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Herbivore-Plant Interactions: Case of *Zonocerus variegatus* and *Chromolaena odorata* in Ghana

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Abstract: In Sub Saharan Africa seasonal outbreaks of *Zonocerus variegatus* coincide with the introduction of the neophyte *Chromolaena odorata*. *Zonocerus variegatus* is known to feed on the flowers of *C. odorata* which contain Pyrrolizidine Alkaloids (PAs), known to protect the grasshopper. A study was carried out with the objective to establish any possible link between the introduction of *C. odorata* and the outbreak of *Z. variegatus*. Questionnaire and field surveys were carried out in Ghana to determine the distribution, density and pest status of *Z. variegatus* and *C. odorata* and also to assess the seasonal populations of *Z. variegatus* with respect to the occurrence of flowers of *C. odorata*. The results indicated that *C. odorata* has spread as far north as latitude 8°30', an increase of 15' within a decade. The occurrence, density and outbreak of the dry season population of the uni-voltine *Z. variegatus* are related to the distribution of *C. odorata* which is also dependent on the rainfall pattern. In areas with dry season outbreaks of *Z. variegatus*, *C. odorata* occurs and the rainfall pattern is bi-modal. In the north where *C. odorata* is absent with only one population of *Z. variegatus*, the latter assumes pest status in isolated spots. The results indicate a strong linkage between the outbreak of dry season populations of *Z. variegatus* and the presence of Pas from the flowers of *C. odorata*, thus proving the existing pharmacophagous relationship proposed between the insect and the weed.

Key words: *Chromolaena odorata*, *Zonocerus variegatus*, pyrrolizidine alkaloids

INTRODUCTION

Zonocerus variegatus (L.) (Orthoptera: Pyrgomorphidae) is a pest of food and plantation crops and widely distributed in West and Central Africa (Toye, 1968; Baker *et al*., 1977; Page and Richards, 1977; Chapman *et al*., 1986; Cruttwell McFadyen, 1988). *Chromolaena odorata* (L.) R.M King and H. Robinson (Eupatoriae: Asteracaea) is an exotic weed native to South America and the Carribeans introduced into Africa in the 1930s (Bennett and Rao, 1968; Muniappan and Marutani, 1988). Coincidentally, *C. odorata* has established within the same geographical distribution of *Z. variegatus* in West and Central Africa within the last half century. In Ghana, *C. odorata* was discovered in 1969 and by 1991 had colonized about two thirds of the total land area (Hall *et al*., 1972; Timbilla and Braimah, 1996).

The introduction and establishment of *C. odorata* is one of three schools of thought regarding seasonal outbreaks of *Z. variegatus* in sub-Saharan Africa (Chapman *et al*., 1986). Work on the distribution of *C. odorata* has been conducted by Timbilla and Braimah (1996), Anning and Yeboah-Gyan (2007) and Castel (2012). Studies on the distribution of *Z. variegatus* in Ghana dates about a half century ago (Chapman, 1962) and to date no empirical data is available.

Chemo-ecological studies conducted in the 1990s led to a proposed pharmacophagous relationship in which *Z. variegatus* consumes the flowers of *C. odorata* as a drug for pyrrolizidine alkaloids (PAs) used for defence against antagonists (Boppre, 1991). It is believed that seasonal outbreak of *Z. variegatus* in the dry season was attributed to the supply of PAs which before the introduction of *C. odorata*, was a limiting factor.

Biller *et al*. (1994) identified five PAs, principally rinderine and intermedine in the flowers and roots of *C. odorata*, thus lending support to the hypothesis of Boppre (1991). If the above assertion is true, then it could be inferred that a close relationship would exist between *Z. variegatus* and *C. odorata* in terms of geographical

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distribution. Some proposals have been made towards the development of an integrated pest management strategy for *Z. variegatus* based on its attraction to PAs (Boppre, 1986; Boppre *et al*., 1984; Boppre and Fischer, 1994; Fischer and Boppre, 1997).

However, from the ecological standpoint, there is no empirical data to validate the coincidental relationship between *C. odorata* and *Z. variegatus* which is of paramount importance towards a better understanding of the role of *C. odorata* in the seasonal outbreaks of *Z. variegatus*. Even though the work by Castel (2012) has empirical data, this is only limited to *C. odorata*. The need to have some combined empirical data on *Z. variegatus* and *C. odorata* cannot be overemphasized.

Questionnaire and ecological surveys were thus conducted with the aim to determine the distribution, density and pest status of *Z. variegatus* and *C. odorata* in Ghana. The survey also gathered information on seasonal populations of *Z. variegatus* with respect to the occurrence of flowers of *C. odorata* and other plants containing PAs. The results of the study would help to establish a possible link between the distribution of *C. odorata* and the seasonal outbreaks of *Z. variegatus*.

MATERIALS AND METHODS

Questionnaire and reconnaissance surveys: The study began in 2002 with a nationwide questionnaire survey to gather information on the occurrence and status of *Z. variegatus* and *C. odorata*. In each of the 10 administrative regions, five questionnaires were administered to five Frontline Staff from the Ministry of Food and Agriculture (MoFA) to complete, giving a total of 50. Additionally, a reconnaissance survey was conducted for supplementary information from farmer groups of 5-10 of both sexes (age range between 18 and 45 years) from 18 villages selected nationwide, namely; High rainforest zone, Coastal savannah zone, Semi deciduous zone Forest Savannah Transition zone, Guinea Savannah and Sudan Savannah) (Fig. 1).

Ecological survey: An ecological survey was conducted in 2003 to determine the distribution and density of *Z. variegatus* and *C. odorata*. This was done by driving along selected towns of the country and making stops at 40±10 km for field observations. In all, 18 fields were selected nationwide (Fig. 1). Stops were made at fallow fields (less than 2 years) with *C. odorata* as the predominant vegetation in the distribution area of *C. odorata*. In northern Ghana, data was taken at irrigation sites at Fumbisi Valley and the Irrigation Company of the Upper Region (ICOUR) in addition to a few randomly selected grasslands.

Using the imaginary quadrat method (Lomer *et al*., 1999) 25 (1 m^2) square quadrats were used to study the distribution of *Z. variegatus*. Plant density per hectare was calculated using the formula:

$$D = I/ha = \frac{T \times 10{,}000}{25}$$

where, D is the density per hectare, I is the individuals and T is the total insects from 25 m^2.

In each field, 5 (5 m^2) square quadrats were used to estimate the density of *C. odorata* and scored as low (i.e., predominantly isolated stands and tufts with few patches of *C. odorata*), moderate (tufts with many patches and few dense thickets) and high (patches with predominantly dense thickets of *C. odorata*) using FAO guidelines (Timbilla and Braimah, 1996).

Statistial analysis: Summary statistics was used to compute data gathered during the questionnaire surveys using GraphPad Prism® 4.00 (GraphPad Software, 2003). The mean population density of *Z. variegatus* and mean density of *C. odorata* were calculated within each ecological zone using the same statistical analysis and software.

RESULTS

Prevalence, seasonal populations and economic status of *Z. variegatus* (questionnaire survey): Respondents in the Sudan Savannah indicated that *Z. variegatus* occurred in low densities in most parts with only one population from May to December/January (Fig. 1). Nymphs occurred in both the dry and wet seasons while adults were predominantly found during the dry season. On pest status, two thirds (66.7%) of the respondents ranked *Z. variegatus* as a major pest (Fig. 2). The respondents claimed that the insect was more prevalent in the area during the rainy season from June to August. Major food crops indicated to be damaged by the insect were cowpeas, rice, sorghum, millet, mango and maize (Table 1).

Table 1: Crops damaged by *Z. variegatus* as indicated by respondents in Ghana in 2002

Ecological zone	Crops damaged
Sudan savannah	Cowpeas, rice, sorghum, millet, mango and maize
Guinea savannah	Cabbage, cowpeas, tomato, eggplant, rice and cassava
Forest savannah transition	Cassava, eggplant, cowpeas and teak
Semi-deciduous	Cassava, maize, citrus, cabbage, eggplant, pepper, tomatoes, cowpeas and teak
High rainforest	Cassava, maize, eggplant, tomato and cabbage
Coastal savannah	Cabbage, eggplant, cassava, maize and tomato

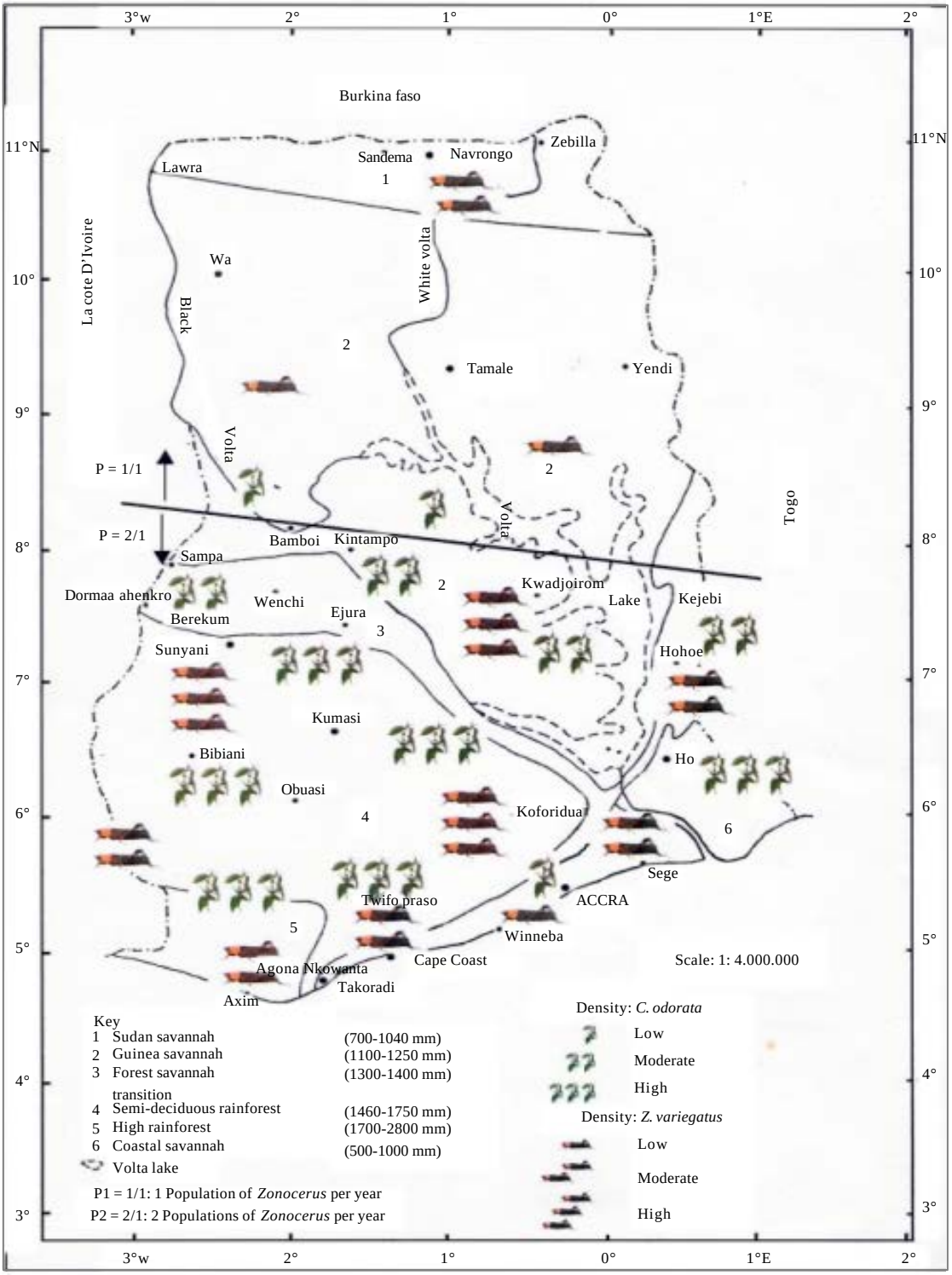

Fig. 1: Ecological map of Ghana showing the distribution and density of *Chromolaena odorata* and *Zonocerus variegatus* and distribution of wet and dry season populations of *Zonocerus variegatus*

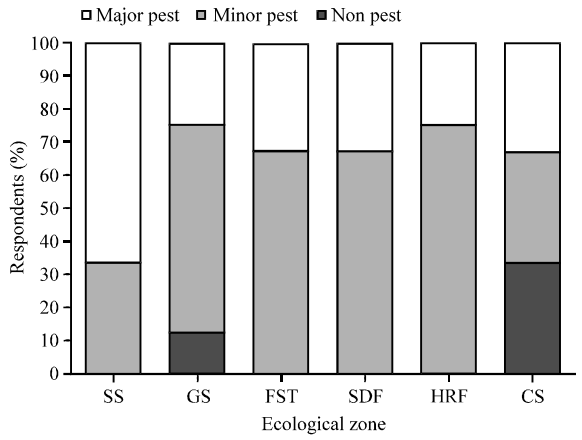

Fig. 2: Level of perception of respondents on pest status of *Zonocerus variegatus* in Ghana, SS: Sudan savannah, GS: Guinea savannah, FST: Forest savannah transition, HRF: High rainforest and CS: Coastal savannah

In the Guinea Savannah, *Z. variegatus* was present in low densities though completely absent in Wa environs (Fig. 1). The respondents here claimed that the insect occurred in a single population above Lat. 8°N in the drier parts but occurred in two distinct wet and dry season populations in the wetter parts below Lat. 8°N (Fig. 1). With respect to the pest status of the insect, majority (62.5%) ranked it as a minor pest (Fig. 2). Crops damaged here were mainly vegetables such as cabbage, cowpeas, tomatoes, eggplant and food crops such as rice and cassava. The respondents claimed that tomato seedlings suffered the most damage between December and January.

In the forest Savannah transition zone, majority of the respondents (66.7%) (Fig. 2) perceived the insect as a moderate pest. *Zonocerus variegatus* was said to occur in two distinct wet and dry season populations with nymphs and adults present in the field all year round (Fig. 1). In addition to food crops and vegetables Teak (*Tectona grandis* (L.) (Verbenaceae) a major timber species was also reported to suffer severe damage by the feeding activities of *Z. variegatus* (Table 1). Crop damage was reported to occur mainly in the dry season from November to February.

In the semi-deciduous forest zone where the respondents were mainly farmers, the survey was conducted at Sunyani, Obuasi and Bibiani (Fig. 1). Here, teak was also indicated to be damaged by *Z. variegatus* in addition to cassava, maize, citrus and vegetables such as cabbage, egg plant, pepper, tomatoes and cowpeas (Table 1). The respondents indicated that *Z. variegatus* exists in two distinct populations in the wet and dry season of the year (Fig. 1). Majority of the respondents (66.7%) perceived the insect as a minor pest often found in the months of August to December (Fig. 2).

The high rainforest or evergreen forest, characterized by high precipitation, occurs in the Western region of Ghana. Here, 75% respondents indicated *Z. variegatus* as occurring in moderate densities (Fig. 1) and a minor pest (Fig. 2). According to the respondents, this zone was also characterized by a distinct wet and dry season population with both nymphs and adults present in the fields throughout the year as in the Semi deciduous zone (Fig. 1). Vegetables and food crops were the most damaged from August to April.

The density of *Z. variegatus* in the Coastal savannah the varied; it was ranked as occurring in high density towards the west at Winneba and low in and around Accra. The insect was, however, distributed throughout this ecological zone (Fig. 1). In the moist parts of this zone, stretching from Takoradi to Winneba and in Ho areas, *Z. variegatus* was indicated to exist in two populations; a wet season population from April to September and a dry season population from August/September to March. However, in the drier parts towards the east at Sege, only one population of *Z. variegatus* was said to exist between May and December (Fig. 1). On the status of *Z. variegatus* as a pest, there was an equal perception of 33.3% each for it being a non-pest, a minor pest and a major pest (Fig. 2). It was indicated as a major pest causing damage on vegetables and food crops.

Prevalence and economic status of *C. odorata*: *Chromolaena odorata* was indicated by the respondents to be completely absent in the Sudan savannah zone (Fig. 1 and 2).

The distribution of *C. odorata* in the Guinea savannah is as far north as Lat. 8°30′ at Bamboi, where it occurred in low densities (Fig. 1). In the wetter parts around Kwadjokrom in the Afram plains, the weed was said to occur in moderate densities. On pest status, the weed was perceived by respondents as a minor weed pest and a beneficial plant with a score of 50% for each (Fig. 3).

The density of the weed in the Forest savannah transition zone as determined from the survey data was classified as low in newly colonized areas such as Sampa, moderate in Berekum and Kedjebi and high (occurring in dense thickets) in the wetter parts at Ejura and Hohoe (Fig. 1). The respondents, however, perceived the weed status of *C. odorata* differently in this zone. While some 50% perceived it as a major weed, the remaining 50% regarded it as a beneficial plant (Fig. 3).

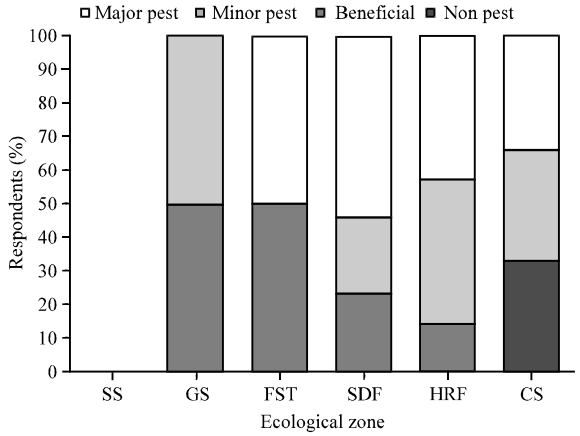

Fig. 3: Level of perception of respondents on pest status of *Chromolaena odorata* in Ghana. SS: Sudan savannah, GS: Guinea savannah, FST: Forest savannah transition, HRF: High rainforest and CS: Coastal savannah

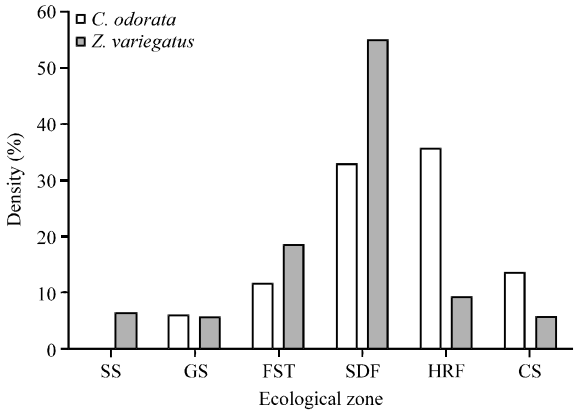

Fig. 4: Density of *Chromolaena odorata* and *Zonocerus. variegatus* in 6 ecological zones of Ghana (August-November, 2003). SS: Sudan savannah, GS: Guinea savannah, FST: Forest savannah transition, SDF: Semi-deciduous forest, HR: High rainforest and CS: Coastal savannah

In the semi-deciduous forest zone *C. odorata* was rated high as occurring in dense thickets, covering several kilometres along roadsides. This area stretched from Sunyani through Obuasi, Twifo Praso and Koforidua and had the widest distribution of *C. odorata* in Ghana. A little over half of the respondents (53.8%) perceived *C. odorata* as a major weed with 23.1% ranking it as a minor weed and another 23.1% ranking it as a beneficial plant (Fig. 3).

The distribution of *C. odorata* in the High rainforest area was similar to its occurrence in the Semi-deciduous forest ecological zone. The whole area is infested with *C. odorata* with mostly dense thickets (high density) at Agona Nkwata and Axim areas towards the border with Cote d'Ivoire. Regarding the weed status of *C. odorata*, it was equally perceived as a major or minor weed (i.e., 42.9% each) while some 14.2% perceived it as a beneficial plant (Fig. 3).

The occurrence of *C. odorata* in the wetter parts of the Coastal savannah zone from Takoradi through Cape Coast to Winneba was rated moderate, but as occurring in high densities at Ho and its environs. *Chromolaena odorata* is however almost absent in and around Accra except at the Weija Dam site and Pokuasi on the outskirts of the city. On the eastern side towards Sege, the weed is completely absent. Here, a third each of the respondents regarded *C. odorata* as a non pest, a minor or a major pest (Fig. 3).

Distribution of plants containing pyrrolizidine alkaloids: The survey revealed that *Ageratum conyzoides* (Asteraceae) and *Crotalaria retusa* (Fabaceae) occurred in all 6 ecological zones of the country (Table 2). In addition to the above, *C. odorata* and *Heliotropium indicum* (Boraginaceae) were indicated to occur in 4 ecological zones; namely the Forest savannah transition, Semi-deciduous, High rainforest and Coastal savannah zones. The results also indicated that *C. odorata* and *H. indicum* do not occur in the north beyond Lat. 8°30'.

Table 2: Occurrence of plants containing pyrrolizidine alkaloids in 6 ecological zones of Ghana

Ecological zone	PA-plants listed by respondents
Sudan savannah	*C. retusa* and *A. conyzoides*
Guinea savannah	*C. odorata*, *C. retusa* and *A. conyzoides*
Forest savannah transition	*C. odorata*, *C. retusa*, *H. indicum* and *A. conyzoides*
Semi-deciduous forest	*C. odorata*, *C. retusa*, *H. indicum* and *A. conyzoides*
High rainforest	*C. odorata*, *C. retusa*, *H. indicum* and *A. conyzoides*
Coastal savannah	*C. odorata*, *C. retusa*, *H. indicum* and *A. conyzoides*

Density of *C. odorata* and *Z. variegatus* in the field: The highest density of 77,330 hoppers ha^{-1} (55.3%) was recorded in the semi-deciduous forest zone, followed by 36,000 hoppers ha^{-1} (18.6%) in the Forest savannah transition zone. The remaining 4 ecological zones recorded values of 8,933 (6.4%), 7,800 (5.6%), 12,670 (9.1%) and 8,133 (5.8%) hoppers ha^{-1} for the Sudan savannah, Guinea savannah, High rainforest and Coastal savannah, respectively (Fig. 4).

Also from Fig. 4, *C. odorata* was ranked as occurring in high densities in 5 of the 6 ecological zones, with

proportionate values in decreasing order from the High rainforest (35.8%), Semi-deciduous (33.1%), Coastal savannah (13.6%), Forest savannah transition (11.6%) and Guinea savannah zones (5.9%). At the time of the survey, the weed was completely absent in the Sudan savannah zone.

DISCUSSION

Combining the questionnaire and reconnaissance surveys, a remarkable 96% of the questionnaires were returned. Ghana is divided into 25 degree zones, thus, approximately, each degree zone was accounted for by two questionnaires, equivalent to the FAO methodology used for the first study on the distribution of *C. odorata* in Ghana (Timbilla and Braimah, 1996).

The values calculated for the density of *Z. variegatus* and *C. odorata* in the field ecological survey, to a very large extent, correlated with the responses received from the questionnaire and reconnaissance surveys. The low density recorded for *Z. variegatus* in the High rainforest zone was probably due to the humid conditions prevalent at the time of the survey, enhancing high mortalities attributed to the fungus *Entomophaga grylii* as observed by Chapman and and Page (1979) and Toye (1982).

The study confirms that *Z. variegatus* is distributed throughout Ghana as observed earlier by Chapman (1962). Also, Kaufmann (1965) had observed, one generation of *Z. variegatus* earlier (before the introduction of *C. odorata* in 1969). However, following the introduction of *C. odorata* and subsequent establishment, the dynamics of the grasshopper has changed. Whereas the insect occurred in one population beyond Lat. 8°N, it existed in two distinct wet and dry season populations below Lat. 8°N. The exception was the drier parts of the Coastal savannah where the insect occurred in one population as in the north. The north which is characterized by a single population of *Z. variegatus* experiences uni-modal rainfall, ranging from 700-1,250 mm per year. This is also true for parts of the Coastal savannah zone with precipitation as low as 500 mm per annum. On the other hand, below Lat. 8°N where *Z. variegatus* occurs in two seasonal populations, the area is characterized by a bi-modal rainfall pattern ranging from 1, 300-2, 800 mm year^{-1}.

Also, *Z. variegatus* was noted to be a pest during the rainy season in areas with a single population and a pest in the dry seasons in places where it occurs in two distinct seasonal populations per year. The density of the insect as observed in areas with one population per year was generally low to moderate while it was generally high in areas where it occurs in two distinct seasonal populations. Thus, the number of populations per year and density of *Z. variegatus* seems to be a function of the rainfall pattern in an area.

From the results, the occurrence of the flowers of *C. odorata* from November to February/March in the dry season (Timbilla and Braimah, 1996) coincided with high densities of *Z. variegatus* and crop damage by the insect. The other PA-plants such as *C. retusa*, *H. indicum* and *A. conyzoides* indicated to occur within the distribution zone of *C. odorata* are mostly present during the wet season when *Z. variegatus* is not considered a pest on crops. These PA-plants grow among other forms of vegetation in the rainy season. From the above, the only most probable factor responsible for the dry season outbreak of *Z. variegatus* is the supply of PAs from the flowers of *C. odorata* between November and February/March as noted by Boppre and Fischer (1994) and Fischer and Boppre (1997).

The spread of *C. odorata* at the time of the survey was as far north as Lat. 8°30', compared with Lat. 8°15' in 1992 (Timbilla and Braimah, 1996). A more recent study by Castel (2012) confirms the current distribution of *C. odorata* in Ghana. It appears *C. odorata* has reached its northernmost limit in the country. Generally, *C. odorata* was either absent or sparsely distributed in areas characterized by uni-modal rainfall pattern.

It is interesting to note that the perception of *Z. variegatus* as a major pest correlates with observations made, though with varying degrees. Damage by *Z. variegatus* to crops has been difficult to quantify over the years as also observed in the present study. However, factors such as season, stage and duration of *Z. variegatus* attack, the growth stage of the particular crop in question and how weedy a field may be, contributed to the magnitude of damage as also observed by Chapman *et al*. (1986) and Fischer and Boppre (1997).

The results indicated a strong linkage between the pestilence of dry season populations of *Z. variegatus* and the presence of Pas from the flowers of *C. odorata*, thus confirming the existing pharmacophagous relationship proposed between the insect and the weed by Boppre (1991). Control strategies initiated on this pharmacophagous relationship holds promise and should be pursued vigorously.

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