfeldt HC, Hall NG. 2012. Dietary protein

quality and malnutrition in Africa. *British Journal of Nutrition*, 108: 69–76.

Sharifi S. 1972. Radiographic studies of the parasite *Choetospila elegans* on the maize weevil, *Sitophilus zeamais*. *Annals of Entomological Society of Am*erica, 65: 852–856.

Throne JE. 1994. Life history of immature maize weevils (Coleoptera: Curculionidae) on corn stored at constant temperature and relative humidities in the laboratory. *Environmental Entomology*, 23: 1459–1471.

Ukeh DA, Udo IA. 2008. Analysis of insect populations in stored crops in Cross River State, Nigeria. *Global Journal of Pure and Applied Sciences,* 14: 31–36.

Van den Assem J, Kuenen DJ. 1958. Host finding of *Choetospila elegans* Westwood (Hym. Chalcid.) a parasite of *Sitophilus granarius* L. (Coleoptera: Curculionidae). *Entomologia Experimentalis et Applicata*, 1: 174–180.

Van Huis A. 1991. Biological methods of bruchid control in the tropics: a review. *International Journal of Tropical Insect Sci*ence, 12: 87–102.

Waongo A, Ba NM, Dabiré-Binso LC, Sanon A. 2015. Diversity and community structure of insect pests developing in stored sorghum in the Northern-Sudan ecological zone of Burkina Faso. *Journal of Stored Products Res*earch*,* 63: 6–14.

Received: 07.09.2020
Accepted: 24.05.2021
Published online: 03.08.2021