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Damage by *Limicolaria* species on maize, environmental factors influencing their population dynamics and potential strategies for their management in Cameroon

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Abstract

Maize (*Zea mays* L.) is an important versatile food and industrial crop in Cameroon, Africa and the world. It is a crucial human food source, animal fodder and feed, and raw material for industries but its production is constrained by many pests including *Limicolaria* species which are currently serious economically important perennial pests of the crop. The extensive losses caused by this pest during the various growth stages of maize are a serious threat to maize production and food security. Therefore, the aim of this study was to investigate the *Limicolaria* snail pest damage, species composition and abundance, population dynamics, the influencing environmental factors and their implications in managing the pest in maize fields. The *Limicolaria* snail species were trapped monthly using baited pitfall and litter traps monitored once every week throughout 2020 and 2021 in maize experimental plots planted at a rate of three per hole at 75 x 50 cm inter and intra-row spacing at 5 cm depth respectively. These polyphagous snails damage mostly the maize leaves, stems, ears, fruits (kernel) and dead plant parts of the crop from the seedling to the mature stage. They damage maize by chewing irregular longitudinal or horizontal, translucent/window-like holes on the leaves. Four *Limicolaria* species were identified namely: *L. zebra* which contributed to 47% of the total number of snails followed by *L. flammea* 21%, *L. numidica* 20%, and *L. aurora* 12%. Temperature was negatively correlated with the number of *Limicolaria* caught in 2020 ($r = -0.7133$) and 2021 ($r = -0.885$). On the other hand, rainfall and relative humidity were positively correlated in 2020 ($r = 0.829$ and 0.540) and 2021 ($r = 0.684$ and 0.759), respectively. Overall, these results highlighted the potential of using baited pitfall and litter traps to monitor/suppress *Limicolaria* species populations in maize fields while the weather factors could be used to predict the periods of high and low pest populations for proper management through cultural control.

Keywords: *Limicolaria* species, abundance, maize damage, environmental factors, litter and pitfall traps

1. Introduction

Maize (*Zea mays* L) known as corn in the United States and Canada, is the third most important cereal grain worldwide after wheat and rice (Golob, *et al.*, 2004) ^[1]. It is referred to as the cereal of the future due to its nutritional value and utilization of its products and by-products (Suleiman, 2013). It is the most commonly produced staple food crop in Sub-Saharan Africa (SSA), providing food and livelihood for around 208 million people (Parihar *et al.*, 2011; Macauley, 2015) ^[2,3] and accounting for 73% of calorific intake (Shiferaw *et al.*, 2011) ^[4]. It is a major source of income for many farmers in sub Saharan Africa (Achancho, 2013) ^[5]. Globally, maize is multipurpose crop with about 67% of it used for livestock feed, 25% for human consumption and industrial purposes and 5% for seed purposes for the next crop (Pardey *et al.*, 2014) ^[6]. Maize is grown in varied soil types across a wide range of agro-ecological zones from wet to hot semi-arid lands.

In Cameroon, maize is widely grown in all the regions and serves as the primary source of food for the majority of the population who consume it the roasted, baked, fried, pounded or fermented forms (Agbato, 2003; Giller *et al.*, 2021) ^[7, 8]. It is also used in many traditional dishes (koki corn, corn chaff, corn fufu and pap) as well as drinks (corn beer and sha). Maize is also a major source of livestock feed and fodder,

food staple and source of livelihood in many parts of the world. Despite the importance of maize, its production suffers from a number of constraints which include poor soil fertility, environmental degradation, diseases, several insect pests (Kamara *et al.*, 2014) ^[9] and molluscs such as slugs and snails. In Cameroon, the *Limicolaria* species of the family Achatinidae (Floyd *et al.*, 2007) ^[10], have emerged as the most important molluscs pest of maize and other food crops most probably due to favorable environmental conditions particularly the long rainy season that runs from Mid-March to mid-November. These snails have conical shells which typically exhibit a range of colours from brown to gray, often adorned with darker bands or stripes; they often grow to around 5-7 centimeters in length and possess a muscular foot that aids in their locomotion (Odafe-Shalome *et al.*, 2020) ^[11].

Several factors affect the ecology and seasonal distribution of *Limicolaria* snails including geo-physical factors such as rainfall, temperature, light and hygrometry of the atmosphere, chemical factors like ion concentration in the soil as well as biological factors such as availability of food, competition and predator-prey interactions (Ofioezie, 1999; Owojori *et al.*, 2006) ^[12, 13]. *Limicolaria* species are predominantly polyphagous phytophagous snails known to occur in abundance in forest edges and modified habitats such as plantations and farms (Raut & Barker, 2002) ^[14].

A majority of these snails are non-host specific and can consume at least 500 different types of plants, including cassava, cocoa, papaya, peanut, banana, beans, okra, cucumber, melon, and cereals like maize, and sorghum (Venette and Larson, 2004) ^[15]. Members of this genus have been reported to damage palm fruits and leguminous cover crops in Cameroon and may even be a greater pest than *Achatina fulica* and *A. marginata*, (Mead A.R and Palcy L., 1996; Okolle *et al.*, 2019) ^[16, 17]. *Limicolaria* snail species are highly adaptive to a wide range of environmental conditions and are capable of modifying their life cycle to suit local conditions. These snails inhabit damp, shady sites and swamps and hence their populations may significantly increase during the rainy season. They usually live in holes, beneath leaf litter or under pebbles and rocks from where they come out to feed at nights (Manyangadze *et al.*, 2021) ^[18].

Limicolaria snail activities differ from one species to another and the activity is influenced by external factors such as temperature, humidity, light intensity, soil conditions and food supply (Tan & Clements, 2011) ^[19]. Moisture also influences the activity of *Limicolaria* snails. They remain in their hides during the day and often after dusk they emerge to go in search of food. A decrease in light intensity with a fall in temperature below 21°C and a rise in humidity through dew fall at dusk cause them to move on to vegetation, while in the morning and during the day the snails return to the upper soil or between the earth clods where it is cool and shady (Venette and Larson 2004) ^[20]. Since snails prefer moist and humid environments, the humid rainforest ecosystem with its characteristics long and extremely moist rainy season therefore offers suitable conditions for the survival and proliferation of diverse *Limicolaria* snail species. However, the lack of research attention paid to these *Limicolaria* species in the face of climate variability and change has allowed these mollusks to emerge as serious pests of many crops including maize particularly at its extremely vulnerable seedling and early vegetative stages. The present study therefore aimed at assessing The *Limicolaria* snail species abundance and diversity in maize fields planted during the first and second cropping seasons in the humid rainforest ecological zone of Cameroon as a first step to developing sustainable management methods for this pest. The

ultimate objective of this study was to identify the different *Limicolaria* snail species attacking maize and to assess their monthly and seasonal population dynamics as well as determine the climatic factors influencing these variations.

2. Materials and Methods

2.1 Study area

This ecological studies were carried out from January 2020 to December 2023 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 and has rich volcanic, rocky soils. The temperature range is 20°C - 32°C and an annual rainfall of 1800-3090 mm with an average relative humidity of 86% (John, *et al.*, 2007) ^[21]. Buea is in the rainforest ecological zone that has an equatorial-tropical rainforest climate with a rainy season from mid-March to mid-November and a dry season from mid-November to mid-March. The site is in a mountainous region with varied topography of gentle slopes, hills and valleys which plays a role in water drainage, soil erosion and microclimatic conditions. The vegetation types include rainforests, agricultural fields and plantations that provide habitat for various animal species. Agriculture is a major economic activity in Buea especially in the Teaching and Research Farm of the Faculty of Agriculture and Veterinary Medicine where varied crops like maize, beans cassava, plantains and vegetables are cultivated annually.

2.2. Land preparation and planting of maize

The land for the study was prepared for the first time from late January to early February 2020. A 380 m² piece of land subdivided into 20 experimental units of 3m by 4m each separated from each other by 1m alley was used for the study. The land was cleared and allowed for two weeks for the emergence of new weeds, before it was it sprayed with a systemic herbicide Glyphader® (active ingredient, glyphosate) as first application using 100 mL/16 L of water in a knapsack sprayer and maize planted with minimal tillage. Maize was planted during the first (March) and second (September) cropping seasons in 2020 and 2021. One kg of certified 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 respectively at 5 cm depth. Three seeds were sown per stand and seedlings later thinned to two per stand at one week after germination. Granular inorganic fertilizer NPK (20:10:10) was applied at 10 g per plant on all experimental at two weeks after germination. Chemical weeding with the contact herbicide-Gramazone (active ingredient, Paraquat) as second application was done at 50 days after planting using 75 mL/16L knapsack sprayer and supplemented by manual weeding using a hoe when needed.

2.3. Sampling of *Limicolaria* snail species through trapping

Quadrat-litter and baited pitfall traps were used in each experimental plot as described by Southwood *et al.*, (2000) ^[22]. For the quadrat method, 2.5 kg dry grass (straw) were used to cover the ground surface of each 3 m x 4 m rectangular plot to a thickness of 3 cm which served as the litter trap placed in the 20 experimental units. The distance of one trap from another was 50 cm apart. Once each week, the straw was carefully lifted at the four angles and the center of each plot and the *Limicolaria* snails found beneath were hand-picked, counted and then destroyed; this was done for two consecutive years. For the

pitfall baited traps, a repurposed 1.5 L plastic bottle was cut into halves of 12 cm high and the bottom half used as a trap. Two opposite holes of 2 cm diameter each were created on two sides at 1cm below the brim to prevent overflow if and whenever it rained. Forty of these plastic halves were used in total. Two of these traps were buried one at the center and the other at the edge of each 3 m x 4 m experimental units such that the brims flushed with the ground surface. Each of the traps was half-filled with 150 mL of fermented maize chyme (Sha) that served as bait to attract the *Limicolaria* snails. These traps were serviced twice each week and the baits replaced to ensure its effectiveness throughout the production cycle. During servicing, the content of each trap was carefully drained through a sieve and the *Limicolaria* snails then counted and recorded weekly. The number snails caught in the litter and pitfall traps was then summed up to give the total number of snails in the field. All observations of the traps were done from 7.00 - 8.00 am when it was cooler and the soil still wet enhancing easy capturing of the snails since they were still active during the morning period just from dawn. Sampling of the snails began one week after germination till the crop maturity stage at twelve weeks after germination. All trapped snails were collected from the traps by hand picking once every week, destroyed and discarded after laboratory identification. Sampling was done twice weekly throughout the rainy and dry seasons and the data then cumulated on a monthly from January to December of 2020 and 2021. On the other hand, monthly temperature, rainfall and relative humidity data for Buea were also collected from the National Observatory on Climate Change Center of Buea (NOCC, 2021) [23] for the two years.

2.4. Identification of *Limicolaria* species

After trapping and collection of the snails from the field, they were taken to the laboratory for identification and differentiation to the various species based on diagnostic features such as; shell shape, colouration, shell strands pattern, height and width according to the guides of Emberton, 2010; Tan and Low, 2011 [24, 25].

2.5. Relative abundance of *Limicolaria* species in maize fields

During the population dynamics study, the relative abundance of the four different species were determined whereby the total number of individual *Limicolaria* species caught was divided by the total number of the four different *Limicolaria* species and multiplied by 100.

$$\text{Relative abundance} = \frac{\text{Total number of individual } Limicolaria \text{ species}}{\text{Total number of four } Limicolaria/\text{species}} \times 100$$

2.6. Statistical analysis

Limicolaria species population dynamics data for each of the traps were reported using line graphs. Correlation graphs were also drawn using Microsoft excel 2016 and Pearson's Correlation Coefficient calculated using SPSS software version 16 and Excel 2016 to determine the relationship between the population abundance and the different climatic factors. All data were tested at 5% probability level.

3. Results

3.1. Description of *Limicolaria* species damage on maize

Limicolaria species are a serious yearly problem on maize and

cause considerable damage on maize plants. These snails damage mostly the leaves, stems, ears, fruits (kernel) and dead plant parts of the maize crop from the seedling to the mature stage. They damage maize by chewing irregular longitudinal or horizontal, translucent/window-like holes on the leaves through scraping with their rasp-like tongues (Fig. 1 a and b). They mostly feed from the underside of the leaves and often leave behind a silvery gray shiny slimy mucus trail, which is often a clear indication of the snail activity, even if when they are not seen on the plants. The snails also leave unusual droppings, faeces or frass near the damage areas (Fig. 1 b). They are primarily active at night, and the fresh damage is often noticed in the morning when the snails have retreated into their hiding places till when it is foggy or dark. Their feeding is distinctive from those other pests in that, they eat from the middle of the maize leaves whereas caterpillars often eat from the edges.

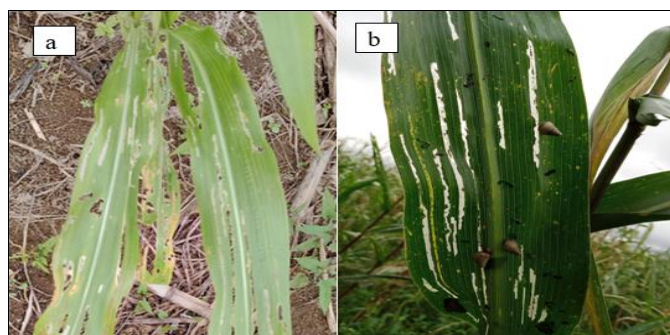


Fig 1: *Limicolaria* species damage on young maize (a) and mature leaf (b) (Image by Nelson N. Suh, University of Buea)

3.2. Snail species diversity

The following four different species of snails were observed on maize plants and fields: *Limicolaria aurora* (Jay 1889), *L. numidica* (Reeve, 1848), *L. flammea* (Muller, 1774) and *L. zebra* (Pilsbry, 1904). The diagnostic features and pictures of the different *Limicolaria* species found in the maize field are as outlined and shown below:

Limicolaria zebra

L. zebra (Pilsbry, 1904) snail attained a height of 70 mm and a width of 28 mm, with 9.5-10 whorls at maturity. The shell is usually smooth, oblong-ovate and displays black less-wavy colour bands/strands on the shell (Fig. 2 a).

Limicolaria flammea

L. flammea (Muller, 1774) snail attained a height of 70 mm and a width of 28 mm, with 9.5-10 whorls at maturity. The shell is smooth, oblong-ovate and displays black larger wavy colour bands/strands on the shell (Fig. 2 b).

Limicolaria numidica

L. numidica (Reeve, 1848) snail attained a height of 65 mm and a width of 28 mm, with 9-9.5 whorls at maturity. The shell is smooth, dull, oblong-ovate and displays faint brownish colour bands/strands on the shell (Fig. 2 c).

Limicolaria aurora

L. aurora (Jay 1889) snail generally attained a height of 60 mm and a width of 28 mm, with 9-9.5 whorls at maturity. The shell is also smooth, creamish-white, oblong-ovate and displays no colour bands/strands on the shell (Fig. 2 d).

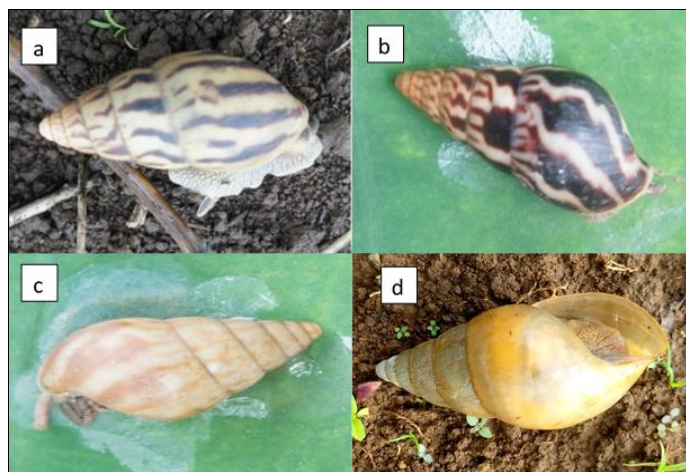


Fig 2: *L. zebra* (a), *L. flammea* (b), *L. numidica* (c) and *L. aurora* (d) (Image by Nelson N. Suh, University of Buea)

Among these four, the following three species of *L. zebra*, *L. flammea* and *L. numidica* were more prominent and abundant in the fields as compared to *L. aurora* which was least abundant.

3.3. Relative abundance of *Limicolaria* species in the maize fields in Buea

Irrespective of the maize growing season, the most abundant snail species was *Limicolaria zebra* (47%); its population was always doubled that of any other species in the research field. The next abundant species was *L. flammea* (21%) which was not very significantly different from *L. numidica* (20%) then *L. aurora* (12%) which was the least (Fig. 3).

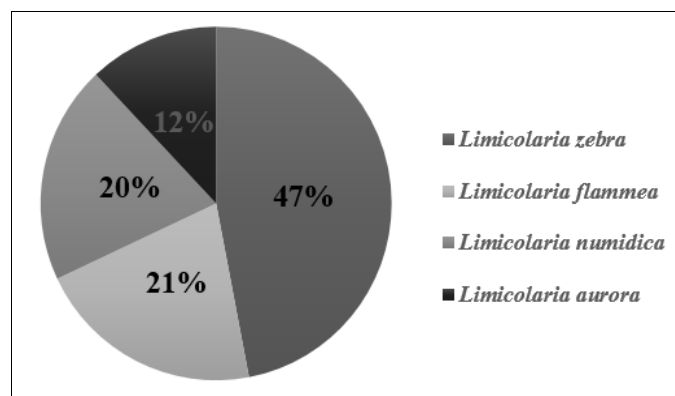


Fig 3: Relative abundance of four different *Limicolaria* species in maize farms in Buea-Cameroon

3.3. Population dynamics of *Limicolaria* snail species

Generally, the annual population abundance of the snails, in 2020 and 2021 of the different *Limicolaria* species had a dome-bell shaped (Fig. 3). Though the trends of the total numbers caught both in years were the same, slightly higher numbers were caught in 2020. There were two population troughs for both years, the first trough around January/February and another one around November/December. There was a major peak in July and August each year. From January, the population increased steadily with corresponding rainfall, then peaks in July and August from when the population gradually dropped to zero in December to February, which corresponded to the period of the dry season (Fig. 4).

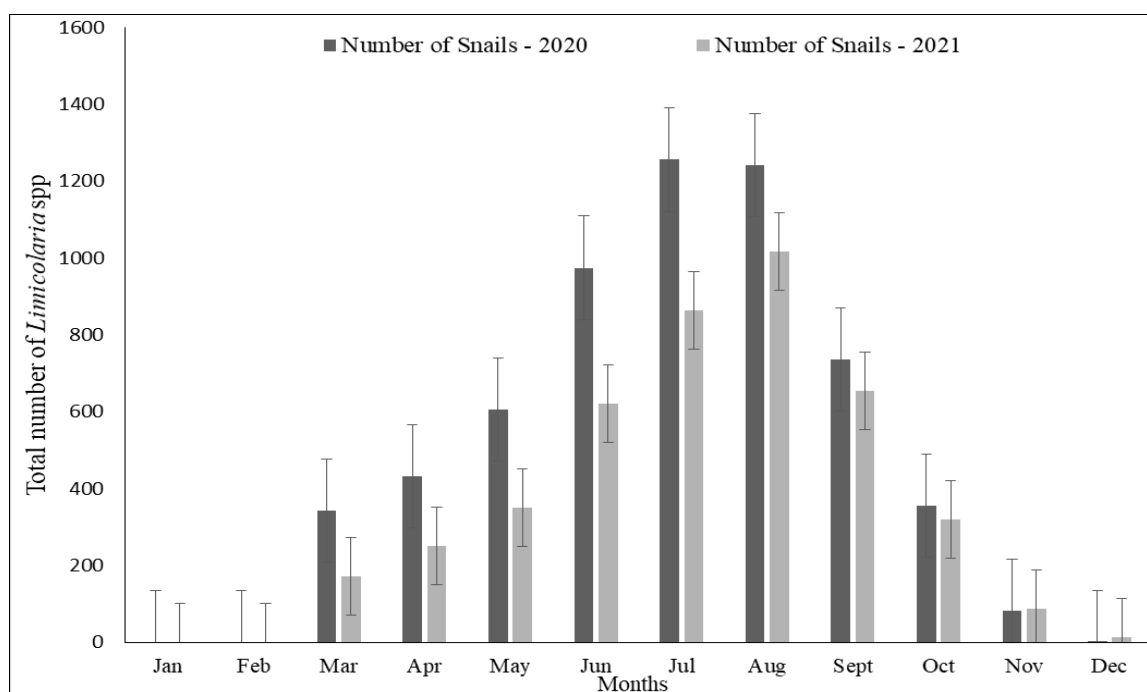


Fig 4: Total number of *Limicolaria* snail species caught in 2020 and 2021 in Buea, Cameroon

3.4. *Limicolaria* species caught in litter and baited pitfall traps in 2020 and 2021

Generally, the litter traps caught more *Limicolaria* species than the baited pitfall traps in both years. The monthly total number of *Limicolaria* species caught during the two years in both the litter and pitfall traps showed that the highest numbers were caught in July and August which corresponded to the peak of the

rainy season) while the lowest numbers were from December to February which was the peak of the dry season.

Irrespective of the year and month, the population of *L. zebra* was the highest, followed by that of *L. numidica*, then *L. flammea* and the lowest was that of *L. aurora* (figs 5 and 6 a and b.)

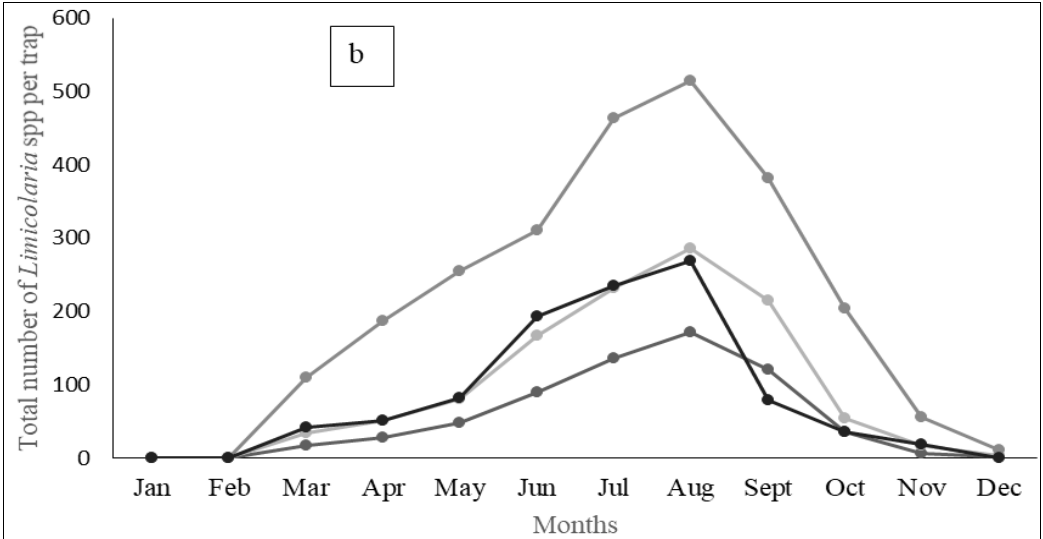
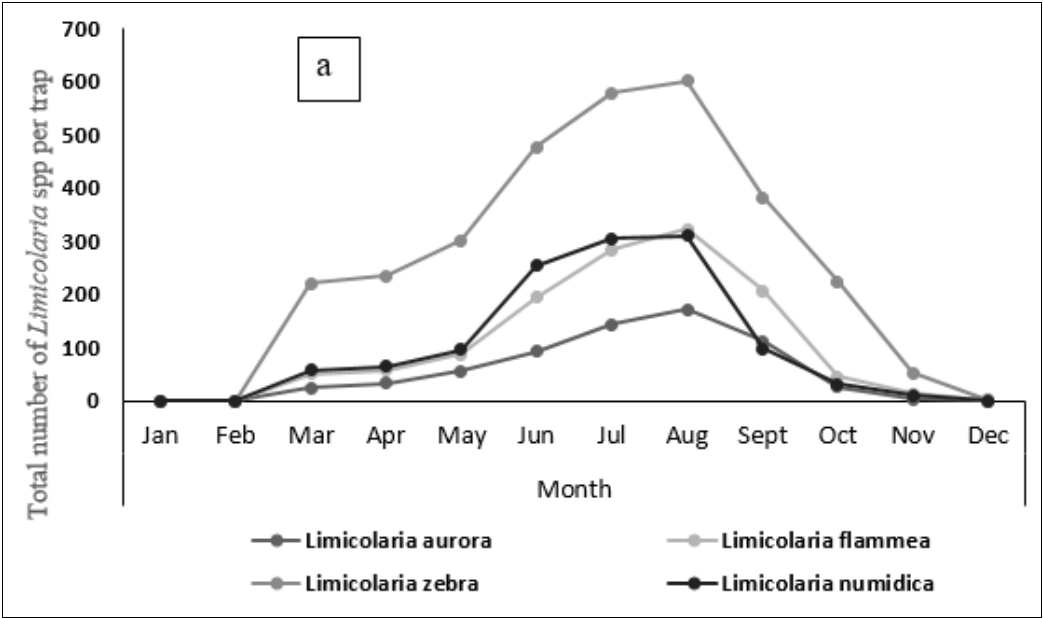
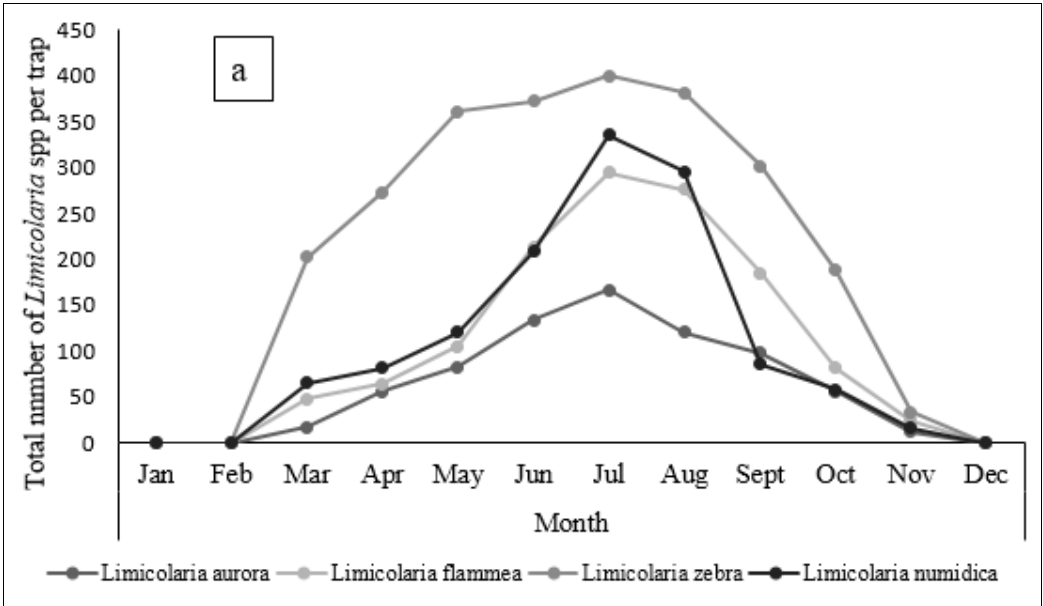


Fig 5: Total monthly numbers of snails caught in litter traps in 2020 (a) and 2021 (b)



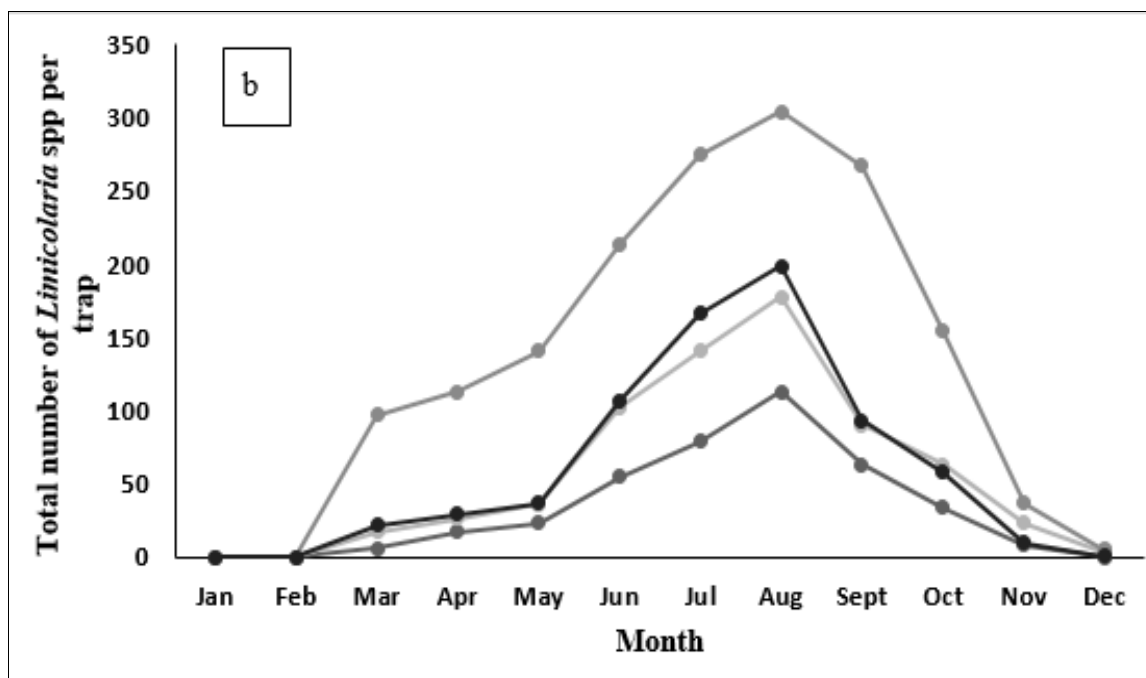
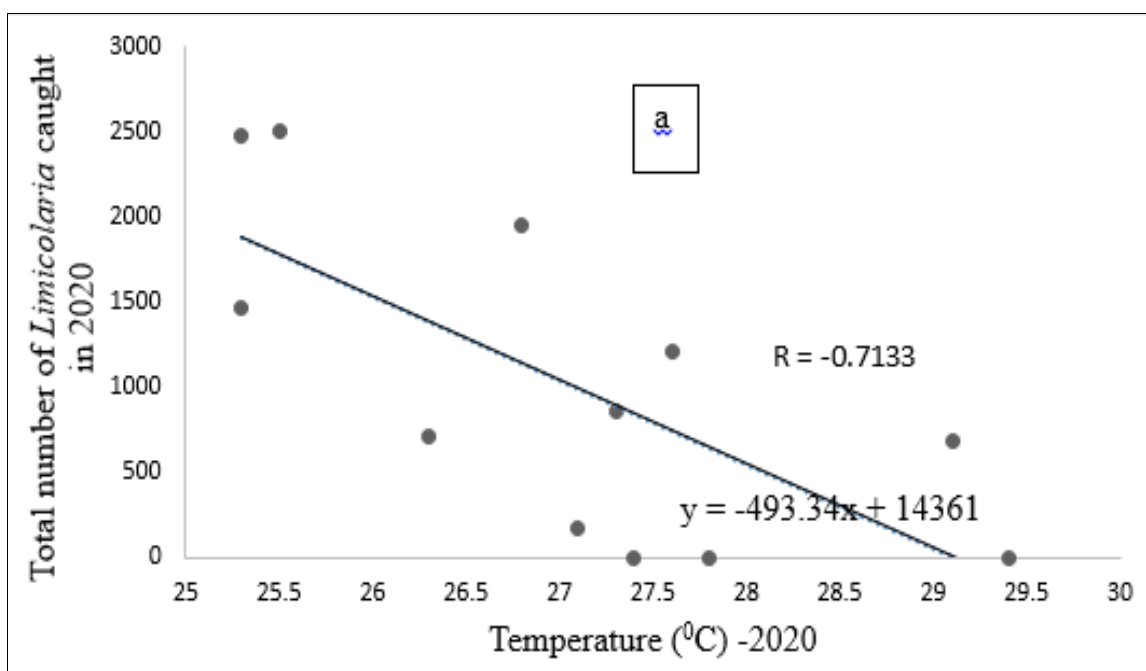


Fig 6: Total monthly number of snails caught in pitfall traps in 2020 (a) and 2021 (b)

3.5. Correlation between temperature and total number of *Limicolaria* species

The total number of *Limicolaria* snails caught in the litter and pitfall traps during the two years was strongly negatively correlated with temperature in 2020 ($r = -0.7133$) and 2021 ($r = -$

0.885) respectively (Fig. 7 a and b). For instance, when temperatures rose to 29°C , the number of *Limicolaria* species were very low or zero in the study site (Fig. 9 a and b). During the dry season when temperatures were high, there were few or no *Limicolaria* found on the soil surface.



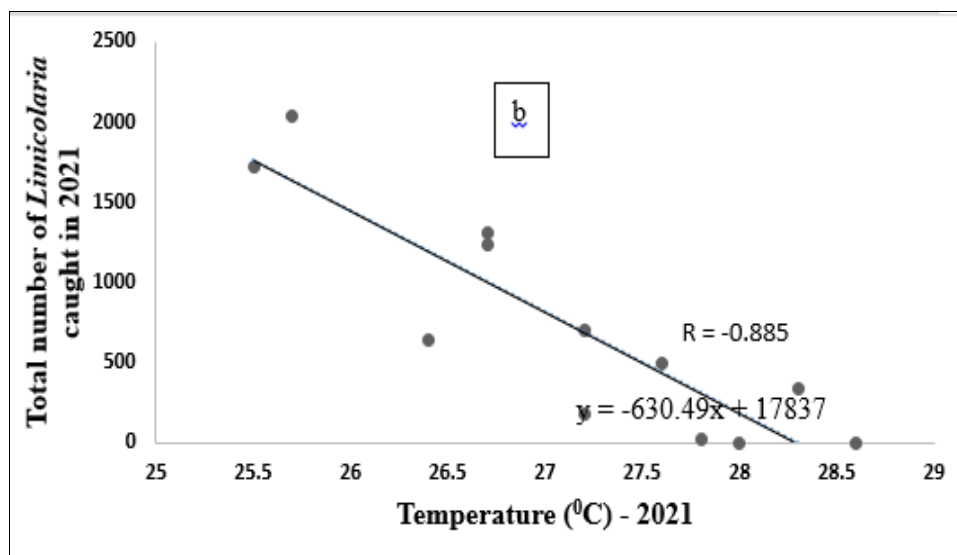


Fig 7: Correlation between temperature and the total number of *Limicolaria* species caught in (a) 2020 and (b) 2021

3.6. Correlation between rainfall and total number of *Limicolaria* species: The total number of *Limicolaria* species caught in the litter and pitfall traps during the two years was positively correlated with the amount of rainfall in 2020 ($r = 0.829$) and 2021 ($r = 0.540$) respectively. Therefore, as the rainfall increased, the number of *Limicolaria* species increased.

The average annual rainfall was 356.58 mm in 2020 and 184.33 mm in 2021. With a rainfall of 0 mm from December to February in 2020 and 2021, no *Limicolaria* species were caught but more than 2000 were caught when the rainfall was > 500 mm from July to September in 2020 (Fig. 8 a) and more than 1500 were caught with a rainfall of 450 mm in 2021 (Fig. 8 b).

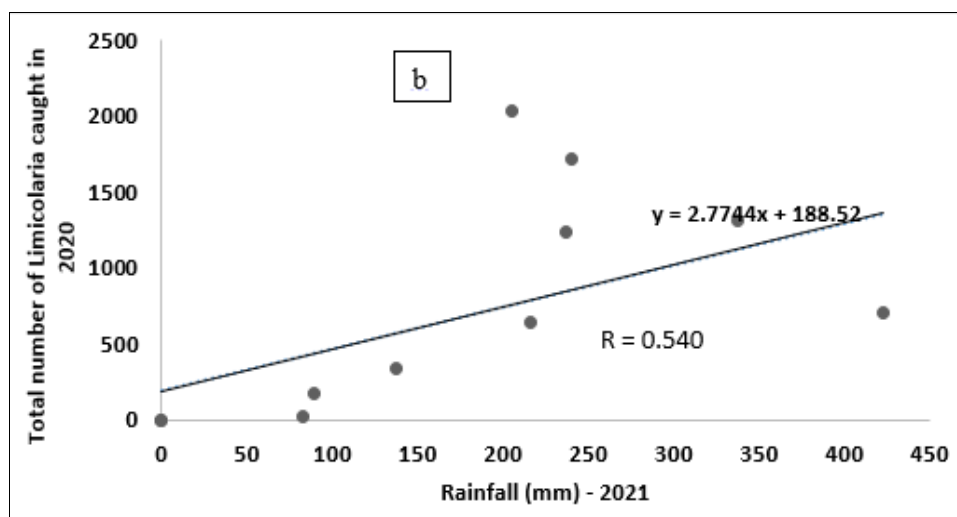
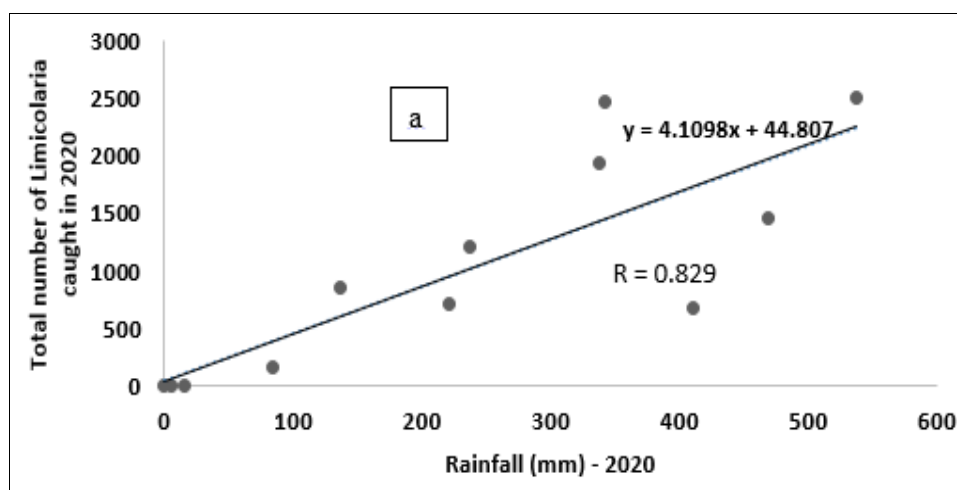


Fig 8: Correlation between rainfall and the total number of *Limicolaria* species caught in (a) 2020 and (b) 2021

3.7. Correlation between relative humidity and total number of *Limicolaria* snails

Similar to rainfall, there was a positive correlation between the relative humidity and the number of *Limicolaria* species in 2020 ($r = 0.684$) and 2021 ($r = 0.759$) respectively (Fig. 12 a and b). The average annual relative humidity was 84.93 in 2020 and

85.08 in 2021. Hence, as the relative humidity increased, more *Limicolaria* species were caught in both types of traps and vice versa in both years. Whenever the atmosphere and the soil were very moist, above 88%, more than 1000 *Limicolaria* species were caught in both traps per year (Fig. 9 a and b).

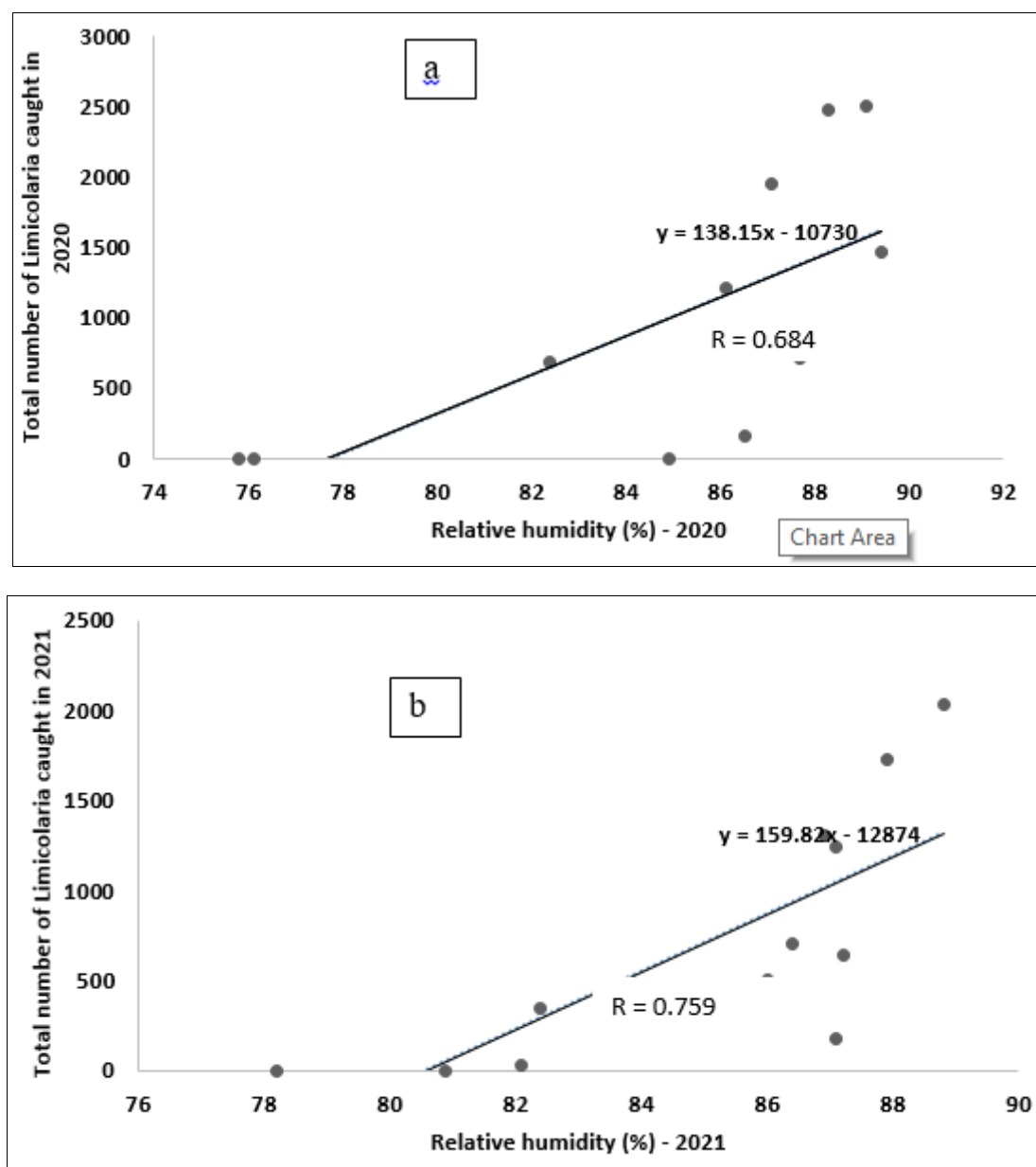


Fig 9: Correlation between relative humidity and the total number of *Limicolaria* species caught in (a) 2020 and (b) 2021

Discussion

A total of 20734 *Limicolaria* snails were collected in 2020 and 2021 belonging to the following four species, *L. zebra*, *L. flammea*, *L. numidica*, and *L. aurora*. This shows that these snails are well adapted to living and reproducing in the humid rainforest ecological zone of Cameroon. This area has a tropical equatorial climate with a long rainy season from mid-November to mid-March which favours the lush growth of different plant species to sustain this diverse and abundant snail populations. Some of the *Limicolaria* species that were abundant in humid forest agro-ecological zone of Cameroon correspond with some which have been identified and reported elsewhere in the neighboring Nigeria (Odafé-Shalome *et al.*, 2020) [26]. This is a further proof that these snails are well adapted to surviving and

reproducing in the humid rainforest areas of West and Central Africa. The abundant rainfall and diverse vegetation cover in the humid rainforest provides appropriate moisture levels and shelter for the snails to thrive. Ahmed and El- Wakei, (2012) [27] stated that snails preferred habitats rich in vegetation and moisture because such environments contain soil salts, nutrient and food supply such as calcium carbonate, which help in the formation of solid shells.

Irrespective of the maize growing season, the most abundant snail species was *Limicolaria zebra* whose population was always doubled that of any other species followed by *L. flammea*, which was not very significantly different from *L. numidica* and the lowest was *L. aurora*. The population densities of these species may vary with geographical location, soil types

and other environmental conditions both biotic and abiotic. For example, Ebenso *et al.*, (2006) ^[28] identified *Limicolaria flammea* as one of the least abundant species in Nigeria because of the species poor adaptive nature. The very high populations of *L. zebra* in the maize fields maybe due its relatively high reproductive and/or survival rate, which have contributed to it being a dominant species in the maize fields. Due to the relative high populations of this dominant species in the fields, it is likely that most of the damage observed on the maize plants is inflicted by this species. Since the *Limicolaria* species are native to West Africa (Tan and Clements, 2011) ^[19], their current high feeding on maize to constitute pest problems may have been due to the reduction/elimination of some of their natural host plants in favor of the current abundant maize crops in this agro-ecological zone. Host plant abundance is known to induce host preference in insects (Ntonifor *et al.*, 1996) ^[29] which might have also been the case with these snails. These maize plants and/or plant debris provide shelter while the maize shoots, leaves and ears serve as appropriate food for the snails.

During the rainy season, the numbers of snails increased gradually to a peak around July and August which coincides with the peak of the rainy season because land snails in general thrive best in humid environments with abundant food sources which corroborates the observations of Ahmed and El-Wakei (2012) ^[27] that snails like other animals tend to prefer habitats with abundant food supply. The long rainy and moist rainy season with abundant food supply most likely led to increased reproduction and hence higher snail populations in accordance with the findings of Silva and Omena (2014) ^[30] and Mohan *et al.*, 2015 ^[31]. These findings corroborate those of Kumari *et al.*, (2007) ^[32] and Justin *et al.*, (2008) ^[33] who reported that the rainy season was most favorable for snail activity amongst all factors. The litter traps caught higher numbers of snails compared to the baited pitfall traps presumably because the litter served as suitable sheltered microhabitats with high humidity where land snails thrive best. Though higher numbers of snails were collected from under the litter traps, the fermented cornmeal chyme (Sha) lures used in the pitfall traps showed good prospects that it can be used as a locally produced attractants that can be used to lure the snails to a particular spot of the field for targeted killing and/or easy collection for destruction as a component of integrated management of the snails in farms. This is in line with Linda *et al.*, (2019) ^[34] and Godlove *et al.*, (2023) ^[35] who reported that regular capture and destruction of snails is an effective control measure in snail population reduction from reaching damaging thresholds. Farmers can therefore be sensitized and trained to adopt such an effective, economical and environmentally friendly snail control method rather than using different synthetic molluscicides to control *Limicolaria* species as reported by Okolle *et al.*, (2019) ^[36].

The highest numbers of snails were caught in July and August, which is the peak of the rainy season. This is consistent with the positive correlation between the numbers of snails and the amount of rainfall as well as relative humidity. During the rainy season, there is increased plant growth and diversity thus offering abundant varied food sources for the snails to feed on, grow and reproduce thereby leading to a rapid population buildup. Often, the higher the amount of rainfall, the higher the environmental humidity which is an additional favorable factor for the survival of snails. In contrast, from December to February corresponding to the peak of the dry season with increased dryness and environmental temperatures, the snails go into aestivation underneath the soil, stones and debris in

agreement with the studies of Okolle *et al.*, (2019) ^[36] and Limunga *et al.*, (2020) ^[37]. This underscores why there was a negative correlation between the number of snails and environmental temperatures, which corroborate the findings of Stensgaard *et al.*, (2006) ^[38]. This study has generated vital basic ecological information that can be exploited to develop sustainable management strategies for *Limicolaria* species in maize and other crop fields. For example, Litter and baited pitfall traps were suitable methods for quantifying the population of these pests and hence can be used to monitor or sample and control these snails in maize fields. The environmental factors of temperature, rainfall and relative humidity can be used to predict periods of their high and low populations. This can be exploited in a cultural practice of altering the maize planting dates to avoid the early more susceptible early growth stages of the crop coinciding with the peak population periods of the snails as a component of the integrated management of these polyphagous pests. The usual planting periods in the humid forest agro-ecological zone is March/April for the first planting and August/September for the second planting. It would therefore be ideal to plant the first season maize in March at the onset of the rainy season when the snail population is very so that the more susceptible early vegetative stages of the maize are passed before the snail population begins to increase significantly during the later stages of the rainy season. In contrast, the second planting period is around when the snail populations are highest (July and August). Therefore, it would be more sensible to plant in early September when the snail populations start declining. Furthermore, prior to planting during this second season, it will be ideal to also establish pitfall and litter traps in the farms to continuously trap and further decrease these snail populations in the farms during the early vegetative stages of the crop.

Conclusion

Four different *Limicolaria* species namely: *L. zebra* with a population almost double that of *L. flammea* > *L. numidica* > *L. aurora* were identified in maize fields highlighting that the *Limicolaria* species are emerged perennial pests in maize fields. Their populations were significantly influenced by climatic variabilities of temperature, rainfall and relative humidity. There was a negative relationship between mean annual temperature and total number of the snail but a positive association between rainfall and relative humidity and the total number of *Limicolaria*. Litter and baited pitfall traps were suitable methods for quantifying the population of this pest and hence can be used to monitor or sample and control these snails in maize fields. The environmental factors of temperature, rainfall and relative humidity can be used to predict periods of their high and low populations. This can be exploited to alter maize planting dates to avoid the early more susceptible growth stages of the crop coinciding with the peak population periods of the snails as a component of the integrated management of these pests.

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