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POPULATION DYNAMICS OF THE BLACK COFFEE TWIG BORER *XYLOSANDRUS COMPACTUS* (EICHHOFF) IN ROBUSTA COFFEE *COFFEA CANEPHORA*

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ABSTRACT

Population dynamics of *Xylosandrus compactus* (Eichhoff) lifestages in Robusta coffee were evaluated at the National Coffee Research Institute, Kituza, Uganda. Results revealed that its population and incidence varied with time, with brood size being highest in December and November 2020. Eggs were maximum in December 2020 and May 2021; larvae in November and December 2020 and May 2021; pupae in July 2021 and May 2021; and, adults in December 2020 and August 2021. Dead adults, live and total pupae decreased significantly ($p \leq 0.05$) with increasing temperature (R^2=0.3435, 0.5598, 0.6017, respectively); eggs and dead pupae increased significantly ($p \leq 0.05$) with increasing rainfall (R^2=0.5266, 0.6349, respectively); and, dead adults and live pupae decreased significantly ($p \leq 0.05$) with increasing relative humidity (R^2= 0.4383, 0.3635, respectively). This information will enable monitoring and predicting population buildup, and thus IPM decisions.

Key words: *Xylosandrus compactus*, adults, ambrosia-beetle, brood-size, eggs, larvae, pupae, seasonal incidence, rainfall, relative humidity, temperature, abundance, lifestages

The black coffee twig borer (BCTB) *Xylosandrus compactus* (Eichhoff) (Insecta: Coleoptera: Curculionidae: Scolytinae) is currently one of the most destructive insect pests of coffee in Uganda (Kagezi et al., 2013, 2016a, b; NaCORI/ MAAIF/ UCDA, 2022; Olango et al., 2023). It attacks both Robusta and Arabica coffee but, in Uganda it generally prefers Robusta (Kagezi et al., 2016a). It is an ambrosia beetle (Greco and Wright, 2015) which together with bark beetles belong to the Xyleborini tribe, all of which feed exclusively on ambrosia fungus cultivated inside the galleries constructed by the adult female beetles (Batra, 1963; Wood, 1982; Six, 2012). This tribe consists of some of the most injurious groups of insects in native and planted forests (Raffa et al., 2015). It is believed to be native to Southeast Asia (Brader, 1964), now distributed worldwide (Hayato, 2007). In Uganda, it was first reported in 1993 near the Democratic Republic of Congo (DRC) border (Adipala-Ekwamu et al., 2001; Egonyu et al., 2009) and since then it has spread to all the major Robusta coffee growing regions (Kagezi et al., 2013, 2016a,b; NaCORI/MAAIF/UCDA, 2022; Olango et al., 2023). This insect pest is highly invasive (Egonyu et al., 2009; Gugliuzzo et al., 2021) and once in a new location, it spreads rapidly within and between coffee gardens but, the reasons behind this are yet to be fully established (Kagezi et al., 2016a).

Weather conditions, particularly temperature, rainfall and relative humidity have been reported to influence the biology, development, population dynamics, flight patterns and shape of ambrosia and bark beetle communities (Marini et al., 2011; Reich et al., 2014). Temperature has been reported to have positive and significant effect on population dynamics and activities of ambrosia and bark beetles (Abbasi et al., 2008; Reich et al., 2014; Johnson and Manoukis, 2021) whereas, (Egonyu et al., 2014, 2016; Gugliuzzo et al., 2020; Tarno et al., 2022) have reported negative effects. Similarly, rainfall has also been shown to have both positive (Reich et al., 2014; Bukomeko et al., 2018; Martínez et al., 2019; Johnson and Manoukis, 2021; Tarno et al., 2022) and negative effects (Bucini et al., 2005; Speranza et al., 2009; Menocal et al., 2022) on ambrosia and bark beetles. Also, Mote and Tambe (2000) and Suárez-Hernández et al., (2023) have reported positive and significant correlation of relative humidity and incidence and population of ambrosia beetles whereas, Chen et al. (2020) and Qureshi et al. (2021) have shown negative relationship.

Therefore, it is necessary to understand the seasonal phenology of *X. compactus* and the relationship with temperature, rainfall and humidity. This information is vital for predicting periods of high activity (Johnson and Manoukis, 2021), and thus guide timely IPM options (Tochen et al., 2016). This information can also be used to develop action thresholds and forecasting models which could also serve as decision support tools (Johnson and Manoukis, 2021). This study thus, explores the seasonal variation of lifestages of *X. compactus* in the galleries of Robusta coffee, *Coffea canephora*.

MATERIALS AND METHODS

This study was conducted at the National Coffee Research Institute (NaCORI), Kituza, located in Mikono district, about 35 km east of Uganda's capital city, Kampala in the Lake Victoria Crescent Agroecological Zone (N0^{0}15`26.9874``, E32$^{0}$47`27.69648``, 1200 masl) (Kobusinge et al., 2023). NaCORI receives 1,000-2,000 mm annual rainfall, with 15 to 28 °C temperature (Kamanyire, 2000; MDLG, 2015). The major soils are Ferralsols constituting sandy clay-loams (Kamanyire, 2000). Data were collected from already existing Robusta coffee trees, aged about 19 years for a period of one year (September 2021-August 2022). At the end of each month, 40 coffee primary branches (twigs) infested by *X. compactus* were randomly harvested and taken to the laboratory (21.7± 0.2 °C, 88± 1.3% RH) to observe the lifestages (eggs, larvae, pupae and adults) under a microscope. These were counted and recorded. Data on temperature and rainfall were recorded from the Agrometeorological Weather Station installed by the Uganda National Meteorological Authority at NaCORI. Means of the brood size and lifestages were computed/ primary branch, and regression analysis was done using SAS software (SAS Institute, 2008).

RESULTS AND DISCUSSION

Determining the seasonal phenology of insect pests and the underlying abiotic drivers are essential for predicting periods of high infestation and activity (Frost et al., 2013; Johnson and Manoukis. 2021). This is therefore a critical step in developing an integrated pest management plan for ambrosia and bark beetles including the black coffee twig borer, *Xylosandrus compactus* (Johnson and Manoukis., 2021). Results showed that that *X. compactus* brood was present throughout the year, but the size fluctuated with time (Fig. 1). Our finding is in agreement with a number of other earlier studies (e.g. Burbano, 2010; Egonyu et al., 2014, 2016; Gugliuzzo et al., 2019a, b, 2020; Monterrosa et al., 2022). Similar trends have also been observed in case of other related ambrosia and bark beetles (e.g. Öhrn, 2012; Reding et al., 2013; Öhrn et al., 2014; Johnson and Manoukis. 2021; Rojano et al., 2021; Monterrosa et al., 2022). The mean size of *X. compactus* brood experienced three major peaks, in November 2020, December 2020 and August 2021, while the lowest numbers were observed in March 2021. This finding partly agrees with Egonyu et al. (2014, 2016) who observed the major peak of *X. compactus* brood in August 2014 in the Lake Victoria Crescent region of Uganda.

Similarly, the incidence of life stages of *X. compactus* varied (Fig. 2); maximum eggs were recovered in December 2020 and May 2021, whereas, no eggs were recovered from the infested primary branches in February, March, July, August and September 2021. Major peaks of larvae were observed in November 2020, December 2020 and May 2021 and the lowest in March, April 2021, 2021 and September 2021. Pupae were maximum in July and May 2021 whereas, no pupae were recovered in September 2021. On the hand, adult beetles had two major peaks, in December 2020 and August 2021 whereas the lowest numbers were observed in March 2021 and June 2021. These findings are partly in agreement with those of Egonyu et al. (2014, 2016). The observed trends could be partly

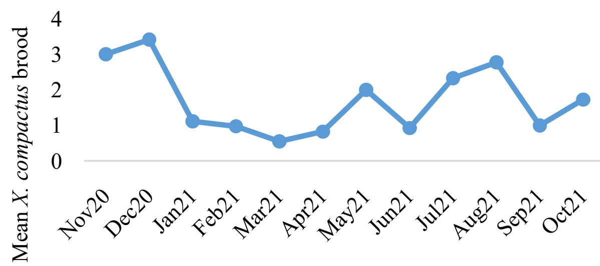

Fig. 1. Brood size of *X. compactus* lifestages-primary branches of Robusta coffee

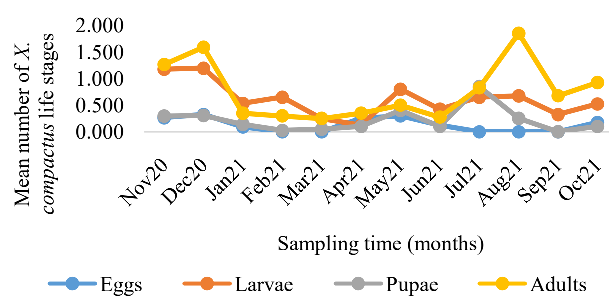

Fig. 2. *Xylosandrus compactus* lifestages- infested Robusta coffee primary branches

attributed to the variability in the times the insect takes to complete each life stage, i.e. 4-6, 7-8, and 8-9 d, respectively (Ngoan et al., 1976; Hara, 1977; Greco and Wright, 2015). Therefore, by identifying peaks, coffee growers can maximize the efficiency of IPM (Frank and Sadof, 2011; Werle, 2016; Johnson and Manoukis, 2021). Peak periods of *X. compactus* lifestage and brood can also be used as an predictor of damage levels or risk to tree damage for accurate timing of control measures (Oliver and Mannion. 2001; Burbano, 2010). Therefore, monitoring of the populations and/or the flight activities of *X. compactus* should be done regularly for precise timing of management decisions (Burbano, 2010; Reding and Ranger 2018). This is a fundamental part of IPM (Burbano et al., 2012).

Being poikilothermic animals (Régnière and Powell, 2013), temperature directly affects many aspects of insect life such as growth rates, survival probability, reproductive rates, and flight propensity (Bale et al., 2002; Brar et al., 2015). Therefore, the effect of temperature on the population dynamics can be used to facilitate timing of IPM strategies (Gaylord et al., 2008). Relationships between temperature and *X. compactus* life stages as given in Table 1 revealed that mean monthly temperature was negatively and significantly related to number of dead (R^2=0.3435; p=0.0452) as well as live (R^2=0.5598; p=0.0051) and total pupae (R^2=0.6017; p=0.003). These findings are in agreement with those of Egonyu et al. (2016). Gugliuzzo et al. (2020) reported that temperature affected significantly the mortality of overwintering *X. compactus* adults in the galleries of carob trees in Sicily, Italy. Temperature has also been reported to be significantly and negatively correlated to the development period of the pupae of a closely related ambrosia beetles, *Xylosandrus crassiusculus* Motschulsky (Qureshi et al., 2021), *X. germanus* Blandford (Yang et al., 2010) and *Xyleborus fornicatus* Eich. (Walgama and Zalucki, 2007) under laboratory conditions. This could in part be due to the fact that temperature affects the availability and development of the ambrosia fungus associated with *X. compactus* in the galleries, leading to variations in the levels of mycophagy (Adams and Six, 2007; Hofstetter et al., 2007; Six and Bentz, 2007). Since the ambrosia fungus acts as the sole source of food for *X. compactus* brood (Greco and Wright, 2015), its low levels result into reduced ability of the beetle to generate offsprings (Umeda and Paine, 2019). Such information is critical in developing models to predict the distribution and development of this insect pest (Walgama and Zalucki, 2007).

Population dynamics and species richness as well as activity and flight of ambrosia and bark beetles have been reported to be influenced by rainfall (Reich et al., 2014; Martínez et al., 2019; Johnson and Manoukis, 2021; Tarno et al., 2022). Present study showed that the amount of rainfall was positively and significantly related to only the mean number eggs (R^2=0.5266, p=0.0075) and dead pupae (R^2=0.6349, p=0.0019) (Table 1). Similarly, rainfall has been reported to positively influence the abundance and species richness of ambrosia beetles, *Xyleborus affinis*, *Xylosandrus crassiusculus* and *Hypothenemus* sp. (Tarno et al., 2022). It is most likely that *X. compactus* initiates attack in dry seasons when coffee is under stress conditions (Hara and Beardsley 1979; Jones and Johnson 1996; Hayato 2007), but starts to lay eggs in the rainy season when humidity is high. High humidity favors the growth of ambrosia fungi such as *Fusarium solani* (Mart.) associated with *X. compactus* and other beetles of the xyleborini tribe (Atkinson and Equihua-Martinez, 1986). Generally, rainfall may also increase the diversity and abundance of ambrosia and bark beetles because it prolongs host plant conditions suitable for their immature stages (Sanguansub et al., 2020) but also increases plant biomass and species richness (Zavaleta et al., 2003; Robertson et al., 2009; Wu et al., 2011). Efforts to manage *X. compactus* should therefore target the dry season before the population of this insect pest builds up to initiate laying of eggs and damage in the wet season (Egonyu et al., 2016).

Relative humidity has also been reported to affect insect physiology, survival, fecundity, reproductive status and behavior (Norhisham et al., 2013; Tochen et al., 2016), either positively or negatively. Results showed that the relative humidity was significantly negatively related to only the mean number of dead adults (R^2 = 0.4383, p=0.019) and live pupae (R^2 = 0.3635, p=0.038) (Table 1). Significant increase of the population of ambrosia beetles with increasing humidity has been reported; for example, Suárez-Hernández et al. (2023) reported a positive correlation between minimum relative humidity and the population of *Dendroctonus mexicanus* and *Hylastes tenuis*. Similarly, Martínez et al. (2020) reported that increasing the relative humidity resulted into capturing of significantly more *Coptoborus ochromactonus* n. sp. beetles in commercial plantations of *Ochroma pyramidale* (Cav. Ex. Lam.) Urb. of Ecuador. The reduction in death of *X. compactus* with increasing humidity would in part be due to the fact that these conditions improve the growth of symbiotic ambrosia fungi that live in

Table 1. Relationship between weather factors vs *X. compactus* lifestages

Temperature (mean monthly)

Lifestages	DF	Parameter Estimate	Standard error	t value	p value
Eggs	1	-0.69148	0.67428	-1.03	0.3293
Dead adults	1	-1.19777	0.52362	-2.29	0.0452
Dead larvae	1	-0.94545	3.564	-0.27	0.7962
Dead pupae	1	-2.11715	2.65602	-0.8	0.4439
Live adults	1	-0.10036	0.15803	-0.64	0.5396
Live larvae	1	-0.34378	0.27121	-1.27	0.2337
Live pupae	1	-0.94188	0.2641	-3.57	0.0051
Total adults	1	-0.19378	0.15822	-1.22	0.2488
Total larvae	1	-0.32224	0.26115	-1.23	0.2454
Total pupae	1	-0.96649	0.24864	-3.89	0.003
Rainfall (mean monthly)					
Eggs	1	377.56346	106.23571	3.55	0.0052
Dead adults	1	-126.4985	140.1049	-0.9	0.3878
Dead larvae	1	1280.60278	697.29112	1.84	0.0961
Dead pupae	1	1388.09357	434.38626	3.2	0.0096
Live adults	1	1.40094	36.33788	0.04	0.9700
Live larvae	1	67.64039	62.30692	1.09	0.3031
Live pupae	1	-36.73483	88.99387	-0.41	0.6885
Total adults	1	-7.16751	38.18741	-0.19	0.8549
Total larvae	1	70.128	59.18387	1.18	0.2634
Total pupae	1	-7.26612	88.79997	-0.08	0.9364
Relative humidity					
Eggs	1	13.1356	8.35991	1.57	0.1472
Dead adults	1	-17.81756	6.37845	-2.79	0.019
Dead larvae	1	37.30458	45.59852	0.82	0.4324
Dead pupae	1	33.83049	34.44875	0.98	0.3492
Live adults	1	2.13164	2.0128	1.06	0.3145
Live larvae	1	2.38228	3.77341	0.63	0.542
Live pupae	1	-9.99526	4.18223	-2.39	0.038
Total adults	1	1.13388	2.20552	0.51	0.6183
Total larvae	1	2.42199	3.61136	0.67	0.5176
Total pupae	1	-9.09162	4.31924	-2.1	0.0616

association with members of the Scolytinae including *X. compactus* (Atkinson and Equihua-Martinez, 1986). The fungus serves as the sole food source for the mother beetle and her off-springs (Ngoan et al., 1976; Hara and Beardsley 1979). Therefore, research should be geared towards determining the optimal amount of humidity that supports the development of ambrosia fungi associated with *X. compactus*. This information is vital in designing and developing IPM strategies for *X. compactus*.

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AUTHOR CONTRIBUTION STATEMENT

This study formed part of Winnie Nanjego's MSc thesis research work. The idea of research, conducting experiments, analyzing the results, and writing were done by the first author and her supervisors.

CONFLICT OF INTEREST

No conflict of interest.

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