

Allelopathic Potential of *Tithonia Diversifolia* and *Lantana Camara* Leafy Materials on Germination and Growth of Sb 19 And Sb 97 Soybean Varieties

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ABSTRACT

Soybean is a legume which is widely grown in western Kenya for its edible seed but their yields are reduced by the effect of low soil fertility. In Western Kenya, farmers are being encouraged to use shrubs as green manure such as *Tithonia diversifolia* and *Lantana camara* which have shown to improve soil fertility by 24% to 54%. Information available on their allelopathic potential on germination and growth of soybean is not exhaustive. The objectives of this study was to investigate the allelopathic effects of fresh leaf aqueous extracts and fresh leaf material of *T. diversifolia* and *L. camara* on germination of seeds, growth and yield of SB97 and SB19 soybean varieties. The experiments were carried out in the laboratory and greenhouse at Maseno University. In the lab, different concentrations of aqueous extracts, (25%, 50%, 75%, and 100%) and the control- tap water was used. Germination experiment was set in petri dishes and growth, yield and physiological parameters was carried out in the green house. Fresh leaf material of *T. diversifolia* and *L. camara* of 4g, 8g, 12g and 16g was added to soil in pots. The control only composed soil. This was replicated four times and laid out in Completely Randomized Design. Data on germination count were recorded daily, while growth parameters were recorded weekly. Data were subjected to analysis of variance using SAS 9.1 to establish significant differences among treatments, varieties and plant materials. The treatment means were separated and compared using the Least Significance Differences at $P = 0.05$. The results revealed that leaf extracts from *Lantana camara* and *Tithonia diversifolia* reduced the germination of both soybean varieties. These extracts contained bioactive compounds that inhibited germination, root and shoot growth and yield of Soybean varieties SB 19 and SB 97. *Lantana camara* exhibited stronger allelopathic activity than *Tithonia diversifolia*. On growth parameters, including shoot height, leaf number, leaf area, fresh and dry weights, and yield, the presence of allelochemicals in the biomass was suggested to have hindered growth by disrupting enzyme activities and nutrient uptake. Farmers are therefore advised not to incorporate *Lantana camara* and *Tithonia diversifolia* leafy biomass in farms where soy bean varieties SB 19 and SB 97 are growing.

Key words; Allelopathic, leafy biomass, germination, growth, soybean

INTRODUCTION

On a global scale, the issue of food and nutritional (in) security remains a significant concern for both developed and developing nations (Todaro and Smith, 2020). Notably, the presence or absence of food security is directly intertwined with poverty at various levels (FAO, 2015). However, the issue of food insecurity is particularly serious in Sub-Saharan African countries like Kenya (da Mota *et al.*, 2019). The Kenya National Bureau of Statistics (KNBS, 2018) reported that nearly 16.4 million Kenyan households live below the poverty line. Recent estimates from FAO (Todaro and Smith, 2020) further indicate that over 10 million people in Kenya experience food insecurity, rendering them unable to meet their required dietary

energy intake, with a significant portion relying on food assistance (Matheri *et al.*, 2023). Despite being a key focus of the agricultural sector achieving food security in Kenya remains a challenge.

The Western region of Kenya holds distinction as the leading soybean producer, with its cultivation often intertwined as an intercrop alongside maize, sorghum, finger millet, cassava, or sugarcane (Mbembe *et al.*, 2019). Despite this, the potential for soybean production and the region's food security status remain unfulfilled, as highlighted by the research conducted by Nyongesa *et al.* (2017) and Mbembe *et al.* (2019). Maseno in Western Kenya have shown the potential to grow and produce soybean however most soils in this region are infertile hence various forest tree species and weed cuttings are being used by farmers as green manure. The unforeseen impact and effects of some green manure remain unknown to local farmers due to their relief on use instead of expensive and unavailable fertilizer (Jama *et al.*, 2000). Most farmers in Maseno have small pieces of land which are only suitable for small scale production of some crops. However this has been reported to be hindered by drought, low fertility and allelochemicals resulting from use of some forest tree species as green manure (Nziguheba *et al.*, 2002).

In the recent years food production has suffered serious setback due to general shortage and unaffordable cost of chemicals fertilizers. Much attention is therefore directed towards the search for alternative fertilizer sources to boost crop production (Wanjikia *et al.*, 2021). The current ecological movement with its fear of soil and water pollution by inorganic fertilizers calls for the use of organic fertilizers that are renewable and less harmful (Akinfasoye, 2008). The increasing cost of fertilizer and its negative impacts on soils has necessitated the use of various alternative sources of soil fertilization including ash, compost manure or green manure depending on the availability (Jama *et al.*, 2000). Some studies have reported that integrating *Lantana camara* trimmings with fertilizer at 50% rates resulted in higher maize yields than either from organic or inorganic resource (Kayuki and Wortmann, 2001). Similarly, green biomass of *Tithonia diversifolia* applied either alone or in combination with fertilizer increases yields of maize by 24% and 54%, respectively compared to plots which received no inputs (Lesser, 2013). Both *Tithonia diversifolia* and *Lantana camara* are widely available and hence have been recommended to farmers for use as green manure without the knowledge of the danger they may pose to their crops at various stages of growth.

Tithonia diversifolia is a member of the family *Asteraceae* and is a perennial native of Mexico and Central America that is cultivated for its beautiful flowers and enormous size (Kato-Noguchi, 2020). African farmers have used the plant in many ways; the most popular use being as organic fertilizers for crops in compost form (Seema *et al.*, 2011). *Tithonia diversifolia* is widely distributed along farm boundaries in Kenyan farms and more often leaf segmentas finds their way in to the farm. It has been utilized as an organic fertilizer for vegetable crops, proving beneficial as green manure by enhancing maize (*Zea mays*) yield. Moreover, it has demonstrated its efficacy as a nutrient source for lowland rice (*Oryza sativa*), as supported by studies conducted by Jama *et al.* (2000), Nziguheba *et al.* (2002) and Sangakkara *et al.* (2002).

Lantana camara has been shown to contain total nitrogen N% 2.86, available P Kg/1.7K kg/ha 12.2 and organic matter 29.95% (Vaidya, 2007). However *Lantana camara* has been documented to have allelopathic effects on various crops despite their nutrient attributes (Otusanya, 2007). Previous study by Hassanain *et al.* (2019), foliar leachates of *Lantana camara* showed no effect on *Morrnia odorata* plant germination percentage and seedling growth but there were allelopathic effects on roots and shoots. However it is equally important to determine whether this leachates have the same allelopathic effects on soybean germination and seedling growth.

Green manure replaces nitrogen and other elements and builds organic matter contents of the soil and some may lead to reduced weed growth, (Nandal, 1998). *Lantana camara* and *Tithornia diversifolia* have been recommended for use as green manure. They have been identified as an alternative to chemical fertilizers to increase soil fertility and improve crop production in sustainable farming but literature indicates that they are allelopathic plants (Oyerinde and Otusunya, 2009; Vaidya, 2003).

The allelopathic effects of *L. camara* and *T. diversifolia* on growth inhibition in crops remain poorly understood and controversial. For example; previous studies have shown fresh aqueous solution of *Tithonia* had no effect on germination of *Cleome gynandra* and *Zea mays* (Oyerinda *et al.*, 2009). On the contrary, the extracts inhibited plumule and radical heights in *Amaranthus cruentus* (Otusanya *et al.*, 2007). Also Sing (1998) observed the germination of seeds was inhibited to a greater extent by boiled and unboiled extracts of the *Lantana camara* due to presence of phenolic compounds. While Arora and Kohli, (1993) found that crude volatile oil extracts from young leaves of *Lantana camara* had adverse effects on chlorophyll content and seed vigour of *Lantana camara* plant. Sahid and Sagau (1993) also noticed that emergency and dry weights of many vegetable species were affected by *L. camara* and *T. diversifolia*. It was therefore necessary to carry out this study to elucidate the effects of each of *L. camara* and *T. diversifolia* leaf aqueous extracts on germination and growth two soybean varieties.

Soybean cultivation is distributed across Western, Nyanza, Rift Valley, Central, and Eastern regions, spanning around 2,500 hectares with an average yield of 0.8 t/ha. This falls below the potential yield of 1.5 - 3.0 t/ha, which varies depending on the location (Chianu, 2006). In 1999, the Ministry of Agriculture projected that achieving self-sufficiency would necessitate 135,000 hectares to produce over 108,000 MT, highlighting the need for proactive measures to boost domestic soybean production and address this demand. The efforts of international agricultural research organizations, including CIAT and IITA, in collaboration with the government, have led to increased awareness of soybean's health benefits and nutritional value. This progress has been particularly notable in Western Kenya, where soybean production has experienced advancements.

Crop productivity is reduced when allelochemicals effects inhibit germination and early seedling growth stage (Zhijie *et al.*, 2020). Furthermore, they predispose crops to other abiotic and biotic stresses. Likyelesh *et al.* (2023) studied allelopathic effects of *L. camara* on *Lepidium sativum* (L.). The researchers found that seedling growth were highly inhibited by the highest biomass. Other researches suggested that secondary compounds in lantana cause negative allelopathy on several plant species growth (Gebreyohannes *et al.*, 2023). Triterpenes, and pentacyclic triterpenoids are allelochemicals from *Lantana* that reduce growth, and function of photosystem II (Janusauskaite, 2023). According to Likyelesh *et al.* (2023) hexane leaf extracts reduced growth significantly higher than ethanolic leaf extracts. However, in this study it was vital to study how this possible secondary metabolites in *Lantana* and *Tithonia* could lead to allelopathy effects in soybean plant varieties.

Allelochemicals interfere with resource mobilization which reduces growth during the early stages of seed germination (Gebreyohannes *et al.*, 2023). Allelochemicals such as phenolic compounds known to be in plant biomass of *Lantana* and *Tithonia* known impair the synthesis of gibberellins and even impair the activity of this hormone and others that might behave antagonistic or synergists (Gebreyohannes *et al.*, 2023). This was suggested to be the reason for reduced growth as the rate at which cells were dividing, elongating and specializing reduced concomitantly. *Lantana* extracts are therefore expected to reduce shoot and root lengths, leaf area that mean reduced photosynthesis, leading to reduced yield of soybean plants. Measuring this parameters of growth and yield would give an insight on how allelochemicals would interfere with important metabolic activities capable of promoting cell division and elongation. In a study by Janusauskaite (2023), Allelopathy has been said to decrease Mg activation and chlorophylls synthesis which eventually decrease carbohydrates, proteins, and nucleic acids formation. A reduction in growth due to these decreases lead to low yields in terms of dry weights and pod number that should be studied in soybeans.

In a review by Zhijie *et al.* (2020), *Lantana* tissue decomposition made allelochemicals enter into soils and invade *L. sativum* roots. It was highly expected that these chemicals will also have an allelopathic effect to growth of soybeans after entering into the soil (Janusauskaite, 2023). However, allelochemicals from *Tithonia* and *Lantana* may be changed into some other nontoxic forms in soils by microbial and physicochemical processes leading to less toxic effects to growth of soy bean plants as suggested Gebreyohannes *et al.* (2023). According to Sahid and Sugau (1993) *Lantana camara* sprouting does not

inhibit growth of other crops but there is high decrease if aquas extracts are applied to seeds before planting. Nevertheless, as found in chickpea and sunflower (Janusauskaite, 2023), allelochemicals may bind to minerals reducing amounts of essential nutrients available in the soil for growth, dry weight and yield of plant crops such as soybeans.

Soybean cultivation holds immense promise as a critical source of protein and oil for both consumption and economic activities in Western Kenya. Farmers in Maseno, western Kenya experience poor crop yields due to low fertility of soil. However, achieving optimal soybean production is hindered by multifaceted constraints, with soil fertility issues exacerbated by the use of forest tree species and weeds as green manure. The green organic matters are known to contain allelopathic chemicals that may be detrimental to commonly grown soybean plants. Therefore, use of *Lantana camara* and *Tithonia diversifolia* green manure as an alternative source of fertilizer may lead to a problem of decrease soybeans crop production. The specific objectives of the study were to determine allelopathic effects of various amounts of fresh leaf segments of *L. camara* and *T. diversifolia* on seeds that germinated daily and plumule length, shoot height, number of leaves, leaf area, number of pods, plant fresh weight and plant dry weight of SB 97 and SB 19 soybean varieties. Human population pressure has led to land subdivision in Western Kenya including Maseno. The incidences of poverty are more pronounced in rural areas where farming majorly takes place. Soybeans are a source of income as well as cheap dietary protein to the residence of rural as well as urban areas (Obongoya, 2002). It is justifiably important to ascertain whether their allelopathy also affect soybean growth before recommending their use as green manure for these crops. Further, studies indicated that when green manure from *Lantana camara* and *Tithonia diversifolia* are used, there is allelopathic effects to most crops. This calls for thorough investigation into allelopathic potential of these shrub species since they may have negative effects on the crops.

MATERIALS AND METHODS

Experimental site

The research was carried out in the green house and laboratory at Maseno university botanic garden. Maseno area is approximately 1500 m above sea level and receives annual mean precipitation of 1750 mm with bimodal pattern of distribution (Musyimi, 2017). Yearly average temperature of Maseno is 28.7 °C The soils in Maseno are classified as Acrisol, deep reddish brown friable clay with pH ranging from 4.5 to 5.5 (Musyimi, 2005). Greenhouse temperatures varied 25±3 °C (day/night). With 27-99% relative humidity.

Experimental Materials

Fresh leaves of *Lantana camara* and *Tithonia diversifolia* was collected from Maseno university field near Botanic garden. The leaves were taken to the laboratory and immediately separated into leaf and stem parts. Seeds of two locally adopted soybean varieties SB19 and SB97 were obtained from International Centre for Tropical Agriculture (CIAT) Maseno centre.

Preparation of fresh extracts of *Lantana* and *Tithonia*

One hundred and eight grams of fresh leaf extracts of *Lantana camara* and *Tithonia diversifolia*, respectively were harvested at vegetative stage and cut into small chips of about 4 cm length, according to Nektarios (2005) and finely ground with pestle and mortar and then soaked in 1 litre of water in a large beaker for 24 hours. The resultant extract was filtered through cheese cloth to remove debris and finally filtered using Watman No. 1 filter paper to have 100% concentration. The aqueous extracts of 25%, 50% 75% and 100% concentration were made by diluting original extract with distilled water.

Laboratory experiment on germination

Aqueous extracts of *Lantana* and *Tithonia* were obtained by cutting their leaves into small pieces and soaking them in water for 48 hours after which the filtrate was used. Germination tests were carried out to varieties SB 19 and SB 97 in the laboratory at the university Botanic Garden. During the process, large, similar sizes of each of varietal seeds were soaked in 5% sodium hypochlorite to prevent fungal infection. The seeds were washed by rinsing them for about 5 minutes in running water. Ten seeds were placed in each clean petri-dish that had been oven dried. The experiments were laid in a completely randomized design (CRD) with four replicates. Lastly, seeds were then lined with two layers of Watman No. 1 filter paper then moistened with 10 ml of water (control) and respective aqueous extracts (treatments) of 25%, 50%, 75%, 100% from *Lantana* and *Tithonia*. Percentage germination was then determined seven days after germination.

Green house experiment on growth

Growth test was carried out in a greenhouse at the university botanic garden. The cut leaf tissues of *Lantana camara* and *Tithonia diversifolia*, respectively were incorporated in the soil contained in 4.5 litre plastic pots at five different rates namely 0 grams (control), 4 grams, 8 grams, 12 grams and 16 grams of fresh weight per pot according to Nektarios (2005). The soybean seeds SB 19 and SB 97 were sown in soils within different pots at rate of 10 seeds per pot and at a depth of 1 cm. The seeded pots were irrigated with tap water daily. The seedlings were thinned to 5 plants per pot after two weeks. Completely randomized design (CRD) with treatments replicated four times was used.

Determination of allelopathic effects of various amounts of fresh leaf segments of *L. camara* and *T. diversifolia* on seeds germination and plumule length

Number of seeds that germinated daily were determined by counting and recording on daily basis. The plumule length was measured using a transparent 30 cm ruler.

Determination of allelopathic effects of various amounts of fresh leaf segments of *L. camara* and *T. diversifolia* on shoot height, number of leaves, leaf area, number of pods, plant fresh weight and plant dry weight

Shoot heights were measured from the soil level to the upper point of the terminal bud of the seedlings using a meter rule for each of the treatment and control after every two weeks for five times. **Number of leaves** were determined, whereby, a plant was marked and used throughout to determine total number of leaves. The total number of leaves on both stem and branches were counted and record on one plant for every two weeks and for five times. A plant was marked and used throughout to determine **leaf area**. Leaf area was determined at an interval of two weeks and for five times, where, the breadth of each plant and the length of the fourth leaf from the top were measured with a ruler. The formula from Otusanya *et al.* (2007), which is reproduced below, was used to calculate leaf area and total leaf area; Leaf Area = Leaf length x leaf width x 0.8; where 0.8 is a commonly used correction factor in soybean leafs to account for leaf shape and margins. Total plant leaf area was then determined by LA times the number of leaves on each plant. To determine **Number of pods**, three plants were randomly selected in every pot. Pods that were fully expanded were counted and recorded on average per pot after every two weeks for five times. At the end of the experiment the plants were carefully uprooted from the soil, and then roots were rinsed to clear off debris after which the root and shoot were separated then weighed using weighing balance (Denver instrument XL-3100D) and recorded as **plant fresh weights**. The shoots and roots were then oven dried for 48 hours at 72° C to attain over 75% dry weight, weighed and recorded as **plant dry weights**.

Statistical Data Analysis

Data collected was subjected to analysis of variance (ANOVA) to establish significant difference among treatments, varieties and plant materials using SAS Software version 9.1. Fisher's Least Significant Difference (LSD) test at 5% significance level was used to separate treatment means. Results

RESULTS

Allelopathic effects of various amounts of fresh leaf segments of *L. camara* and *T. diversifolia* on seeds that germinated daily and plumule length

Number of seeds that germinated after seven days

The *Tithonia diversifolia* shoot extracts significantly reduced seed germination of SB 97 and SB 19 compared to the control treatments (Fig.1).

Number of seeds that germinated daily were significantly different ($p < 0.05$) under plant extracts from *Lantana camara* and *Tithonia diversifolia*, percentage extracts, and between varieties. The interaction between varieties and plant extracts from *Lantana camara* and *Tithonia diversifolia* were significant ($p < 0.05$). Fisher's LSD showed that T0 (8.34) mean was significantly higher than that of T1 (7.59), T2 (6.95), T3 (6.67) and T4 (6.05) respectively. Means for T1, T2, T3 and T4 were significantly higher when comparisons were made between any two of them. *Tithonia diversifolia* shoot extracts had significantly higher seed germination (8.10) compared to 6.14 mean of *Lantana camara* shoot extracts. Significantly more seeds germinated in SB97 (7.74) than SB 19 (6.50) under the extracts treatments.

Plumule length

Variety SB 97 showed that mean for T0 was significantly higher compared to T1, T2, T3 and T4 respectively for *L. camara* (Fig. 2).

Plumule lengths were significantly different for percentage extracts, between varieties and when plant extracts from *Lantana camara* and *Tithonia diversifolia* interacted with percentage extracts (Fig. 2). Fisher's LSD showed that T0 (3.55) mean was significantly higher than that of T1 (3.14), T2 (2.59), T3 (2.25) and T4 (2.04) respectively. Means for T1, T2, T3 and T4 were significantly higher when comparisons were made between either of them respectively. Similarly, mean of SB 19 (7.74) variety was significantly higher than that of SB 97 (2.51).

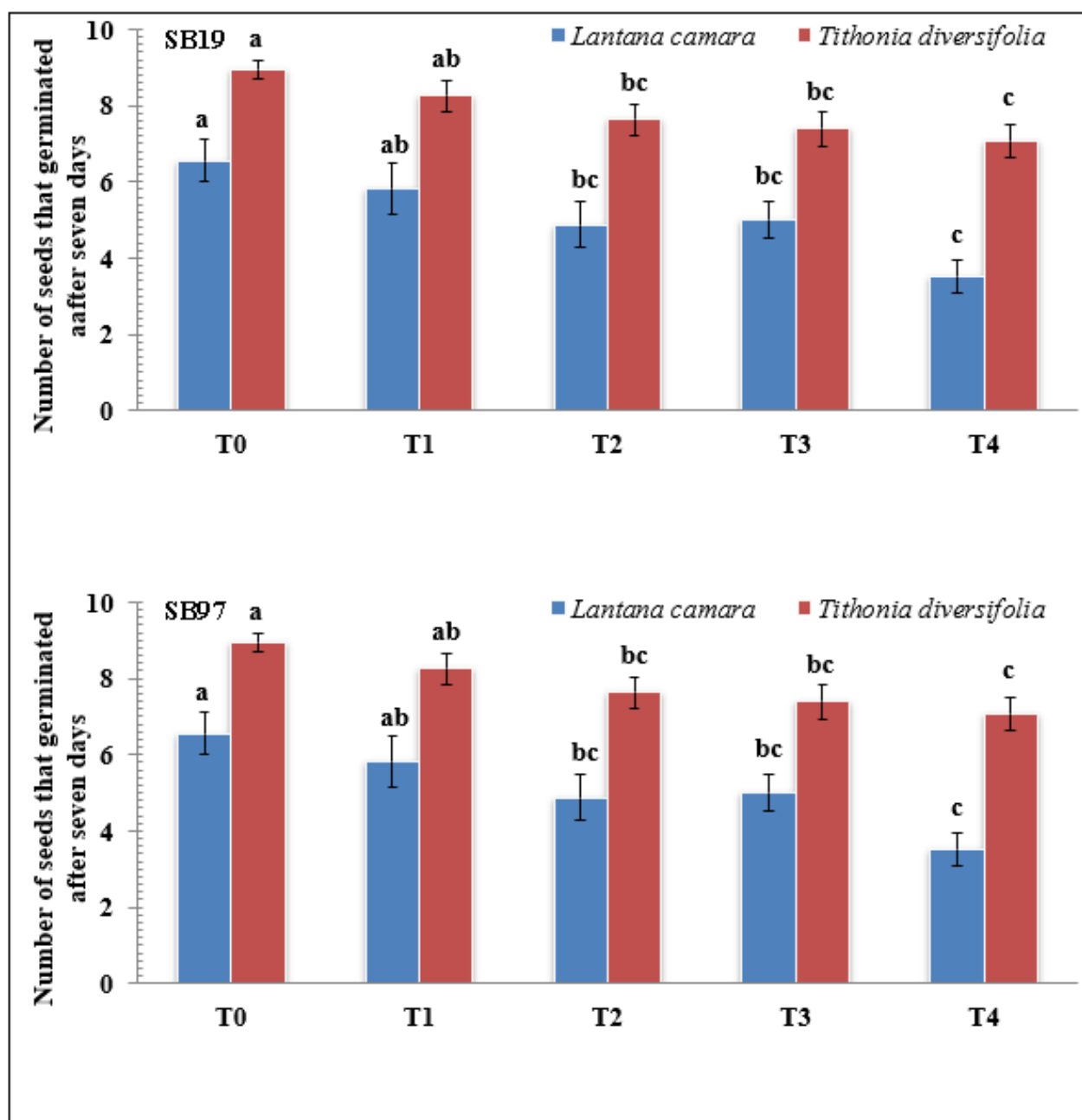


Fig. 1. Number of seedlings that germinated in two soy bean varieties subjected to various treatments of % extract concentrations. Values are means of four replicates $\pm$ SEs. Control (T0), 25% extract concentration (T1), 50% extract concentration (T2), and 75% extract concentration (T3) and 100% extract concentration (T4) from both *L. camara* and *T. diversifolia*. Means with the same latter are not significantly different among treatments for variety SB 19 and SB 97.

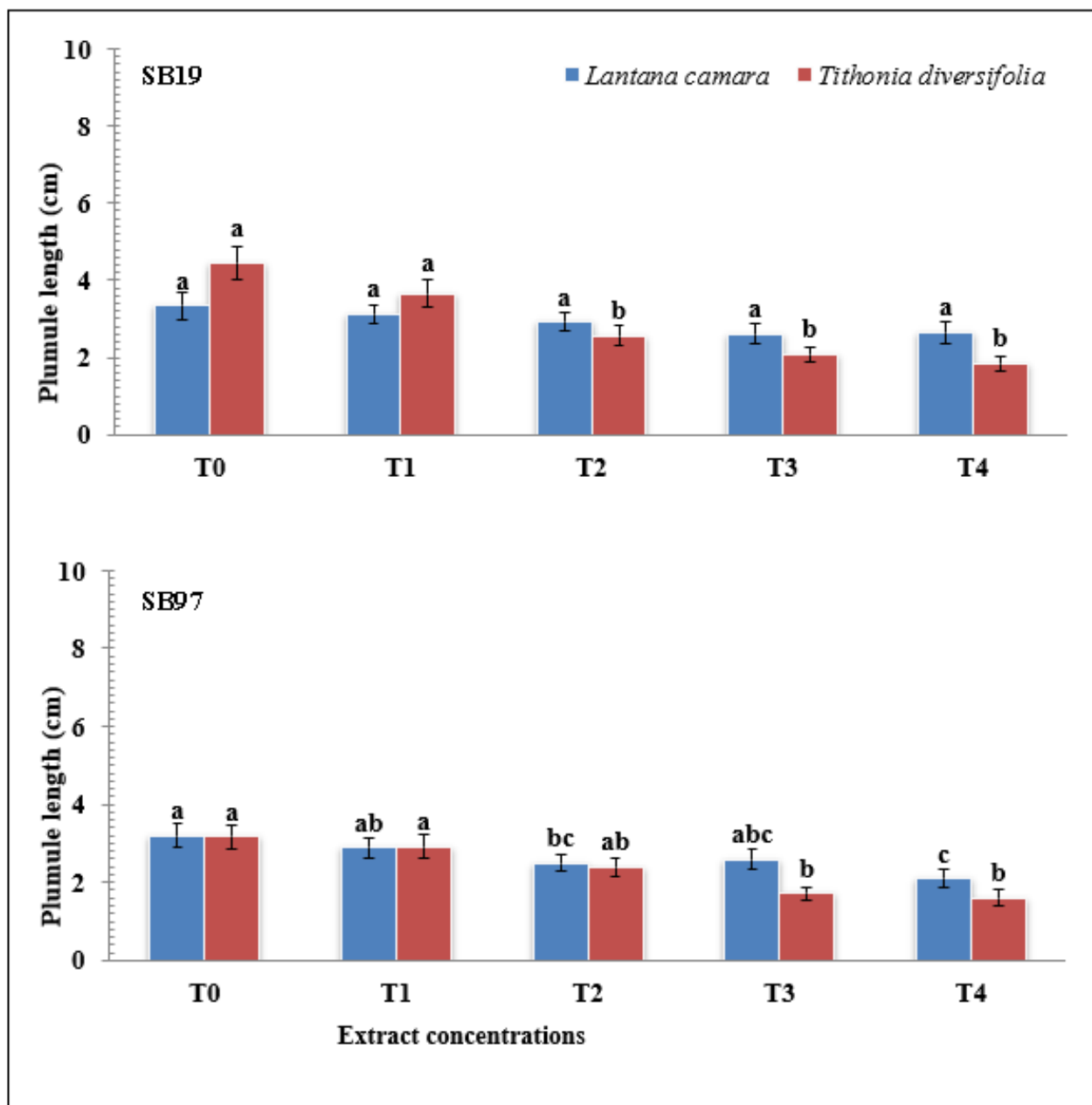


Fig. 2. Total radicle and plumule length in two soy bean varieties subjected to various treatments of % extract concentrations. Values are means of four replicates $\pm$ SEs. Control (T0), 25% extract concentration (T1), 50% extract concentration (T2), and 75% extract concentration (T3) and 100% extract concentration (T4) from both *L. camara* and *T. diversifolia*. Means with the same letter are not significantly different among treatments for variety SB 19 and SB 97.

Allelopathic effects of various amounts of fresh leaf segments of *L. camara* and *T. diversifolia* on shoot height, number of leaves, leaf area, number of pods, plant fresh weight and plant dry weight

Shoot height

Shoot heights were significantly different ($p < 0.05$) under plant extracts from *Lantana camara* and *Tithonia diversifolia*, and between varieties (Table 1). The interaction between varieties and plant extracts from *Lantana camara* and *Tithonia diversifolia* was significant for shoot heights ($p < 0.05$). Fisher's LSD showed that T0 mean of 8.34 was significantly higher than that of T1 (7.59), T2 (6.95), T3 (6.67) and T4 (6.05) respectively (Appendix 6). Similarly, mean of SB 97 (23.84) variety was significantly higher than that of SB19 (20.58).

Number of leaves

Variety SB19 showed that mean for T2, T3 and T4 were respectively significantly lower whenever each was compared to T0 for both *L. camara* and *T. diversifolia* (Table 2). However, variety SB 97 showed mean for T4 to be significantly lower compared to T0 and T1 respectively for both *L. camara* and *T. diversifolia* (Table 4.2.2).

Number of leaves were significantly different ($p < 0.05$) for percentage extracts and *Lantana camara* and *Tithonia diversifolia* extracts (Appendix 5). Fisher's LSD showed that T0 mean of 7.06 was significantly higher than that of T1 (6.19), T2 (4.37), T3 (3.44) and T4 (2.44) respectively. Means for T1, T2, T3 and T4 were significantly higher when comparisons were made between them respectively. *Lantana camara* extract mean 5.33 was significantly higher when compared to extracts mean of *Tithonia diversifolia* (4.08).

Leaf area

Variety SB 97 showed that mean for T1 was significantly higher compared to T0, T2, T3 and T4 respectively for both *L. camara* and *T. diversifolia* (Table 3).

Leaf area was significantly different ($p < 0.05$) for fresh leaf segments from *Lantana camara* and *Tithonia diversifolia* (Appendix 5). The interaction between varieties and plant extracts from *Lantana camara* and *Tithonia diversifolia* was also significant ($p < 0.01$).

Fisher's LSD showed that T1 mean of 58.20 was significantly higher than that of T0 (56.46), T2 (55.07), T3 (53.47) and T4 (51.74), respectively. Means for T1, T2, T3 and T4 were significantly higher when comparisons were made between either two of them, respectively. *Lantana camara* extracts mean of 57.49 was significantly higher when compared to extracts from *Tithonia diversifolia* (52.49).

Table 1. Shoot heights of two soy bean varieties subjected to various amount of fresh leaf segments of *L. camara* and *T. diversifolia*. Values are means of four replicates $\pm$ SEs. Means with the same letter in the column are not significantly different.

Amount of fresh leaf segments (g)	Shoot height					
	<i>Lantana camara</i>			<i>Tithonia diversifolia</i>		
	Varieties		Amount of fresh leaf segments means (g)	Varieties		Amount of fresh leaf segments means (g)
	SB 19	SB 97		SB 19	SB 97	
T0	20.97 $\pm$ 0.21a	23.53 $\pm$ 2.66a	23.25 $\pm$ 1.71a	21.56 $\pm$ 2.36a	22.75 $\pm$ 2.17a	22.16 $\pm$ 1.58a
T1	220.22 $\pm$ 2.1a	28.09 $\pm$ 2.96a	24.16 $\pm$ 1.92a	20.81 $\pm$ 2.64b	20.69 $\pm$ 1.77a	20.75 $\pm$ 1.46a
T2	20.81 $\pm$ 2.29a	26.94 $\pm$ 2.61a	23.88 $\pm$ 1.8a	21.32 $\pm$ 2.45a	22.16 $\pm$ 2.11a	21.73 $\pm$ 1.6a
T3	19 $\pm$ 2.03a	25.28 $\pm$ 2.6a	22.14 $\pm$ 1.72a	21.69 $\pm$ 2.48ab	21.75 $\pm$ 1.95a	21.72 $\pm$ 1.55a
T4	20.94 $\pm$ 2.19a	24.47 $\pm$ 2.61a	22.7 $\pm$ 1.7a	18.44 $\pm$ 0.56a	20.67 $\pm$ 2a	22.16 $\pm$ 1.52a
Means for varieties	20.39 $\pm$ 0.94b	26.06 $\pm$ 1.18a		21.6 $\pm$ 0.88b	8.98 $\pm$ 0.51a	

Control (T0), 4g of fresh leaf segments (T1), 8g of fresh leaf segments (T2), 12g of fresh leaf segments (T3) and 16g of fresh leaf segments (T4) from both *L. camara* and *T. diversifolia*

Table 2. Number of leaves of two soy bean varieties subjected to various amount of fresh leaf segments of *L. camara* and *T. diversifolia*. Values are means of four replicates $\pm$ SEs. Means with the same letter in the column are not significantly different.

Amount of fresh leaf segments (g)	Number of leaves					
	<i>Lantana camara</i>			<i>Tithonia diversifolia</i>		
	Varities SB 19	SB 97	Amount of fresh leaf segments means in (g)	Varities SB 19	SB 97	Amount of fresh leaf segments means in (g)
T0	7.5 $\pm$ 0.65a	6.75 $\pm$ 1.38a	7.13 $\pm$ 0.72a	8.5 $\pm$ 0.25a	5.75 $\pm$ 1.31a	7 $\pm$ 0.78a
T1	7 $\pm$ 0.91a	7.75 $\pm$ 1.03a	7.38 $\pm$ 1.05a	4.5 $\pm$ 1.5b	5.5 $\pm$ 0.5a	5 $\pm$ 0.76ab
T2	4.5 $\pm$ 0.63b	6.75 $\pm$ 0.48a	5.63 $\pm$ 0.56a	2.25 $\pm$ 0.47b	4 $\pm$ 1.35ab	3.13 $\pm$ 0.74bc
T3	4.25 $\pm$ 1.11b	2.5 $\pm$ 1.44b	3.75 $\pm$ 0.91b	2.5 $\pm$ 1.5bc	4.5 $\pm$ 0.65a	3.5 $\pm$ 0.85bc
T4	3.25 $\pm$ 0.48b	3 $\pm$ 0.71b	3.13 $\pm$ 0.4b	1 $\pm$ 0.71c	2.5 $\pm$ 0.63b	1.75 $\pm$ 0.53c
Means for varieties	2.2 $\pm$ 0.49a	5.35 $\pm$ 0.65a		3.7 $\pm$ 0.711a	4.45 $\pm$ 0.47a	

Control (T0), 4g of fresh leaf segments (T1), 8g of fresh leaf segments (T2), 12g of fresh leaf segments (T3) and 16g of fresh leaf segments (T4) from both *L. camara* and *T. diversifolia*

Table 3. Leaf area of two soy bean varieties amount of fresh leaf segments from *L. camara* and *T. diversifolia*. Values are means of four replicates $\pm$ SEs. Means with the same letter in the column are not significantly different.

Amount of fresh leaf segments in (g)	Leaf area					
	<i>Lantana camara</i>			<i>Tithonia diversifolia</i>		
	Varities SB 19	SB 97	Amount of fresh leaf segment means in (g)	Varities SB 19	SB 97	Amount of fresh leaf segment means in (g)
T0	63.06 $\pm$ 5.19a	54.72 $\pm$ 3.59ab	63.4 $\pm$ 3.87ab	51.75 $\pm$ 1.36a	56.3 $\pm$ 2.58ab	52.8 $\pm$ 3.21a
T1	68 $\pm$ 5.48a	59.2 $\pm$ 5.38a	58.89 $\pm$ 3.2a	45.77 $\pm$ 2.84a	59.48 $\pm$ 5.11a	52.4 $\pm$ 1.52a
T2	62.64 $\pm$ 4.22a	52.82 $\pm$ 4.72ab	55.04 $\pm$ 2.57ab	51.13 $\pm$ 2.42a	53.68 $\pm$ 1.87ab	52.4 $\pm$ 1.5a
T3	60.47 $\pm$ 3.27a	49.62 $\pm$ 3.39ab	55.04 $\pm$ 2.67ab	50.75 $\pm$ 2.63a	53.06 $\pm$ 2.66ab	51.9 $\pm$ 1.85a
T4	57.87 $\pm$ 4.86a	46.48 $\pm$ 4.52b	52.18 $\pm$ 3.46b	52.7 $\pm$ 3.03a	49.88 $\pm$ 6.38b	51.29 $\pm$ 1.73a
Means for varieties	62.41 $\pm$ 2.06a	52.67 $\pm$ 1.98b		50.42 $\pm$ 1.13b	54.55 $\pm$ 1.39a	

Control (T0), 4g of fresh leaf segments (T1), 8g of fresh leaf segments (T2), 12g of fresh leaf segments (T3) and 16g of fresh leaf segments (T4) from both *L. camara* and *T. diversifolia*

Number of pods

Variety SB19 showed that means for T4 and T2 were significantly higher whenever each was compared to T0, T1 and T3 respectively, for *T. diversifolia* while for SB97 mean was significantly higher for T1 compared to T0, T2, T3 and T4 respectively, for *L. camara* (Table 4).

The number of pods differed significantly under varying amounts of green leaf segments of each plant type ($p < 0.05$). Number of pods were significant ($p < 0.01$) for varieties and for the interaction between varieties and fresh leaf segments from *lantana camara* and *tithonia diversifolia*. Similarly, there was a significant interaction between the amount of leaf segments and plant type on the number of pods ($p < 0.05$).

Fisher's LSD showed that T3 (19.19) mean was significantly higher than that of T4 (17.81), T2 (17.56), T1 (16.88) and T0 (16.00) respectively. Means for T4, T2 and T1 were significantly higher when comparisons were made to T0 respectively. *Tithonia diversifolia* (18.10) type of fresh leaf segments means were significantly higher when compared to type of fresh leaf segments from *Lantana camara* (16.88). Similarly, mean of SB 19 (19.90) variety was significantly higher than that of SB 97 (15.08) as in Table 4.2.4.

Plant fresh weights

Variety SB19 showed that mean for T4 was significantly lower compared to T1, T2, T3 and T0 respectively for *L. camara* while the data for SB 97 showed mean for T1 to be significantly higher compared to T0, T3, T4 and T2 respectively for *T. diversifolia* (Table 5).

The plant fresh weight were significantly different under varying amount of fresh leaf segments of each plant type ($p < 0.05$). Plant fresh weights were significantly different ($p < 0.05$) for type of fresh leaf segments from *Lantana camara* and *Tithonia diversifolia*. The interaction between the amount of leaf segments and plant type significantly influenced fresh weight ($p < 0.05$). The interaction among ($p < 0.01$) varieties, type of fresh leaf segments from *Lantana camara* and *Tithonia diversifolia* and amount of fresh leaf segments was significant.

Table 4. Number of pods of two soy bean varieties subjected to various amount of fresh leaf segments of *L. camara* and *T. diversifolia*. Values are means of four replicates $\pm$ SEs. Means with the same letter in the column are not significantly different.

Amount of fresh leaf segments in (g)	Number of pods					
	<i>Lantana camara</i>			<i>Tithonia diversifolia</i>		
	SB 19	SB 97	Amount of fresh leaf segment means in (g)	SB 19	SB 97	Amount of fresh leaf segment means in (g)
T0	17.25 $\pm$ 1.38b	12.40 $\pm$ 0.67c	14.62 $\pm$ 1.05c	20.54 $\pm$ 0.63b	14.25 $\pm$ 1.65a	17.39 $\pm$ 1.44ab
T1	16.75 $\pm$ 1.6b	19.25 $\pm$ 2.5a	18 $\pm$ 1.45ab	19 $\pm$ 1.38b	12 $\pm$ 1.26a	15.75 $\pm$ 1.54b
T2	15.54 $\pm$ 1.71b	16.75 $\pm$ 0.85ab	16.13 $\pm$ 0.91bc	24 $\pm$ 1.08a	14 $\pm$ 2.16a	19 $\pm$ 2.2a
T3	12.75 $\pm$ 1.93a	17 $\pm$ 1.29ab	19.38 $\pm$ 1.4a	22 $\pm$ 0.91ab	16 $\pm$ 1.47a	19 $\pm$ 1.39a
T4	18.25 $\pm$ 0.63ab	14.25 $\pm$ 0.75bc	16.25 $\pm$ 0.88bc	24 $\pm$ 0.91a	14.75 $\pm$ 1.11a	19.38 $\pm$ 1.87a
Means for varieties	17.9 $\pm$ 0.74a	15.85 $\pm$ 0.79b		21.9 $\pm$ 0.62a	14.3 $\pm$ 0.68b	

Control (T0), 4g of fresh leaf segments (T1), 8g of fresh leaf segments (T2), and 12g of fresh leaf segments (T3) and 16g of fresh leaf segments (T4) from both *L. camara* and *T. diversifolia*

Table 5. Fresh weight of two soy bean varieties subjected to various amount of fresh leaf segments from *L. camara* and *T. diversifolia*. Values are means of four replicates±SEs. Means with the same letter in the column are not significantly different.

Amount of fresh leaf segments in (g)	Fresh weight			
	<i>Lantana camara</i>		<i>Tithonia diversifolia</i>	
	Amount of fresh leaf segments means in (g)	Amount of fresh leaf segments means in (g)	Amount of fresh leaf segments means in (g)	Amount of fresh leaf segments means in (g)
T0	8.61±0.44b	9.78±0.68ab	11.76±1.19a	10.65±0.94a
T1	11.08±0.22a	10.94±1.06a	12.33±0.91a	10.61±1.12a
T2	8.86±0.71b	11.77±0.98a	12.14±0.55a	9.91±0.91a
T3	8.45±0.8b	9.51±0.98a	11.39±0.44a	10.41±0.6a
T4	6.08±0.67c	11.63±0.53a	11.9±0.61a	10.66±0.51a
Means for varieties	8.61±0.44b	11.1±0.42a	11.91±0.32a	9.38±0.54b

Control (T0), 4g of fresh leaf segments (T1), 8g of fresh leaf segments (T2), and 12g of fresh leaf segments (T3) and 16g of fresh leaf segments (T4) from both *L. camara* and *T. diversifolia*

Plant dry weights

Variety SB19 showed that mean for T3 and T4 were significantly lower compared to T1, and T2 respectively for *L. camara* (Table 6). Hence plant dry weight differed significantly under varying amount of green leaf segments of each plant type ($p<0.05$). The interaction between the amount of fresh leaf segments and plant type significantly influenced plant dry weight.

Plant dry weights were significantly different ($p<0.05$) for amount of fresh leaf segments from both *Lantana camara* and *Tithonia diversifolia*, varieties, and for the interactions between amount of fresh leaf segments and varieties. Similarly there was a significant interaction between the amount of fresh leaf segments varieties and plant type on the plant dry weight ($p<0.01$).

Fisher's LSD showed that mean of dry weights for T1 (10.50) was significantly higher than that of T3 (9.79), T2 (9.01), T0 (8.37) and T4 (7.72), respectively. Means for T1, T2, T3 and T4 were significantly higher when comparisons were made between respectively. Similarly, mean of SB 97 (9.67) variety was significantly higher than that of SB19 (8.49).

Table 6. Plant dry weight of two soybean varieties subjected to various amount of fresh leaf segments from *L. camara* and *T. diversifolia*. Values are means of four replicates $\pm$ SE. Means with the same letter in the column are not significantly different

Amount of fresh leaf segments in (g)	Dryweight			
	<i>Lantana camara</i>		<i>Tithonia diversifolia</i>	
	Varieties SB 19	SB 97	Varieties SB 19	SB 97
T0	7.15 $\pm$ 0.72ab	11.03 $\pm$ 0.67a	9.09 $\pm$ 0.86a	8.48 $\pm$ 1.38a
T1	8.08 $\pm$ 0.72a	10.94 $\pm$ 0.97a	9.38 $\pm$ 0.44a	13.08 $\pm$ 2.19a
T2	8.82 $\pm$ 0.43a	9.94 $\pm$ 0.71a	9.38 $\pm$ 0.44a	10.42 $\pm$ 1.13a
T3	7.81 $\pm$ 0.63ab	0.95 $\pm$ 0.59a	9.38 $\pm$ 0.71a	9.66 $\pm$ 1.04a
T4	6.08 $\pm$ 0.71b	8.91 $\pm$ 0.77a	7.5 $\pm$ 0.72b	6.96 $\pm$ 0.56a
Means for varieties	7.59 $\pm$ 0.34b	10.36 $\pm$ 0.35a	9.39 $\pm$ 0.73a	9.98 $\pm$ 0.51a

Control (T0), 4g of fresh leaf segments (T1), 8g of fresh leaf segments (T2), and 12g of fresh leaf segments (T3) and 16g of fresh leaf segments (T4) from both *L. camara* and *T. diversifolia*

DISCUSSIONS

Allelopathic effects of *Lantana camara* and *Tithonia diversifolia* leaf extracts on on seeds that germinated daily and plumule length of SB 19 and SB 97 soybean varieties

Leaf extracts of *Lantana camara* and *Tithonia diversifolia* were found to inhibit the germination of the two soybean varieties (Fig. 1 & 2). Seed germination is a crucial stage, particularly in stressful conditions, as it initiates essential biochemical changes that lay the foundation for subsequent growth and development (Wanjukia *et al.*, 2021; Matheri *et al.*, 2023). The inhibition of crop seed germination may be attributed to disruptions in the activities of enzymes like peroxidase, alpha-amylase, and acid phosphatases (Musyimi *et al.*, 2017). *Lantana camara* and *Tithonia diversifolia* plant extracts may contain bioactive compounds that inhibit germination by delaying seed dormancy, retarding root and shoot growth, and limiting nutrients to young seedlings (Musyimi *et al.*, 2017). *Lantana Camara* leaf extracts indicated a stronger allelopathic activity as compared to *Tithonia diversifolia* on soy bean germination (Fig. 1). These results agree with those reported by Ahmed *et al.* (2007) and Bansal (1998). The researchers found *Lantana camara* plant extracts to have inhibited seed germination, emergence and development of chickpea and rice. Significant differences were observed for seeds that emerged i.e., a higher one was found for SB 97 when it was compared to SB 19 (Fig. 1) and also higher for *diversifolia* when compared to *Lantana*. The two comparisons indicate that *T. diversifolia* leaf extracts are desirable in enhancing SB 97 germination (Fig. 1). General implication was that leaf extracts inhibited significantly germination of soybean varieties and may be attributed to action by some allelochemicals that are involved in cell division (Kato-Noguchi, 2020). This is in agreement with the study by Kato-Noguchi (2020) and Oyerinde *et al.*, (2009) who showed that aqueous shoot extracts of *T. diversifolia* extracts suppressed the growth of radicles and plumules of maize (*Zea mays* L.) seedlings. Similarly in Alves *et al.* (2011) the extract was found to inhibit germination in lettuce (*Lactuca sativa* L.) and *Pidens pilosa* (L.)

The radicle and plumule lengths of soybean varieties were both slightly inhibited as the concentration of plant extract increased (Fig. 2). Radicle and plumule lengths of SB19 variety was significantly higher than those of SB 97 (Fig. 2). Results indicate that *Lantana camara* did not inhibit growth in SB 19 but instead

showed stimulatory effects compared to *Tithonia diversifolia* with which significant differences were found within treatments. This is in agreement with the studies by Tadele (2014) whose findings indicated that *Lantana camara* leaf extracts had stimulatory effects on early growth of maize and finger millet. On the other hand, leaf extracts of *Tithonia diversifolia* inhibited the radicle and plumule length. The results are in agreements with the findings of Taiwo and Makinde *et al.* (2005) who reported that *Tithonia diversifolia* fresh and dried shoot extracts reduced radical and plumule growth of the germinating *Oryza sativa* L. seedlings. Allelochemicals may have reduced cell division hence reducing plumule and radicle elongation as reported by Kang *et al.* (2018). For instance, inhibition activity of phytochemicals such as p –coumaric, and ferulic acids and volatile constituents of essential oils from plants families such as the *Asteraceae* family where *T. diversifolia* belong are known (Musyimi *et al.*, 2015).

Allelopathic effects of *Lantana camara* and *Tithonia diversifolia* fresh leaf segments on shoot height, number of leaves, leaf area, number of pods, plant fresh weight and plant dry weight of SB 19 and SB 97 soybean varieties

Number of leaf and shoot heights indicates T0 to be significantly higher compared to each of T1, T2, T3 and T4 (Table 1). Similarly, for leaf area, T1 was significantly higher compared to T0, T2, T3 and T4. Significant differences were also found in number of pods (Table 4) and fresh weights (Table 5) within treatments for the SB 19 on *Lantana* extract application and SB 97 under *Tithonia*. These indicates inhibition of growth parameters including shoot height, number of leaves leaf area and yields may be due to the presence of higher amount of volatile chemicals in *Lantana camara* and *Tithonia diversifolia* fresh leaf segments. Water-soluble allelochemicals of *Lantana* have been reported to inhibit early seedling growth of *Oryza sativa*, *Triticum aestivum*, *Vigna sinensis*, *V. mungo*, *V. radiata*, *Cucurbita pepo*, *Abelmoschus esculentus*, *Amaranthus tricolor*, and other crops (Sharma *et al.*, 2005; Hossain and Alam, 2010). Inhibition of nutrient uptake and decreased shoot turgor pressure caused by some phenolic compounds of *Lantana* were reported by Barkosky and Einhellig (2003). These phenolic compounds may have interfered with phosphorylation pathway or inhibited the activation of magnesium ions and ATPase activity. They may also decrease in synthesis of total carbohydrates, proteins and nucleic acids and, interfered with mineral uptake and biosynthetic processes (Hussain *et al.*, 2007). Gebreyohannes *et al.* (2023) reported that allelochemicals have a negative influence on the amount and availability of plant essential nutrients in the soil, hence reducing the plant growth. Therefore the water soluble allelochemicals in leaf segments inhibited shoot length of radish, onion and tomatoes which is in line with the present study. *Tithonia diversifolia* also presented significant inhibition of shoot height, number of leaves, leaf area, fresh and dry weights of the two soybean varieties (Table 5). A similar trend was observed in growth of other test plants (Kato-Noguchi, 2020). Otusanya *et al.* (2007) have demonstrated that aqueous extract and shoot extract of *T. diversifolia* had inhibitory effect on growth of *Amaranthus cruentus*. Although the principle of allelopathy was not investigate in the present study, earlier investigators have suggested that allelochemicals or toxins are released from the weed by the action of micro-organisms during decomposition (Matheri *et al.*, 2023), which may interfere with the plant growth processes (Oyerinde *et al.*, 2009).

The yield represented by number of pods of soybean varieties increased significantly with amount of fresh leaf segments of *Tithonia diversifolia* than control (Table. 4) except at T2. The leaf cuttings decompose and release nutrients which are taken up by soy bean plants.

A similar growth promoting effect on wheat seedlings was reported by Hussain *et al.* (2007), where application of Senna mulching was the allelochemical source. Oyerinde *et al.* (2009), was also of the view that plants species that display allelopathic effects e.g. *T. diversifolia*, have species-selective allelopathic function. These findings were in line with the views of some researchers who suggested that the nutrient-rich green biomass of *Tithonia diversifolia* could effectively provide nutrients for *Zea mays* (Jama *et al.*, 2000; Nziguheba *et al.*, 2002).

It might just indicate that the nutrients have a superior effect as compared to the allelopathic effect. Thus, the allelopathic effects are overcome by nutrient uptake leading to higher growth and productivity. Sangakkara *et al.* (2002) also noted in their study that *T. diversifolia* has the potential to act as a beneficial green manure and organic fertilizer for vegetable crops. This idea is supported by Ilori *et al.* (2007), who demonstrated the stimulatory impact of *T. diversifolia* on the germination and growth of *Oryza sativa*. The viewpoints and findings of these authors likely explain the observed enhancement in growth parameters resulting from the use of leaf segments.

Fresh and dry weights of SB 19 soybean variety evidently were affected differently by the leaf segments of *Lantana camara* showing inhibitory activity but *Tithonia diversifolia* showed stimulatory effect (Table 5 and Fig. 6) for the same variety. Fresh weights of SB19 were significantly reduced with increase in *Lantana camara* amount of fresh leaf segments from T1 to T4 but there was no effect on fresh weights of SB97 with increase in *Lantana camara* amount of fresh leaf segments (Table 5).

In Zanardo *et al.* (2009) reported that p-coumaric acid reduced soybean fresh and dry weights, while Matheri *et al.* (2023) demonstrated that p-coumaric acid significantly reduced total dry weight. SB 19 variety recorded a significantly higher pod number under increasing amount of fresh leaf segments of both *Lantana camara* and *Tithonia diversifolia* amount of fresh leaf segments depicting its ability to assimilate nutrients in presence of a stimulatory effect of the two plant cuttings as compared to SB97 variety.

CONCLUSIONS

Lantana camara and *Tithonia diversifolia* leaf extracts hindered the number of seedlings that germinated daily for soybean varieties, with *Lantana camara* exhibiting stronger allelopathic activity at T4 (100%) compared to *Tithonia diversifolia*. There might have been delayed seed germination due to reduced alpha-amylase enzyme activity which reduced embryo root and shoot development at T4 for *Lantana*.

Extracts of *Lantana camara* inhibited the leaf number of soybean SB19, but *Tithonia diversifolia* exhibited a stimulatory effect at T3 for SB97. Water soluble allelochemicals from *Lantana* on high percentage extract concentration application might therefore have had highly inhibited phosphorylation and ATPase activity which lead to low nutrient uptake and decreased turgor pressure. A phenomenon that was observed also for dry weight of SB 19 at T1 and T2.

Lantana camara and *Tithonia diversifolia* leaf extracts inhibited the germination of Variety SB19 and SB 97 hence the plants are not recommended to be incorporated in farms where these soybean varieties seeds have been sown. *Lantana camara* and *Tithonia diversifolia* leaf extracts inhibited most of the growth parameters of the two soya bean varieties hence not recommended to be incorporated in farming systems where Variety SB19 and SB 97 are growing.

Further research should focus on identifying and understanding the specific allelochemicals present in *Lantana camara* and *Tithonia diversifolia* extracts responsible for inhibiting soybean germination and growth. Further research should focus on conducting field trials to evaluate the impacts of *Lantana camara* and *Tithonia diversifolia* on other varieties of soybeans under different environmental conditions.

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