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Research Article

Heteronychus arator Population Dynamics and its Influencing Climatic Factors in the Humid Rainforest Maize Field in Cameroon

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Abstract

Background and Objective: Maize (*Zea mays* L.) is an important versatile food and industrial crop in Cameroon but its production is constraint by many pests including the black maize beetle, *Heteronychus arator* currently an emerged, serious subterranean perennial pest of the crop. This study aimed to monitor the population dynamics of the pest in maize fields together with influential climatic factors. **Materials and Methods:** Monthly samples of *H. arator* adults were collected in 2020 and 2021 in fields planted at a rate of three per hole at 75×50 cm inter and intra-row spacing at 5 cm depth, respectively. Adult beetles were trapped via pitfall and litter traps once every week and data was combined monthly from January to December. **Results:** In 2020, 9637 adults were caught in both traps and 8980 in 2021 giving a total of 18617. During the peak rainy season, higher numbers were caught in litter traps than the pitfall while during the dry season, the pitfall traps caught higher numbers. Temperature was positively correlated with the number of beetles caught with r = 0.713 in 2020 and r = 0.700 in 2021. In contrast, rainfall and soil moisture were negatively correlated with r = -0.695 and -0.435 in 2020 and r = -0.761 and -0.657, respectively for rainfall and soil moisture in 2021. **Conclusion:** Baited pitfall and litter traps can be used to monitor and/or sample for *H. arator* adults in maize fields while the environmental factors can be used to predict the periods of high and low populations of the pest.

Key words: *Heteronychus arator*, population dynamics, maize, pitfall baited and litter traps, perennial pest, Buea

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Maize (*Zea mays* L.) is the third most important cereal grown in the humid tropics and Sub-Saharan Africa after wheat and rice[1].

It is a major source of livestock feed, food staple and source of livelihood in many parts of the world. Maize is used globally for several purposes, 67% of maize is used for livestock feed, 25% for human consumption and industrial purposes and 5% is used for seed purposes for the next crop[2]. In Sub-Saharan Africa (SSA) it accounts for 40% of the cereal production, where more than 80% is used as food[2]. Almost all or most SSA countries grow it as their primary cereal and one of the top two cereals in over three-quarters of these countries[3]. The crop provides about 60% of the total calorie intake of people in Sub-Saharan Africa[4]. Over the next 30 years, the population of SSA is projected to double[5] and demand for cereals is predicted to increase by three-fold[6].

Maize is grown across a wide range of agro-ecological zones from wet to hot semi-arid lands and in different soil types. It is produced extensively in Cameroon, where it is consumed roasted, baked, fried, pounded or fermented[7]. In Cameroon, it is used in many traditional dishes (koki corn, corn chaff, corn fufu and pap) as well as drinks (corn beer and sha). It is a major source of income for many farmers in SSA[8].

Despite the importance of the crop, maize production suffers from a number of constraints which include poor soil fertility, environmental degradation, diseases and several insect pests.

In Cameroon most especially, the black maize beetle, *Heteronychus arator* Fabricius (Coleoptera: Scarabaeidae), has emerged as the most important insect pest that attacks the subterranean parts of maize. This pest is indigenous to South Africa but also occurs in Australia, New Zealand, Zimbabwe and Zambia[9].

The maize black beetle is not only a univoltine pest, its nocturnal adults are attracted to artificial light after emerging from the soil but are often found near the soil surface[10].

Adults spend most of their time underground and feed on the subterranean parts of maize and other plants, especially root and tubers, they are not adversely affected by heavy rain and can even tolerate long periods of submersion in water[11]. Larvae are able to move through the soil and some are found near the moist root systems of maize. The adult is the main pest stage but the larvae also cause damage to underground crop portions[12].

It is a polyphagous insect that attacks a wide range of cultivated crops, during various stages of growth, from seedling to maturity[13]. Older larvae attack plant roots meanwhile young larvae feed on soil organic matter. It has been reported that this pest causes losses of up to 20-30% of planted maize[10]. It equally causes severe toppling of the whole maize plant especially when the population is high.

Ecological factors, such as soil temperature, rainfall, soil moisture and diseases affect their abundance, dispersal, distribution and damage[14] as well as food[15]. In spite of the ubiquitous nature of *H. arator* in maize fields in the humid rainforest and other ecosystems of Cameroon and their clearly visible damage to the crop, there is a paucity of information about the pest in the country. However, there have been frequent complaints by farmers of the damaging nature of this pest in their maize fields especially where ‘Mandola’ grass, (*Panicum maximum*) is found. The lack of research attention paid to *H. arator* has allowed this insect to emerge as a serious pest of maize, especially at the seedling stages. Therefore, there is a need to study the bioecology of this pest in maize fields as a first step to developing sustainable management methods for this pest. The purpose therefore of this research was to study the seasonal abundance of this pest within a maize field in Buea.

MATERIALS AND METHODS

Study site: This research was carried out from January, 2020 to December, 2022 in the Teaching and Research Farm of the Faculty of Agriculture and Veterinary Medicine, University of Buea, Cameroon. Buea is located at the foot of Mount Cameroon at an altitude of 870 m above sea level between latitudes 4°3"N and 4°12"N and longitudes 9°12"E and 9°20"E with rich volcanic, rocky soils[16]. Buea has an average relative humidity of 86%, a temperature range of 20-32°C and an annual rainfall of 1800-4090 mm[17].

Buea has a humid rainforest ecological zone, located in the South West Region of Cameroon with an equatorial climate and a rainy season from mid-March to mid-November and a dry season from mid-November to mid-March.

Land preparation and planting of maize: The land was prepared for the first time from January to February, 2020. The total area of the selected field was 380 m^2 divided into 20 experimental units of 3×4 m separated from each other by a 1 m alley to determine the seasonal abundance per plot for both the litter and pitfall traps. The land was cleared and allowed for two weeks for new weeds to emerge before spraying with a systemic herbicide (Glyphader®, active ingredient, Glyphosate at 100 mL/16 L knapsack sprayer) and planting was done under zero tillage. The maize was planted during the first (March) and second (September) cropping seasons of 2020 and 2021. One kilogram of maize seeds of the medium maturing maize variety UBNMS001 from the University of Buea were planted at a planting distance of 75×50 cm inter and intra row spacing at 5 cm depth, respectively and later thinned to two seedlings per stand after one week. Granular inorganic fertilizer NPK (20:10:10) was applied at 10 g per plant on all experimental units. Chemical weeding using the contact herbicide-Gramoxone, the active ingredient, Paraquat at 75 mL/16 L knapsack sprayer weeding was done 50 days after planting and supplemented by manual weeding using a hoe when needed.

Sampling and trapping of *H. arator* adults: Sampling of an average of 190 adult beetles began one week after germination right up to the crop maturity stage. The beetles were trapped and later collected from the traps by hand picking once every week and data was combined monthly from January to December. Quadrats (litter traps) and pitfall-baited traps were used[18]. For the quadrat method, dry grasses of 2.5 kg weight, were uniformly placed in a circle of 15 cm diameter and 3 cm thick in each plot measuring 3×4 m to serve as a litter trap. These litter traps were replicated 10 times within the 380 m^2 experimental field. These traps served as a conducive environment for *H. arator* adults to hide under. Once each week, the adult beetles were sampled by carefully raising up the grass, hand-picking the beetles, counting and killing them.

For the pitfall baited traps, repurposed 1.5 L plastic bottles were each cut into half 12 cm high and used as traps. Two opposite holes of 2 cm in diameter each were created on two sides at 1 cm below the brim to prevent overflow whenever it rained. Forty of these plastic halves were used in total. Two of these traps were buried in each plot of 3×4 m such that the brims flushed with the ground surface. Each of the traps was half filled with 150 mL of fermented maize extract (Sha) that served as bait to attract the adult beetles. These traps were serviced twice each week and the bait was replaced to guarantee its strength and effectiveness.

During servicing, each trap was carefully drained through a sieve and the beetle counted and recorded weekly. The number of beetles caught in the litter and pitfall traps was then summed up to give the total population abundance of *H. arator* in the field. All observations of the traps were done in the morning periods since the soil and environment were still wet and cold therefore, enhancing effective capturing due to the slow activity/inactiveness of the beetles. Sampling was carried out once weekly throughout the rainy and dry seasons with or without maize in the field and data was cumulated on a monthly basis and recorded from January to December for each of the years 2020 and 2021.

Temperature and rainfall data for Buea were collected from scientists in the agro-ecological lab in the University of Buea who collect their climatological data using satellite information. The soil moisture content data were collected using a Moisture meter, MD7822 made in China. It is made of a big screen LCD, a supply power plug with a battery and a measurement probe. The soil moisture content readings were obtained by inserting the measurement probe 10-15 cm deep in the soil of the maize field beside the root system at 3 different points. These data were recorded once every week and summed up to obtain the average monthly readings.

Statistical analysis: *Heteronychus arator* population density data were analyzed using descriptive statistics and subjected to Pearson's Correlation Coefficient using the SPSS software version 16 to determine the relationship between the population abundance and the different climatic factors. All data were tested at 0.05 significant levels.

RESULTS

Beetles caught in litter and pitfall traps: A total of 18617 adult *H. arator* were captured in the two different traps during the two cropping seasons of both years. Out of these, 9637 were captured in 2020 and 8980 in 2021. Out of the 9637 in 2020, 5162 were caught in the pitfall traps and 4475 in the litter traps. Meanwhile, out of the 8980 in 2021, 5353 were caught in the pitfall traps and 3627 in the litter traps.

From the onset of the dry season in October/November until the onset of the rainy season in April/May, significantly (at 95%) higher numbers of the beetles were caught in the pitfall traps. In contrast, during the peak rainy season from June to September, higher numbers of beetles were caught in the litter traps (Fig. 1).

Generally, the pitfall traps caught more beetles than the litter traps in both years. However, the litter traps caught higher numbers of adult beetles during the peak of the rainy season as opposed to the pitfall traps which caught higher numbers during the dry season.

Population dynamics of the beetles for 2020 and 2021: The total number of beetles caught in the two years in both the pitfall and litter traps each month showed that the highest numbers were caught in December (dry season) and the lowest was in September (peak of rainy season). Generally, in the dry season months from November to April and May significantly higher numbers of beetles were caught in both types of traps and years compared to the main rainy season months from June to September (Fig. 1).

Though the trends of the numbers caught both in 2020 and 2021 were the same slightly higher numbers were sampled in 2020 (Fig. 2a-b). There were generally two population peaks each year, the first peak around April/May and another one around November/December. There was a long major trough in June to September each year (Fig. 2a-b).

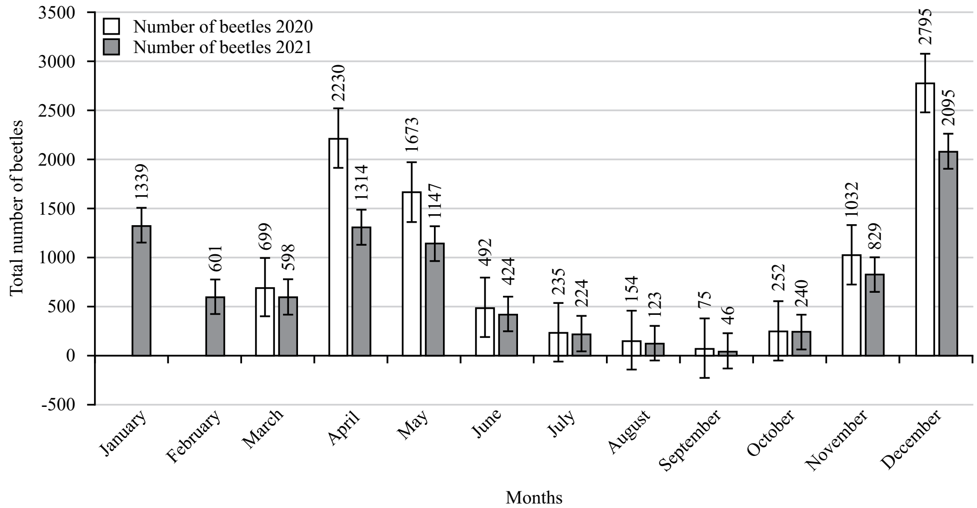

Fig. 1: Monthly number of *Heteronychus arator* adults caught in pitfall and litter traps in 2020 and 2021 in Buea, Cameroon

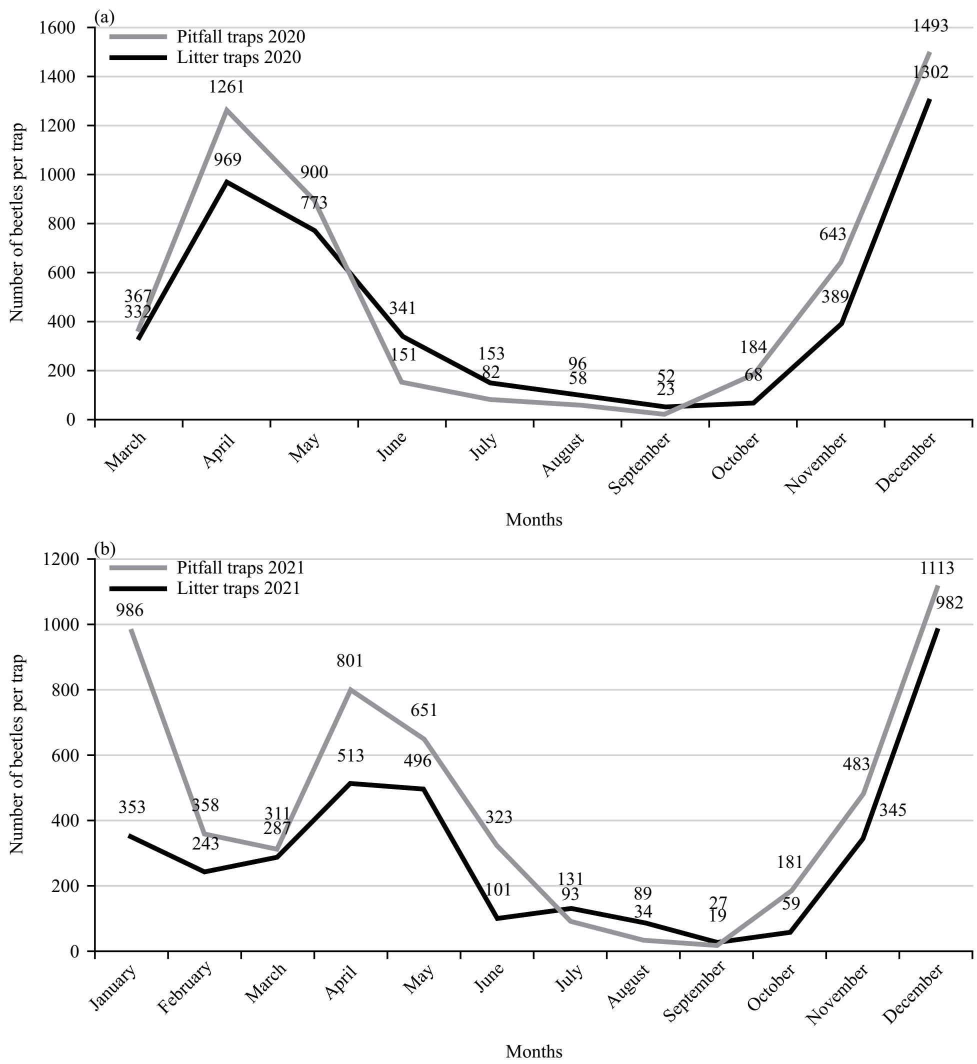

Fig. 2(a-b): Monthly number of *Heteronychus arator* in pitfall and litter traps trends for (a) 2020 and (b) 2021 in Buea, Cameroon

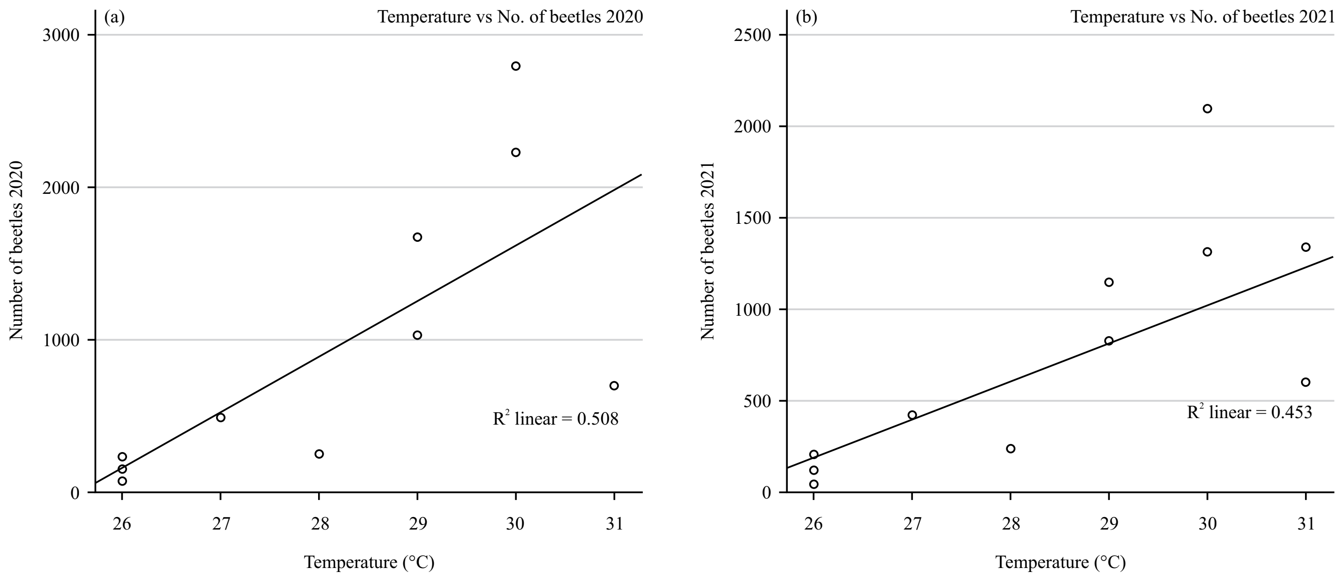

Fig. 3(a-b): Correlationship between environmental temperatures and the numbers of adult *Heteronychus arator* beetles in (a) 2020 and (b) 2021

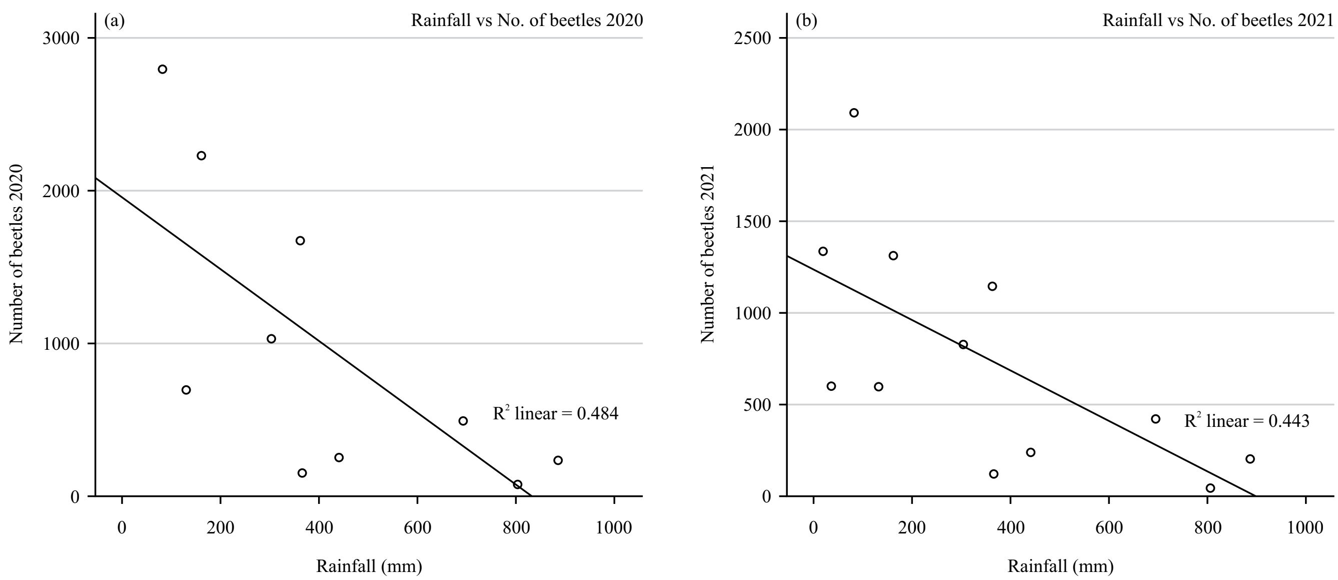

Fig. 4(a-b): Correlationship between the number of adult *Heteronychus arator* beetles caught and amount of rainfall in (a) 2020 and (b) 2021

Correlation between the number of beetles caught and temperature: Regarding environmental temperatures, the number of beetles caught in both types of traps was strongly positively correlated with the environmental temperature with r = 0.713 in 2020 and r = 0.700 in 2021. This implies that the higher the ambient temperature, the higher the number of beetles found on the soil surface. For instance, when temperatures rise up to 31°C, the number of beetles increase to about 2000 (Fig. 3a-b). During the dry season when the temperatures were high and the soil particles were dry and loose, the adult beetles were often seen roosting on the soil surface during the early morning sun but when disturbed they easily burry themselves beneath the loose soil particles.

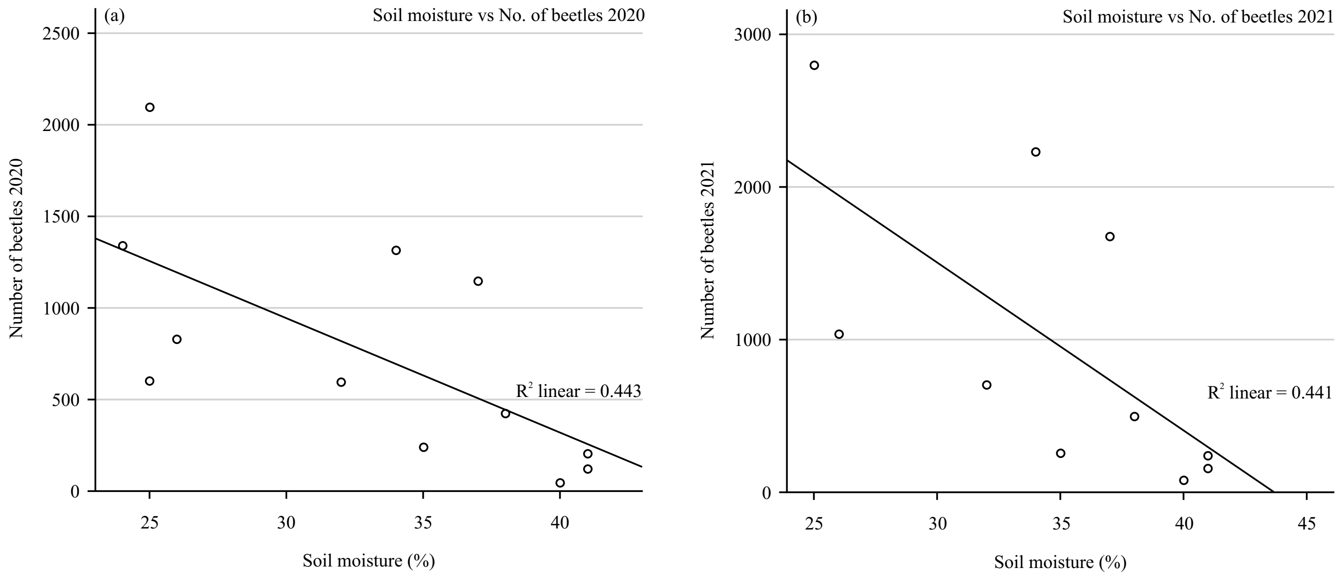

Fig. 5(a-b): Correlationship between soil moisture content and the number of adult *Heteronychus arator* beetles caught in (a) 2020 (a) and (b) 2021

Correlation between rainfall and the number of beetles: The number of beetles caught in both the litter and pitfall traps during the two years was strongly negatively correlated with the amount of rainfall with r = -0.695 in 2020 and r = -0.435 in 2021. Therefore, as the rainfall increased, very few adult beetles were found on the soil surfaces. At a rate of rainfall 80 mm in both years (2020 and 2021), less than 50 adult beetles were caught meanwhile more than 2000 adult beetles were caught at a rainfall intensity of less than 25 mm. The few adult beetles that were found during the peak rainy season were always hiding under soil litter/debris and also under the litter in the litter traps. At times, some are found seeking refuge under the brace roots of the maize plants in the field. The relationship between the number of beetles caught and the amount of rainfall was shown in Fig. 4(a-b).

Correlation between soil moisture and number of beetles: The relationship between the soil moisture content and the number of beetles caught in the pitfall and litter traps in 2020 and 2021 was shown in Fig. 5a-b. Similar to the case of rainfall, there was a negative correlation between soil moisture content and number of beetles caught in 2020 and 2021. Therefore, as the soil moisture content increased, lower number of adult beetles were caught in the two traps and vice versa. Whenever the soils were very moist, above 40%, often due to a prolonged rainfall period, no adult beetle was found on the soil surfaces, meanwhile at soil moisture less 25% more than 1500 adult beetles were caught.

DISCUSSION

The numbers of African black maize beetle adults caught in pitfall traps and litter traps in each of the years 2020 and 2021 were not significantly different. This shows that these two types of trapping methods are suitable for the sampling of the adults of this predominantly subterranean beetle. Appropriate and timely monitoring of pest populations is a fundamental step in the eco-friendly management of pest populations[19]. Therefore, the baited pitfall traps and litter traps used in this study can be used to monitor the adult populations of *H. arator* in maize fields in the humid rainforest ecosystem of Buea where this insect is currently a clearly emerged pest of maize. Pitfall traps have been reported to be an efficient method of sampling ground-dwelling insects[20].

Though not significantly different (at a p-value of 0.835 and 0.876), the total number of beetles caught annually in the pitfall traps was 5162 in 2020 and 5353 in 2021 meanwhile litter traps gave 4475 in 2020 and 3627 in 2021 giving a total cumulative population of 9637 and 8980, respectively. This result agreed as reported by researchers[10,20]. During the peak of the rainy season, the litter traps caught a higher number of beetles compared to the pitfall traps. This is because during the rainy periods, the beetles often seek for shelter from the rains and the litter traps provide such shelters thus attracting more beetles during these rainy periods. However, during the dry season, the pitfall traps caught a higher number than the litter traps. The reason is that increased temperature increases their movement in search of food and mates which allows them to easily fall into the pitfall-baited traps. A higher number of beetles 9637 were caught in 2020 compared to 8980 in 2021. The reason for this higher number of beetles in the first year 2020 than in the second year 2021 could be attributed to the constant capture and destruction of the adult beetles during the study period that reduced the population density, which in pest management is an effective control measure in beetle population reduction and control from reaching a damaging threshold. This low-cost but effective cultural control method of setting baited traps can be used to control this soil-dwelling pest which is usually a big challenge to manage in most farmer's fields since they mostly feed on underground parts of plants and are nocturnal in nature. Therefore, farmers should be trained and sensitized to adopt such an effective, economical and environmentally friendly pest control method compared to the use of insecticides as in the case of Mansfield *et al*.[21] in South Africa to control the beetles. Insecticide use is often very costly and not environmentally friendly.

From March to April 2020 and 2021, there was a significant increase in the population of beetles, which then dropped from May right up to October in conformity with the studies of Mansfield *et al*.[21]. This could be attributed to high rainfall and high humidity which is not conducive to insect survival, thus causing some to undergo natural death, burrow deeper into the soil and probably due to the stage of their life cycle. Moreover, such environmental conditions of high rainfall and humidity favour the proliferation of entomopathogens which could equally serve as natural pest to the adult beetles which infects and kills them causing a population reduction similar to results reported by Koppenhöfer *et al*.[22].

Overall, it was observed that the beetle population increased during the dry season (November to February) and decreased during the rainy season (March to October) in agreement with the studies of Staley *et al*.[23], which holds generally with most insect pests. The lowest beetle population occurred in September and the highest in December which is in line with Koppenhöfer *et al*.[22].

There was a strong positive correlation between the total number of beetles caught and the environmental temperatures (Fig. 3). This is understandable since insects are cold-blooded animals whose metabolism and activities are neatly influenced by the environmental temperatures. Hence, a low temperature slows down their activities including movement to the soil surface while a higher temperature stimulates their activities. This explains why an increase in temperature leads to an increase in the beetle population. This observation suggests that the life cycle of the beetle is temperature dependent and hence the beetle thrives well under higher temperatures. In this study, the temperature range between 26 to 31°C is a favourable range for the beetle to thrive. This result was similar to that reported by Matthiessen and Ridsdill-Smith[24], in agreement that beetle thrives most favorably between 20 to 30°C. Therefore, temperature proves to be one of the major environmental factors that can be manipulated for the management of most insect pests.

On the other hand, there was a moderate but negative correlation between rainfall and the number of beetles caught. This implies that rainfall variation is significantly associated with the number of adult beetles. This explains why wherever there is an increase in rainfall, automatically the number of beetles reduces. Hence, the drastic reduction in the population from June right up to October is due to the high rain intensity in Fig. 1. This could be attributed to the fact that the beetle spends a significant quota of its life cycle underground, which could lead to waterlogging thus reducing its rate of respiration and action/flight in agreement with what Mansfield *et al*.[21] explained in his work that supports this study.

Soil moisture content is the third climatic factor that contributes significantly to the number of adult beetles. Like rainfall, there was a strong and moderate but negative correlation between soil moisture content and the number of adult beetles caught in both years. Henceforth, soil moisture content variation is significantly associated with the beetle population. That is why wherever there is an increase in rainfall and soil moisture content across the months, there is a drop in the number of adult beetles meanwhile a decrease in rainfall and soil moisture content leads to an increase in the number of beetles in the field which was in agreement with Kirichenko-Babko *et al*.[25].

Given that the three climatic factors (temperature, rainfall and soil moisture content) are significantly associated with the number of adult beetles in both years, the survival of the beetle is significantly reliant on climatic factors, which can therefore be manipulated to control or influence the ecology and abundance of the beetle.

This study has generated vital basic ecological information that can be exploited to develop sustainable management strategies for *H. arator* in maize fields. For instance, scouting, surveillance and monitoring are essential at the first 1-2 weeks early stage of the crop cycle.

Proper agronomic/cultural and bio-ecological applicable research synchronization should be carried out most especially on the larvae of *H. arator*.

Given the fact that most farmers and other stakeholders are not cognizant or familiar with this particular pest. *Heteronychus arator*, there should be a creation of awareness, sensitization campaigns and capacity-building programs for farmers, extension officers, input dealers and government stakeholders.

Due to the fact that there are no effective soil-specific black beetle larvae insecticides for fumigation underground, the researcher recommends that further research should be carried out in this particular domain.

CONCLUSION

This study highlights that *Heteronychus arator* is an emerged perennial pest in fields and its population is significantly influenced by climatic variabilities of temperature, rainfall and soil moisture content. There was a strong positive relationship between mean annual temperature and adult beetle numbers, but a strong negative association between rainfall and soil moisture content and the adult numbers. Baited litter and pitfall traps were suitable methods for quantifying the seasonal variations of this pest. Such traps can thus be used to monitor and/or sample for this ground-dwelling pest in maize fields while the environmental factors of temperature, rainfall and soil moisture content can be used to predict its periods of high and low populations.

SIGNIFICANCE STATEMENT

The black maize beetle, a previously unreported pest in Cameroon has become an emerged perennial pest of maize seedlings, mature plants and other crops. The purpose of this study was to elucidate its population dynamics and associated environmental factors influencing it as a prelude to formulating sound management practices for the pest. The pest population was highest in April/May (onset of rainy season), then decreased significantly from June to August (peak rainy season) to the lowest population in September. Climatic factors significantly influenced the number of beetles caught in the study area. Further research on the population variations is recommended to be carried out in different Agroecological Zones in Cameroon to actually quantify this pest and its ecological behaviour.

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