Allelopathic potentials of extracts of *Tithonia diversifolia* (Hemsley) A. Gray in biological control of weeds in cowpea cropping system

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DECLARATION

I, Ajayi Oyinlola Arike declare that this research was carried out and the thesis was written by me. Any assistance that I have received in the course of my research work and the preparation of the thesis has been acknowledged. In addition, I certify that all information sources and literature are indicated in the thesis.

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DEDICATION

This work is dedicated to the almighty God, the father of my Lord Jesus Christ, my caring and loving husband, Dr. M.A. Ajayi and my wonderful children: Tope, Taiwo, Kehinde and Favour.

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ABSTRACT

The limitations of physical, mechanical and chemical methods of weed control coupled with the global concern about the risks associated with the use of synthetic herbicides in controlling weeds in agroecosystems has necessitated concerted efforts on promoting alternatives to synthetic herbicides. The aim of this research was to carry out field appraisal of the allelopathic potentials of aqueous extracts of *Tithonia diversifolia* (Hemsley) A. Gray in biological control of weeds in cowpea [*Vigna unguiculata* (L.) Walp.] cropping system in order to improve on the measures that have been adopted in biological control of weeds in agroecosystem. The allelochemical constituents of aqueous extracts of *T. diversifolia* were determined by spectrophotometric method while the phenolic compounds were identified and quantified using High Performance Liquid Chromatography (HPLC). The experiments were laid out in a randomized complete block design (RCBD) with plot size of 3 m x 3 m and three replicates. Aqueous extracts from the root, stem and leaf of *T. diversifolia* (10.0%, 7.5% and 5.0% w/v) concentrations were applied at 2, 21 and 35 days after planting (DAP) at the rate of 20 l/ha in the two field trials at the experimental farm located at Owode, Ede, Osun State, Nigeria. For comparison, glyphosate herbicide, hand weeding, sorghum-based bioherbicide (*Sorghum bicolor* L. extract) and weedy plots were maintained as the checks (controls). The allelopathic effects of aqueous extracts from the different parts of *Tithonia* on germination of seeds and seedling growth of cowpea were investigated by collecting data on germination and seedling growth parameters of two accessions (IT 84E-124 and Ife Brown) at seven DAP and four weeks after planting. The weed suppressive effects of aqueous extracts from different parts of *Tithonia* on weeds of cowpea cropping system were assessed from the data collected on weed density at 30 and 65 DAP and weed dry weight at 65 DAP. The allelopathic effects of aqueous extracts from the different parts of *Tithonia* on cowpea yield were evaluated from the data collected on yield parameters which include plant height at six weeks after planting, pods per plants, seeds per pod, 1000-seeds weight and grain yield. The allelochemicals detected in the aqueous extracts of *Tithonia* were phenols, flavonoids, tannins, saponins and alkaloids. The metabolites were more concentrated in *Tithonia* leaf extract than in the stem and root extracts. Results also indicated that aqueous extracts of *Tithonia* did not have significant stimulatory or inhibitory effect ($p = 0.51$) on germination of cowpea seeds. However, the seedling growth was significantly ($p = 0.01$) enhanced. Application of *Tithonia* leaf extract at 10.0% (w/v) concentration led to significant ($p = 0.00$) increase in shoot dry weight 44.70% and 38.67%, in the two accessions respectively. The corresponding increase in root dry weight were 62.90% and 52.30%. The reduction in weed density at 65 DAP obtained with the application of *Tithonia* leaf extract at 10% and 7.5% (w/v) concentrations were 65.49% and 62.05% while the weed control efficiencies (WCE) were 69.92% and 59.26% respectively. In relation to the weedy check (control), maximum cowpea grain yield increases were recorded from the application of *Tithonia* leaf extract at 10.0% and 7.5% (w/v) concentrations with 66.45% and 65.32% increase respectively. The yield recorded with the application of 10.0% w/v and 7.5% w/v *Tithonia* leaf extract at 20 l/ha was significantly ($p = 0.01$) higher than the yield recorded in the handweeded and glyphosate treated plots. This implies that the weeds were controlled effectively beyond the critical period of weed interference in cowpea. Thus, aqueous leaf extract of *T. diversifolia* is recommended for biological control of weeds in cowpea cropping systems.

Key words: Allelochemicals, Bioherbicides, Cowpea, Synthetic herbicides

CHAPTER ONE

1.0 INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Agriculture is a global activity that is associated with the history of man. Agriculture is an indispensable human activity because it is the source of most of the food consumed by man. Due to the global exponential increase in human population and the corresponding food demand, agricultural activities have become highly complex and mechanized, involving ploughing, fertilizer in-put, use of pesticides including insecticides and herbicides, irrigation and many more (Bunch and Lopez, 1999; Sabiiti, 2011). These activities have many negative impacts on the environment such as soil erosion, increase in salinity of soil, depletion of soil organic matter, underground and surface water pollution, and desertification.

Tilman (1999) has identified agriculture as the leading source of environmental pollution. Agriculture and forestry are the second largest source of greenhouse gases in the United Kingdom, accounting for 7% of the United Kingdom total emissions. Agriculture is responsible for 66% of the United Kingdom's nitrous oxides emission and 46% of United Kingdom Methane emission (Bunch and Lopez, 1999). The main source of the nitrous oxides emission globally is agriculture (Mckenzie, 1998). It is estimated that agricultural land degradation is leading to an irreversible decline in fertility on about 6 million of fertile land each year (Sims and Cupples 1999). The United States Environmental Protection Agency (USEPA) reported that agricultural activities are a major cause of wetland degradation and ground water pollution (USEPA, 1994). Numerous reports and studies have also indicated similar concerns in many developed and developing countries (Bunch and Lopez, 1999). Thus, the possibility of feeding the world's ever growing

population in a way that does not compromise the air we breathe, the water we drink and the soil that nourishes us, is a global concern (Warf and Jean, 2002; Bignall and Mckracken, 2004). The ability of a farm to produce food indefinitely without causing irreversible damages to the ecosystem health is of paramount importance.

The global concern about the adverse effects of extensive use of synthetic pesticides in controlling pests in agroecosystem has obliged concerted efforts on promoting alternatives to synthetic pesticides (Pretty and Waibel, 2005; Pretty, 2008). There is widespread evidence that exposure to certain pesticides is significant additional risk factor in many chronic diseases including different forms of cancer, neurodegenerative diseases and disruptions of the digestive system (Gupta, 2004; Kamel and Hoppin, 2004). Various studies among farmers, farm workers and their family showed increase incidences of several types of cancers such as lymphatic and blood system, lip, stomach, prostate, brain, testes and skin cancers (Cernea, 1991; Chambers, 2005). Herbicides account for 42% of global pesticides' use (Bunch and Lopez, 1999). Therefore, recent emphases have been on biological weed control measures so as to reduce dependence on synthetic herbicides and finding alternative strategies for weed control in agroecosystems (Farooq *et al*., 2011). Allelopathy is one of such strategies that can be explored for biological weed control of cropping systems.

There had been studies on the potential of extracts of allelopathic plants in biological weed control in some part of the world, however past studies in Nigeria have been limited to laboratory and non-field experiments. Allelopathy is a phenomenon by which some plants influence the germination, growth and development of neighbouring plants by secreting chemical substances known as allelochemicals. The influence may be inhibitory or stimulatory (Farooq *et al*., 2011). Laboratory and non-field experiments represent a too-

simplified reality and the result obtained cannot be fully applied by local farmers. Moreso, one of the arguments of the earliest critics of the field of allelopathy is lack of adequate field studies as most of the studies reported are based on laboratory and non-field experiments (Singh *et al*., 2001). Farooq *et al*. (2013) also reported that allelopathy application in the field is still lacking practical evidences. Moreover, it is not possible to expect the same effects as allelopathy is a dynamic process that involves more than just donor and target plants (Jabran *et al*., 2008). Variation in the type of soil, water and nutrients availability and climatic conditions are also determinants of the occurrence of effective allelopathic activity. Consequently, past researchers in allelopathy had recommended the possibility of adopting it as a method of weed control that may be environment friendly (Khaliq, 2000; Sisodia and Siddiqui, 2010; Farooq *et al*., 2011; Jafariehya and Javidfar, 2011; Marzieh *et al*., 2013; Awodoyin and Akande, 2014).

Tithonia diversifolia (Hemsley) A. Gray (family: Asteraceae) is a species of flowering plant that originated from Mexico where it spread to other parts of Central and South America (Orwa *et al*., 2009). It is commonly reffered to as Mexican sunflower or wild sunflower. *T. diversifolia* was brought to Africa and Asia as an ornamental plant and has become an invasive weed that is widely spread (Jama *et al*., 2000). Igbo tribe in Nigeria called it anyanwu okokosisi while Yoruba called it ewe iba or jogbo. Its presence in Nigeria soil has impacts on the environment. *T. diversifolia* has the ability to restore phosphorus in higher amount to the soil, and as a fertilizer, it contains 1.76% nitrogen, 0.82% phosphorus and 3.92% potassium (Nzigueba *et al*., 2002; Olabode *et al*., 2007). However, the invasion of the tropical rainforest landscape of Nigeria by *T. diversifolia* is generating a lot of concern in view of its aggressive growth rate, heavy seed production and allelopathic property (Ayeni *et al.*, 1997). As an invasive species, it has encroached into many ecosystems and communities disrupting ecosystem structure and function thus,

reducing native species (Borgmann and Rodewald, 2005). A major reason for its invasiveness is its allelopathic property (Orwa *et al*., 2009). Although, studies have been done on allelopathic property of *T. diversifolia* but its allelopathic property has rarely been explored for biological control of weed in cropping systems. Moreover, information on how this invasive species could be prudently managed is scarce.

Vigna unguiculata (L.) Walp. (cowpea) (Family: Fabaceae) is a staple food and chief source of protein in developing countries including Nigeria. It plays a major role in subsistence farming and livestock fodder, the crop is seen as a major cash crop by Central and West African farmers, with an estimated 200 million people consuming cowpea on a daily basis in Africa (Lagyintuo *et al*., 2003). The average cowpea yield in Africa was estimated at 417 kg/ha which is below the potential yield (Dzeme, 2010). A major cause for the observed low yield is weed infestation (Ajeigbe *et al*., 2005; Ajeigbe *et al*., 2010). Cowpea is being cultivated in some parts of Osun State including Iwo, Erin Ijesa, Ede and its environs (Sofoluwe and Kareem, 2011).

1.2 STATEMENT OF THE PROBLEM

Cowpea is a multipurpose crop grown for its edible grain and leaves and may be used as nitrogen source for agroecosystem soil. In spite of its multipurpose quality, cowpea is reported to have a low yield in Africa including Nigeria due to weed infestation and other constraints (Dugje *et al*., 2009; Ajeigbe *et al*., 2010; Dzeme, 2010). Meanwhile, the synthetic herbicides that are commonly used to control weeds of cowpea have many adverse effects such as crop injury, damage to other organisms, environmental contaminations, health issues and resistance by weeds (Milberg and Hallgren, 2004; Jabran *et al*., 2008; Farooq *et al*., 2011).

The search for natural weed control methods is emphasized worldwide; allelopathy had been recognized nowadays as a natural weed control approach (Rice, 1984; Ferguson and Rathinasabapathi, 2009). Allelopathy as a method of weed control could reduce the labour and increase efficiency (Khaliq, 2000; Farooq *et al*., 2008; Farooq *et al*., 2011; Bano *et al*., 2012). The use of allelopathic plants in weed control is to provide an alternative strategy for weed control in order to reduce dependence on synthetic herbicides and their detrimental effect on the environment and human health (Weston, 1996; Mattice *et al*., 2001; Asghari and Tewari, 2007). However, most studies on the use of allelopathic plant extracts in biological control of weeds have been limited to laboratory and non-field experiments (Singh *et al*., 2001). Laboratory and non-field experiments represent a simple fact and the result obtained cannot be fully applied by local farmers. Moreover, it is not possible to expect the same effects as allelopathy is a dynamic process that involves more than just donor and target plants; hence there is need for research that is purely field work which can be easily adopted by local farmers (Vivanco *et al*., 2004; Jabran *et al*., 2008; Kafashzadeh *et al*. 2010; Khan *et al*., 2013).

An invasive species like *T. diversifolia* is widely spread in Nigeria and it had been shown to have allelopathic property (Ayeni *et al*., 1997, Adebowale and Olorode, 2005). Though, some studies had been carried out on the allelopathic property of *T. diversifolia*, the past studies were laboratotry and green house investigations. Findings from such studies need to be substantiated with purely field work in the cropping system.

1.3 AIM AND OBJECTIVES

1.3.1 Aim

The aim of the research was to carry out field appraisal of allelopathic potentials of aqueous extracts of *T. diversifolia* in biological control of weeds in cowpea cropping system.

1.3.2 Objectives of the research

The objectives of the research were to:

- determine the allelochemical constituents of the aqueous extracts from the different parts of *T. diversifolia*
- identify and quantify some of the phenolic compounds in the different parts of *T. diversifolia*
- investigate the allelopathic effects of the aqueous extracts from the different parts of *T. diversifolia* on germination and seedling growth of cowpea.
- assess the weed suppressive effects of the aqueous extracts from the different parts of *T. diversifolia* on weeds of cowpea cropping system.
- evaluate the allelopathic effects of the aqueous extracts from the different parts of *T. diversifolia* on yield of cowpea.

1.4 SIGNIFICANCE OF THE STUDY

The study will advance knowledge on how the extracts from the different parts of *T. diversifolia* can work as bioherbicides. The use of the extracts from this plant will reduce dependence on synthetic herbicides which hitherto are found not to be totally safe when they are continuously used for weed control in agroecosystems. This will promote a safer control of weeds in agroecosystems. Researchers, farmers and as many that are concerned

with food security and environmental protection would benefit from the findings of the study.

1.5 OPERATIONAL DEFINITIONS OF TERMS

Agroecosystem: An ecosystem that is managed for the production of crops.

Allelochemicals: These refer to chemical substances produced by a plant in order to defend it against herbivores or competing plants.

Allelopathy: This is a phenomenon by which some plants influence the germination, growth and development of neighbouring plants by secreting chemical substances known as allelochemicals. The influence may be inhibitory or stimulatory.

Biofertilizers: These are growth promoting substances that are produced or got from living organisms.

Bioherbicides: These refer to herbicides that are produced from living organisms.

Crop residues: These are the thrash or leftovers from agricultural products such as maize stover, sorghum stalks, corn cobs, wheat and rice straw.

Experimental farm: A piece of land set aside for cultivation of cowpea in the two field experiments.

Invasive species: These refer to plants that are not native to a specific location and which have the tendency to spread to a degree that can threaten natural ecosystems and/or rangeland over wide geographical area.

Multifaceted: This refers to many sided approach in solving a problem.

Plant extract: This refers to the collection of crude mixtures obtained from different parts of plants.

Synthetic herbicides: These refer to synthetic / artificial organic and inorganic chemicals used in weed control.

Weeds: Weeds are plants that negatively affect crop production by competing with crops for limited resources in agroecosystem.

1.6 LIST OF ABBREVIATIONS AND ACRONYMS

DAP: Days After Planting.

FIIRO: Federal Institute of Indusrial Research, Oshodi.

GLY: Glyphosate herbicide

GY: Grain Yield

HPLC: High Performance Liquid Chromatography

HW: Hand weeding

JSE: *Jatropha* Shoot Extract

LPP: Leaves per Plant

PH: Plant Height

PPP: Pods per Plant

RDW: Root Dry Weightt

SE: *Sorghum* Extract

SPP: Seeds per Pod

TE: *Tithonia* Extract

TLE: *Tithonia* Leaf Extract

TRE: *Tithonia* Root Extract

TSE: *Tithonia* Stem Extract

USEPA: United State Environmental Protection Agency

WAP: Weeks after planting

WC: Weedy check

WCE: Weed Control Efficiency

WD: Weed Density

WDW: Weed Dry Weight

w/v: weight to volume

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 CONCEPT OF WEEDS

Weeds are generally defined as those plants that negatively affect the various interest of human principally crop production. A weed is any plant, native or non-native, that interferes with crop by competing with crops for limited resources in agroecosystems and has the habit of encroaching where it is not wanted (Das, 2011; Awodoyin and Akande, 2014). Weeds are the most costly category of agroecosystem pests in terms of yield reduction, labour demand and cost. Yield losses of 35-75% and 70-100% have been recorded in lowland and upland agroecosystems as a result of weed interference (Farooq *et al.*, 2008). Weeds increase production cost through the cost of controlling them and the insects and diseases they harbour. They also reduce crop quality through contamination (Benson, 1982; Jabran *et al*., 2008; Farooq *et al*., 2011).

2.1.1 General characteristics of weeds

Weeds are also like other plants but have special characteristics that tend to put them in the categories of unwanted plants.Weeds have some features in common: they produce large numbers of seeds and can germinate under variety of conditions. Weeds develop rapidly and are able to self-pollinate, disperse widely and tolerate wide range of environmental conditions (Akobundu, 1987; Frick and Johnson, 2012). Weeds are often excellent at surviving and reproducing in disturbed environment and are often the first species to colonize and dominate in these conditions. Weeds may grow faster than crops and successfully compete for available nutrients, water, space and sunlight (Akobundu and Agwakwa, 1998; Milberg and Hallgren, 2004; Hamma and Ibrahim, 2013).

Weeds are capable of rapid development from the seedling stage to the flowering stage. Weeds produce large quantities of seeds within this brief period of time (Schonbeck, 2013). In addition to seed production, they are capable of vegetative reproductions which ascertain continuation of the species even without seed dispersal. Weeds also have long-lived viable seeds within the seed bank (Kelton and Price, 2008).

The success of weeds is based on most of their features. Annual weeds produce enormous quantity of seeds, e.g. wild oats (*Avena fatua*) produces 250 seeds per plant, whereas wild amaranth (*Amaranthus viridis*) produces nearly 11 million seeds per plant. Kelton and Price (2008) observed that the average seed production in perennial weeds was 26,500 per plant. Weeds have the capacity to withstand adverse conditions in the field, because they can modify their seed production and growth according to the availability of moisture and temperature. Weeds can also germinate under adverse soil moisture conditions and they produce seeds earlier than most of the cultivated crops (Akobundu, 1987 and Akobundu and Agyakwa, 1998).

Weed seeds remain viable for longer period without losing their viability, e.g. annual meadow grass (*Poa annua*) and scarlet pimpernel (*Anagallis arvensis*) remain viable for about eight years; creeping thistle (*Cirsium arvense*) for 20 years and field bind weed (*Convolvulus arvensis*) for about 50 years (Akobundu, 1987). Weed seeds have a tremendous capacity to disperse from one place to another through wind, water and animals including man. Many times, weed seeds mimic the crop seeds due to their size and get transported from one place to another along with them (Hoffman *et al*., 1998; Kelton and Price, 2008).

2.1.2 Classification of weeds

There are many ways weeds can be classified into groups for convenience of planning, interpreting and recording control measures against them. Weeds can be classified based on their life cycle; habitat, mode of living / growth habit; morphology / life style / crop-weed interaction and climate (Akobundu, 1987).

i Classification of weeds based on life cycle

Based on life cycle, weeds can be classified into:

Ephemerals: These are weeds that grow for a short time but may produce two or more life cycle within a growing season, e.g. *Euphorbia* spp.

Annuals: These are weeds that complete one life cycle in one or two growing season within a year, e.g. *Agerantum conyzoides, Tridax procumbens* and *Digitaria* sp. They produce large quantity of seeds and large populations; have efficient mechanisms of seed dispersal and exhibit seed dormancy.

Biennial weeds: These are weeds that complete one life cycle in two years: in the first year they produce an extensive root system and a cluster of leaves or rosette while in the second year, they produce flower, set seeds, mature and die, e.g. *Daucus carota* (wild carrot) and *Lunea* sp.

Perennial weeds: These are weeds that grow year-in-year-out regardless of seed production in the previous season, and propagate and survive using perenating organs, such as stolons (*Cynodon dactylon*), tubers (*Cyperus* spp), bulbs (*Oxalis latifolia*) and leaf cuttings (*Bryophyllum* sp.) (Akobundu 1987).

ii Classification of weeds based on habitat

Based on where the weeds are found, they are grouped into:

Terrestrial weeds: These are weeds that are free-living on land where crops are cultivated (cropland) or not (non cropland) e.g. *Echinochloa* sp, *A. conyzoides, C. odorata, Talinum. triagulare* and *T. procumbens* (Akobundu, 1987).

Aquatic weeds: These are weeds that live, propagate and survive inside (submerged, e.g *Eloidea* spp.), within (emergent, e.g *Nymphaea* spp., *Cyperus difformis*), or on (e.g. *Eichhornia crassipers, Oryza longistaminata, Paspalum orbiculare and Ipomea* sp.) water bodies (Akobundu, 1987).

iii Classification of weeds based on mode of living

Weeds are classified into:

Free living / autotrophic weeds: These are weeds that live independently and manufacture their own food through photosynthesis, e.g *A. conyzoides, T. procumbens, C. odorata* and *T. triangulare*.

Parasitic weeds: These are weeds that grow on living tissues of other plants (hosts) from which they derive all (total parasites) or part (hemi-parasite) of their food, water and mineral nutrients requirements, e.g. S*triga* spp., *Orobanche crenata* and C*uscuta australis,* (Akobundu and Agyakwa, 1998).

iv Classification based on morphology

Weeds are classified into:

Narrow-leaf weeds: These are weeds that have narrow leaves with parallel venation. They are monocotyledonous weeds. Most grass weeds belong to this group, e.g. *Cynodon dactylon, Panicum maximum*, etc. Sedge weeds are also narrow-leaved, e.g *Cyperus* spp.and *Mariscus* spp.

Broadleaf weeds: These are weeds with broad leaves and are characterized by net venation.They are dicotyledonous weeds, e.g. *C. odorata, A. conyzoides* and spiderworts such as *Commelina* spp. (Akobundu, 1987).

v Classification based on climate

Weeds are classified based on the influences of rainfall (mainly), temperature, light, relative humidity and air quality:

Tropical weeds: These are weeds that grow well in tropical climates (Akobundu, 1987; Akobundu and Agyakwa, 1998).

Temperate weeds: These are weeds that grow well in temperate climate.

Subtropical weeds: These are weeds that grow well in subtropical climate.

2.2 WEEDS AND CROPS

Weeds are plants that negatively affect crop plants by competing with them for limited resources in the agroecosystem. Weeds have a controversial nature. To the agriculturists, they are plants that need to be controlled in an economical and practical way, in order to produce food, forage, and fibre for humans and animals (Schonbeck, 2013). In this context, the negative impact of weeds is directly affecting all living beings. Weeds reduce farm and forest productivity, invade crops, smother pastures and some can harm livestock. Weeds aggressively compete for water, nutrients and sunlight, resulting in reduced crop yield and poor crop quality (Haney, *et al*., 2000; Milberg and Hallgren, 2004; Hamma and Ibrahim, 2013). For example, prickle bushes such as gorse, blackberries, prickly acacia, parkinsonia and mesquite can invade vast areas of grazing land preventing the productive use of that land (Liebman and Gallandt, 1997).

Weeds most commonly retard crop growth by competing directly for resources. Weed-crop competition can be likened to a race, the outcome of which can range from essentially no impact on crop yield (when weed growth is minimal compared to that of the crop) to complete crop loss (the weeds overwhelm the crop) (Chikoye and Ekeleme, 2001; Usman, 2013). The factors that determine the competitive balance include weed density,

planting pattern and density of crop, growth rate, mature height of weed and crop plants and relative times of emergence of weed and crop (Liebman and Gallandt, 1997; Mohler, 2001). Weeds that emerge before the crop have the most severe impact on crops, while weeds that emerge with or shortly after the crop can substantially reduce yield unless controlled. However, additional weeds that emerge after cultivation, may still affect the crop through competition unless they are removed. However, the later the weeds emerge relative to the crop, the less their impact becomes (Liebman and Gallandt, 1997). The severity of weed competition with crops is related to weed density, timing of weed emergence relative to the crop and proportion of resources (light, water nutrients) consumed by weeds (Rao, 1982; Johnson, 1995; Schonbeck, 2013).

Weeds have serious impacts on agricultural production. Weeds are the most costly of agricultural pests (Milberg and Hallgren, 2004; Chikoye *et al*., 2005). Worldwide, weeds cause more yield loss and add more to farmers' production costs than insect pests, crop pathogens, root-feeding nematode or warm-blooded rodents (Akobundu and Agyakwa, 1998; Hamma and Ibrahim, 2013; Schonbeck, 2013). Weeds are very important in agroecosystem because they lower crop yields to as high as 50% (Akobundu, 1987). In some cases, crop yield losses may be as high as 100% under heavy weed infestation of some crops such as rice, millet and cowpea (Kolo and Daniya, 2006).

Research studies have demonstrated that there was up to 80% yield loss in okra as a result of weed infestation (Aladesanwa and Adejobi, 2007). Lado *et al*. (2008) reported that weeds reduce onion bulbs, heads in lettuce and cabbage, and fruit size in apple. Weeds also convey pests from season to season while some weeds have shown allelopathic effects on some crops. *Centrosema* sp. has allelopathic effect on banana and plantain in Nigeria (Okezie, 2000). It is estimated that in general, weeds cause 5% loss in agricultural

production in most developed countries, 10% loss in less developed countries and 25% loss in least developed countries (Akobundu, 1987). In India, crop yield losses due to weeds are more than those from pests and diseases (Sangakkara, 1999; Martin *et al*., 2001). Yield losses due to weeds vary with the crops, however, every crop is exposed to severe competition from weeds (Reeves, 2006). Most of these weeds exhibit spontaneous growth and they provide competition caused by their faster rate of growth in the initial stages of crop growth (Wall and Smith, 2000). In some crops, the yields are reduced by more than 50% due to weed infestation (Milberg and Hallgren, 2004).

Weeds may as well host pests and disease causing micro-organisms (Rao, 2000). Madukwe *et al*. (2012) reported that the presence of weeds affected the performance of cowpea in terms of plant height, leaf production and yield components. Ofuya (1989) reported that weed infestation increases the colonization of cowpea by *Aphis craccivora* and its major predators in Nigeria.

Weeds have been observed to interfere with farm operations like fertilizer application and harvesting making farmers'movement difficult. In crops like potatoes with underground structures, these result in losses of tubers which are unharvestable (Hamma and Ibrahim, 2013). Weeds have also been shown to block waterways and impede navigation. Some weeds block drainage pipes and make irrigation difficult especially during dry-season farming (Das, 2011; Hamma and Ibrahim, 2013).

2.3 EFFECTS OF WEEDS ON THE ECOSYSTEM

Weeds are evidence of nature struggling to bring about ecological succession. Modern agroecosystem is typified by large acreages of a single plant type accompanied by a high percentage of bare ground (Schonbeck, 2013). Weeds are so prevalent in many areas of landscape. Weeds are a serious threat to primary production and biodiversity as they

displace native species and contribute significantly to land and water degradation. The costs of weeds to the natural environment are also high, with weed invasion being ranked second only to habitat loss in causing biodiversity decline (Holm *et al*., 1997; Verma *et al*., 1999; Liebman *et al*., 2001).

Despite considerable government and private sector investment, weed invasion still represents a major threat to both the productive capacity of land and water as well as the integrity of our natural ecosystems. However, weeds as primary producers are nature ways of covering soil that has become exposed by fire, flood, landslide, clear cutting, clean tillage or other disturbances. The exposed soil surface is at risk of erosion by rain or wind, especially if root systems have also been removed or disrupted (Liebman and Gallandt, 1997). Weeds are often the pioneer plants and can rapidly cover bare soil and begin performing one or more of the vital ecological functions. Weeds protect the soil from erosion and replenish organic matter and restore soil life. They also absorb, conserve and recycle soluble materials that would otherwise leach away. They also absorb carbon dioxide from the atmosphere. They restore biodiversities and provide habitat for insects and animals (Schonbeck, 2013).

2.4 CONVENTIONAL METHODS OF WEED CONTROL

Weed control is an important component of plant protection and improving the production potential of crops. It includes control of weeds in a way that the crop sustains its production potential without being harmed by the weeds. Weed control is done through the mechanical, cultural and chemical methods (Akobundu, 1987; Akobundu and Agyakwa 1998; Hamma and Ibrahim, 2013). However, the use of biological control methods in field crops is being considered, but still not much in use. The use of herbicides is an important method in the modern concept of weed control (Chikoye *et al*., 2005). New

hand tools and implements have also been designed to assist in weed control. Weed control in crop production involves a wide range of techniques. There are five major techniques used in conventional weed control: these are preventive, cultural, mechanical, physical and chemical techniques (Hamma and Ibrahim, 2013).

i Preventive technique of weed control

Preventive weed control technique refers to any control method that aims to prevent weeds from being established in a cultivated crop, a pasture, or a greenhouse. Examples of preventive weed control are cultivating certified weed free seed, only transporting hay that is weed free; making sure farm equipment is cleaned before moving from one location to another and screening irrigation water to prevent weed seeds from traveling along irrigation ditches (Peruzzi *et al*., 2007; Schonbeck, 2013). Also, aborting seed formation in weeds to reduce spread, is a preventive weed control (Kasasian, 1971).

ii Cultural method of weed control

Cultural method of weed control refers to any technique that involves maintaining field conditions such that weeds are less likely to become established and/or increase in number. Examples of cultural weed control are crop rotation, avoiding overgrazing of pastures or rangeland, using well-adapted competitive forage species, and maintaining good soil fertility (Peruzzi *et al*., 2007; Schonbeck, 2013).

iii Mechanical technique of weed control

Mechanical weed control refers to any technique that involves the use of farm equipment to control weeds. The mechanical control techniques most often used are tillage, mowing and flaming. Tillage is the turning over of soil to bury the weeds and their seeds. Tillage can be done on a small scale with tools such as small hand pushed rotary tillers or on a large scale with tractor mounted plows (Akobundu and Agyakwa, 1998). Tillage is able to

control weeds because the soil is overturned, the shoot systems are damaged and the root systems are exposed (Hamma and Ibrahim, 2013). The type and the age of weeds are the determining factors on the success of this technique; the younger weeds can be controlled readily with tillage than the older weeds while the annual weeds can be effectively controlled than the perennials. However, to control mature perennial weeds, repeated tillage is necessary (Akobundu, 1987; Akobundu and Agyakwa, 1998).

Mowing cut or shred the above ground of the weeds can prevent and reduce seed population as well as restrict the growth of weeds (Crafts, 1975; Peruzzi *et al*., 2007). Mowing can be a successful control technique for many annual weeds. Properly timed mowing operations can also suppress some perennial weeds such as established *Shorghum halepense*. However, repeated mowing over a period of time (seasons or years) without any other means of weed control tends to favour the establishment of low-growing perennial grasses, which are very competitive for water and nutrients. Also, species that have flower heads below the level of the blade, are not effectively controlled (Akobundu, 1987).

Flaming can be used before planting or on weeds between crop rows. For most plants, flame causes the cell wall to rupture when they reach a temperature of 45° C to 55° C (Schonbeck, 2013). In order to avoid injuring the crop, the flame should be directed at young weeds between the rows. Broadleaf weeds are controlled more effectively by flaming than grasses are, and young weeds are better controlled than older ones (Hamma and Ibrahim, 2013). Because of the shortcomings of flaming which include the cost of fuel, the time required for covering the beds, and potential injury and fire hazard, flaming is not a widely used method of weed control (Schonbeck, 2013).

iv Physical method of weed control

Physical method of weed control involves manual removal ranging from hand pulling to the use of hoes and cutlasses. Hand-pulling of weeds is always a part of crop management as other methods do not remove all of the weeds, thus, there are always weed to uproot in a farmland. In some crops, there may not be any other method of control. By removing the few remaining weeds in the crop, not only will there be less competition, but fewer weed seeds will be produced. Hand pulling is the oldest method of weed control. It is the predominant weed control practice on smallholder farms (Vissoh *et al*., 2004); however, it is labour intensive. It has been reported that smallholder farmers spend 50 - 70% of their total labour time on hand weeding (Chikoye *et al*., 2007).

Mulching can also be considered as physical technique since it uses physical barrier to block light and impede weed seed germination and seedling establishment (Vissoh *et al*., 2004). Fine organic mulch (finished yard waste) may require only two to three inches of material to totally eliminate light and suppress growth of weeds. An advantage of mulching is that after the crop is harvested, the mulch can be incorporated into the soil to improve soil structure, drainage and water-holding capacity of the soil (Schonbeck, 2013).

v Chemical weed control technique

Chemical weed control refers to any technique that involves the use of synthetic herbicides to kill or inhibit weed growth. This affects the weed by drying out the leaves or stems or by making it drop its leaves. Chemical weed control is fast, cost effective and it saves time (Chikoye *et al*., 2005; Farooq *et al*., 2011). Research has shown that synthetic herbicides produce greater yield at less cost than other methods of weed control (Walley *et al*., 2006; *Chikoye et al*., 2007). The use of herbicides to remove weeds require only two hours of labour per hectare (Gouse *et al*., 2006). Research with maize in Nigeria demonstrated that

the use of herbicides reduced the need for labour at the peak period by 29 - 42% (Ogungbile and Lagoke, 1986; Reddy and Whiting, 2000; Reddy, 2001). However, the person applying the herbicides need specialized knowledge of herbicide products, the weeds they control and the crops they are used for as well as their toxicity and how to handle them. Moreso, the knowledge of the condition at which they work, application methods and rates as well as the types of nozzles for spraying are equally essential. Herbicides also require capital which must be available at the onset of season (Reddy, 2002).

2.5 SYNTHETIC HERBICIDES

Chemical control involves the use of synthetic herbicides which are substances used to kill certain plants or inhibit their growth. Synthetic herbicides are used extensively in agriculture and are used at a lower scale in homes (Ogungbile and Lagoke, 1986). They are toxic substances that should be used or applied with caution. Persistent herbicides can remain active in the environment for long period of time potentially causing soil and water contaminations. In some cases, compound that results from herbicide degradation may continue to be significantly toxic to the environment (Rattner, 2009; Leonard, 2011; Lamberth *et al*., 2013).

Environmental impact of herbicides consists of the effect of herbicides on non-target species. Over 95% of herbicides reach a destination other than their target species because they are sprayed or spread across agricultural fields (George, 2004). Runoff can carry herbicides into aquatic environment while wind can carry them to other fields, grazing areas, human settlements and undeveloped areas, thus potentially affecting other species (Lamberth *et al*., 2013). Other problems emerge from poor production, transport and storage practices, wrong application and lack of adequate knowledge of their hazardous

effect by the farmers (Chikoye, *et al*., 2005). Herbicides are also used both privately and publicly to control weeds in gardens and parks on school ground, sport field along road, sidewalks and fences (Chikoye *et al*., 2007).

2.5.1 Classification of Synthetic Herbicides

Herbicides can be classified using three major criteria: these are activity, time of application and the type of vegetation control (Schmidt, 1998; Kamel and Hoppin; 2004).

On the basis of activity, there are two major types: contact and systemic herbicides.

Contact herbicides are those that destroy only plant tissue they come in direct contact with. They are the fastest acting herbicides whose effects can be seen within thirty minutes of spraying (Weed Science Society of America, 2002). However, they are the less effective on perennial plants which are able to re-grow from roots or tubers (Akobundu, 1987). Contact herbicides commonly used in the tropics include paraquat, propanil, oryzalin and diquat.

Systemic herbicides are those that are translocated through the plant either from foliar application down to the root or from soil application where it is taken up by the roots and translocated up to the leaves; their effects may take few days. However, they can destroy a greater amount of plant tissue than contact herbicides (Sprague and Hager, 2002a; George, 2004). Systemic herbicides are particularly useful in controlling perennial weeds because underground perennating organs and roots are killed in addition to the shoot (Akobundu, 1987). Examples of systemic herbicides are atrazine, dalapon and glyphosate.

On the basis of time of application, herbicides can be grouped into:

Pre-emergence herbicides: Pre-emergence herbicides are usually applied to the soil before the weed emerges to prevent germination or seedling establishment. Examples of pre-emergence herbicides are diuron and atrazine (Schmidt, 1998).

Post emergence herbicides: Post emergence herbicides are applied after the weed has emerged to destroy growing weeds (Schmidt, 1998). Examples of post-emergence herbicides are propanil and paraquat.

On the basis of vegetation controlled, synthetic herbicides are grouped into:

Selective herbicides: Selective herbicides are those that will preferentially kill certain plants species at recommended rates but without harm to other plants they come in contact with. Examples of selective herbicides are fluometuron and metolachor (Schmidt, 1998).

Non selective herbicide: Non selective herbicides are those herbicides that exert toxic effect on all plant that may come in contact with them. Examples of non-selective herbicides are diquat, glyphosate, paraquat and sodium chlorate (Retzinger and Mallory, 1997).

2.5.2 Positive Impacts of Synthetic Herbicides

Researchers have shown that herbicides produce greater yield at less cost than the typical practice of hand weeding (Chikoye *et al*., 2007). Comparisons of the economics of different weed control techniques indicate that herbicide reduce the labour requirement for manual weeding (Benson, 1982). The use of herbicides to remove weeds require only two hours of labour per hectare (Chikoye *et al*., 2007; Gianessi and King, 2009). The use of herbicides in chemical weed control is a better alternative as it is cheaper, faster and effective (Chikoye *et al*., 2005). In addition, the potential benefits of synthetic herbicides include increased income, reduced drudgery, improved food security and nutrition. Using herbicides in crop production saves time thus, allowing timely attention to other tasks including potentially significant increase in the area planted with crops (Gianessi and King, 2009). Herbicides are used on more than 90% of the crop land in developed countries and are used by more than 90% of large scale commercial farmers in Africa (Chikoye *et al*., 2005; Gianessi and Reigner, 2007).

2.5.3 Adverse Effect of Synthetic Herbicides

Synthetic herbicides, though, cost effective, have adverse effects. These include crop injury, damage to other organisms, environmental contamination, human health issues and herbicide resistance in weeds (Jabran *et al*., 2008; Farooq *et al*., 2011; Hamid and Zarah, 2012).

i Crop injury

Crop injury refers to injury to the target crops caused by off – target drift from an herbicide application to a neighbouring plant, tank contamination due to fungicide or insecticide application that has herbicide residues in the spray solution when applied, adverse environmental conditions around the time of application or crop emergence and excessive product rate due to a miscalculation. Herbicides may have direct harmful effect on plant including poor root hair development, shoot yellowing and reduced plant growth (Milberg and Hallgren 2004). Plate 1 shows the example of crop injury caused by herbicides. Crop growth stage, variety, stress, environmental conditions and adjuvant will all affect the potential amount and severity of crop injury.

Plate 1: Cowpea response to glyphosate drift with characteristic bleaching of leaves and leaf distortation

Source: Milberg and Hallgren (2004)

ii Damage to other organisms

Synthetic herbicides often have significant effect on non-target species. Over 95% of herbicide reaches a destination other than their target species. Herbicides can affect the flora of ecosystem or nearby fields. Herbicides can have unintended consequences on non-target plant species, species composition, plant richness and diversity (Tyser *et al*., 1998; Pokorny *et al*., 2005). Data have indicated that some herbicides can have a synergistic effect with commonly used insecticides when they runoff into surface waters (Belden *et al*., 2007; Lamberth *et al*., 2013). Some herbicides can have subtle but significant physiological effect on animals including developmental effects (Tatum, 2004; Gill *et al*., 2012). Synthetic herbicides also have indirect effects on wild life by altering vegetative cover and structure. It had been reported that the use of imazapyr to control encroaching woody growth in long leaf pine stands (*Pinus palustris*) can increase forage for northern bobwhite (*Colinus virgimanus*) (Welch *et al*., 2004). Conversely, silvicultural practices that use herbicide to eliminate competitive deciduous shrubs to promote revegetation by conifers, can negatively impact song bird reproductive process (Easton and Martin, 2002).

iii Environmental Contamination

Herbicides can contaminate ground water and surface water due to several factors which include spills, leaks, improperly discarded herbicides containers and rinsing equipment near drainage areas. Contamination can also occur due to surface runoff or leaching of herbicides. In the United States, herbicides were found to pollute every stream and over 90 % of wells sampled in a study (Gillion *et al*., 2007).

Herbicides can influence soil pH and soil microbial activities (Haney *et al*., 2000; Scheffler and Sharpe, 2003). Herbicides can also reduce the growth and function of mycorrhizal fungi which increase the ability of plants to absorb and translocate nutrients

from the soil (Haney *et al*., 2000). The use of herbicides decreases general biodiversity in the soil. It has been reported that farming activities that avoid synthetic chemicals result in higher soil quality (Johnson and Mullinix, 1995).

iv Human health issues

Herbicides applicator generally face the greatest risk particularly during mixing and loading while the general public can be affected by direct contact through spray drift, accidental drift, indirect contact through consumption of contaminated food or water. Residues of herbicides can travel up the food chain thus, affecting human (Lamberth *et al*., 2013). Herbicides can also enter the body through inhalation of dust and vapour that contain herbicides (Gupta, 2004). Exposure effect can range from mild skin irritation to birth defects, tumors, genetic changes, blood and nerve disorders, endocrine disruption, coma or death (Stephenson, 2000).

v Weed resistance to herbicides

Resistance of a weed to herbicide refers to the ability of that plant to grow normally in spite of its exposure to a normal use dose of an herbicide. Weeds may evolve to become resistant to herbicides. Many weeds that had been very susceptible to a particular herbicide have become resistant and thus survive to reproduce due to mutations in their genetic make-up (Maxwell *et al*., 1990; Sprague and Hager 2002b). The first report of weed resistance to herbicides (atrazine) was in 1968. By 1991, 120 weed biotypes that were resistant to atrazine herbicides and other herbicides families were documented throughout the world. Result of a 1992 North Central Weed Science Society survey of the North Central United States and Canada reflected a worldwide trend of increasing appearance of herbicide resistance (Gressel, 1992).

The risks associated with the use of synthetic herbicides are significant and tremendously outweigh the cost effectiveness of chemical weed control in the long term. Thus, there is urgent need to improve on and possibly increase the available alternative measures that can be adopted in sustainable weed control in agroecosystem.

2.6 BIOLOGICAL WEED CONTROL

Biological weed control is the utilization of organisms for the regulation of weed densities. Biological weed control offers an environment friendly approach that complements conventional methods. It becomes imperative due to the hazardous effects of synthetic herbicides and the limitations of other conventional methods (Auld and Morin, 1995; Gupta, 2004). Biological weed control involves the use of organisms such as insects, nematode, bacteria, fungi or plants or their products to reduce weed populations. It is a low cost, effective and environment friendly weed control method. Biological control agents can reduce vigour, size and competitiveness of weed infestations; however, they rarely get rid of weeds altogether. Biological control of weeds is designed to reduce the ability of weeds to compete with crop plants or to reduce future populations of weeds (Shepherd, 1993).

Biological control agents are generally perceived by the public to be more environment friendly than synthetic herbicides (Auld and Morin, 1995). They are also perceived to be safer for uses than conventional herbicides and to leave no chemical residues in or on produce that could affect the safety of consumers. Biological control agents can be used in inaccessible areas and in areas such as national parks where disruption of food chain must be avoided. They may provide a cheap alternative to conventional herbicides (Moran and Hoffmann, 1996). The use of allelopathy which is a natural phenomenon by which a plant produces chemical substances that influence the germination, growth and development of

neighbouring plants, is an emerging biological method of weed control (Leather, 1987; Farooq *et al*., 2008; Mudassir *et al*., 2013).

Weeds can be controlled by conventional herbicides when a short term solution is required to keep them at acceptable levels or to prevent them from invading new area. However, for long term control, biological weed control must be integrated into the weed control techniques so as to minimize the present and future impact of weeds and synthetic herbicides on agricultural production and natural ecosystems (Shepherd, 1993; Auld and Morin, 1995).

2.7 ALLELOPATHY IN WEED CONTROL

Allelopathy is derived from the Greek word 'allelon' which means 'of each other' and 'pathos' which means to 'suffer'. Thus, allelopathy literarily means the injurious effect of one upon the other (Shilling *et al*., 1985; Rizvi *et. al*., 1992; Benyas *et al*., 2010; Iqbal *et al*., 2010; Awan *et al*., 2012). However, the term is now used in a wider sense. It is a phenomenon where a plant species chemically interferes with the germination, growth or development of other plant species. It involves direct or indirect effect of one plant upon another through the production of secondary chemical compounds that technically escape into the environment (Cheema *et al*., 2000; Scheffler *et al*., 2001; Khaliq *et al*., 2002; Haddadehi and Grevivani 2009; Daliri *et al*., 2011). Allelopathy can also be defined as the ability of plants to inhibit or stimulate growth of other plants in the environment by exuding chemicals. It plays an important role in agroecosystems and in the plant covers among the crop-crop and crop-weed interactions (Scheffler *et al*., 2001; Sadeghi *et al*., 2010; Moosavi *et al*., 2011). Currently, a more complete definition includes the positive and negative effects of chemical compounds produced mainly from secondary metabolism of plants, micro-organism, viruses and fungi that have an influence on the growth and

development of agricultural and biological ecosystem (Rice, 1984; Al saadawi *et al*., 1986; Seligler, 1996; Kruse *et al*., 2000; Olofsdotter *et al.*, 2002; Panahyan *et al*., 2010).

Allelopathic interactions among plants have been studied in both managed and natural ecosystems. In agroecosystems, allelopathic interractions could be part of the interference between crops and weeds that may affect the economical outcome of plant production (Alam *et al*., 2001; Agarwal *et al*., 2002; Javed and Asghari, 2008; Om *et al*., 2012). Several researchers have suggested that allelopathy holds great prospects for finding alternative strategies for weed control in both natural and agroecosystems, hence it reduces reliance on synthetic herbicides (Putman and De-Frank, 1979; Quassem, 1995; Inderjit *et al*., 1999; Olofsdotter *et al*., 2002; Ilori and Ilori, 2012; Mahrokh *et al*., 2013).

Allelopathic effects are achieved due to the release of active biomolecules commonly called allelochemicals from allelopathic plants (Kruse *et al*., 2000; Bertin *et al*., 2003a; Anjum and Bajwa, 2007). Allelochemicals can be found in different concentrations in several parts of plants such as leaves, stems, roots, rhizomes, seeds, flowers and even pollen (Bertin *et al*., 2003b). Numerous crops have been investigated for allelopathic activities towards weeds or other crops. Prominent among these are alfalfa (*Medicago sativa*), barley (*Hordeum vulgare*), rice (*Oryza sativa*), sorghum *(Sorghum* spp.), sunflower (*Helianthus annuus*), sweet potato (*Ipomoea batatas*) and wheat (*Triticum aestvum*) (Narwal, 2004; Anjum and Bajwa, 2005a; Anjum and Bajwa, 2007; Ashraf *et al*., 2007; Labbaly *et al*., 2009; Hosseini, 2011; Khan *et al*., 2013 Mudassir *et al*., 2013).

Allelopathic crops can be used to control weeds by: planting crop cultivars with allelopathic properties; applying residues and straw of allelopathic crop as mulches; using allelopathic crop in a rotational sequence where the allelopathic crop can function as a smoother crop or where the residue are left to interfere with weed population of the next

crop and foliar spray of allelopathic plant extract (Ashraf *et al*., 2008; Rua *et al*., 2008; Thorpe *et al*., 2009; Cheema *et al*., 2012; Reza *et al*., 2012). Allelopathic plants may also be considered as potential source of new molecules with herbicidal actions for the chemical industry (Schuster *et al*., 1992; Kruse *et al.*, 2000; Bhowmik and Inderjit, 2003; Anjum *et al*., 2005; Anjum and Bajwa, 2005b; Rejila and Vijaya 2011).

Iqbal and Anwar (2011) studied the allelophatic potential of *Sorghum halepense* on some wheat weeds. They discovered that shoot and inflorescence extracts have significant effects on the germination percentage and early seedling growth of two monocot and dicot weed species; however the effect was more pronounced on *Avena fatua* (wild oat) and *Cephalaria syriaca* than *Lathyrus sativa* and *Lolium temulentum* (Guad). It was also observed that sunflower water extracts (100%) inhibited weed growth of weed species such as broad leaf clock, swine cress, lambsquarters and fumitory by 24, 61, 31 and 21% and yield increase of wheat by 7% over the control (Muhammad *et al*., 2009). In another study, mulberry extract inhibited the seedling growth of Bermuda grass more than wheat seedling and interestingly, its foliar spray at 100% concentration significantly inhibited the growth of Bermuda grass and stimulated wheat growth (Haq *et al*., 2010). Alabi *et al*. (2005) also reported that fresh and dry leaf aqueous extracts of *Vernonia. amygdalina* significantly improved the yield of cowpea plants in terms of pod and grain weight. Allelopathic potential of aqueous extract of leaves and root of *Medicago sativa* and *Vicia cracca* were studied in laboratory condition. It was discovered that 50% concentration of all the plants part significantly inhibited the germination and radical length of the four weed species (*Amaranthus retroflexus* L., *Lolium perenne* L., *Ipomoea hederacead* L and *Portulaca oleracea* L.) (Onur, 2007).

The possibility of using sorghum or sunflower residues for weed control in wheat was investigated by Hozayn *et al*. (2011). The study showed that sorghum and sunflower residues can suppress the growth of some weeds associated with wheat. The authors concluded that field studies are needed to evaluate suppressive efficacy of residues under natural conditions. Marzieh *et al*. (2013) assessed the allelopathic potential of *Crocus sativus; Ricinus communis, Nicotiana tabaccum, Datura inoxa, Nerium oleander* and *Sorghum* on germination and growth of field bind weed (*Convolvulus arvensis*). It was discovered that application of all the botanical extracts at 10 g/l significantly reduced all the measured growth parameters and that the aqueous extracts of these species could be used as post emergence bioherbicides against field bind weed. It was concluded that the impact of these plants on field bind weed control should be investigated on the field.

2.7.1 *Sorghum* Allelopathy

Sorghum allelopathy is a new technique which has been tested for controlling weeds of wheat and sunflower as a substitute for chemical herbicides to reduce environmental pollution (Ahmad *et al*., 2000; Cheema *et al.*, 2000; Khaliq, 2000; Cheema *et al.*, 2003). Mature sorghum herbage contains a number of soluble secondary chemical substances (allelochemicals). Sorghum allelopathy can be used as sorgaab (water extract of mature *S. bicolor* plants obtained after soaking in water for 24 hours and spray as a natural herbicide), sorghum mulch, and sorghum soil incorporation and in crop rotation (Anwar *et al*., 2003). Different doses of sorghum water extract (sorgaab) applied as single and multiple foliar sprays at different days after planting (DAP) reduced total weed density at 120 DAP by 48% in wheat cropping system (Cheema *et al.,* 2000). In another study grain yield of wheat was increased by 21% by application of 100% concentration of sorgaab at 30 and 60 DAP with 19% and 33% decrease in weed density and dry weight respectively (Cheema *et al*., 2012). Ahmad *et al*. (2000) reported that foliar spraying of *Sorghum*

extract (Sorgaab) reduced total weed density by 34-57% and total weed biomass by 13-54% while the yield of sunflower was increased by 33-37%.

Application of allelopathic water extracts of mature sorghum in combination with reduced doses of herbicides provide an effective weed control as full herbicides dose in wheat (Cheema *et al*., 2003). Cheema *et al.* (2012) also reported that sorghum, sunflower and mulberry are potent allelopathic crops and that combination of water extract of the crops each at 18 l/ha can be used in weed control. There was 87% decrease in total weed density and 19.5% increase in wheat grain yield by the application of these allelopathic crops extract. Arif *et al*. (2015) recorded 48-59% yield increase and 57% reduction in weed densities by applying allelopathic water extract of sorghum, sunflower and brassica tank mixed at 25 , 40 and 55 DAP each at 18 and 20 l/ha in wheat. The possibility of using sorghum or sunflower residues for weed control in wheat was investigated by Hozayn *et al*. (2011). The study showed that sorghum and sunflower residues can suppress the growth of some weeds associated with wheat. The authors concluded that field studies are needed to evaluate weed suppressive efficacy of residues under natural conditions.

2.7.2 *Tithonia diversifolia* Allelopathy

T. diversifolia had been noted to be an aggressive weed with high invasive capacity because it is known to exhibit allelopathy (Akobundu, 1987; Ayeni *et al*., 1997; Tongma *et al*., 1997). It has been reported that fresh biomass of *T. diversifolia* can serve as an effective source of nutrients for *Zea mays* and other crops (Jama *et al*., 2000; Nziguheba *et al*., 2002; Olabode *et al*., 2007; *Ademiluyi* and Omotoso, 2008; Ademiluyi and Ajewole, 2013). Fresh aqueous extract of *T. diversifolia* shoot have both inhibitory and stimulatory effect on seedling growth of maize (Nzighuheba *et al*., 2003). Also, Taiwo and Makinde (2005) reported that aqueous of *T. diversifolia* stimulated germination and growth of

cowpea in a non-field experiment. This is further corroborated by Ilori *et al*. (2007) who reported the stimulatory effect of *T. diversifolia* shoot extract on the germination and growth of *O. sativa.* Otusanya *et al*. (2007) have reported that aqueous extracts of root and shoot of *T. diversifolia* were inhibitory to germination and growth of *Amaranthus cruentus.* Oyerinde *et al*. (2009) investigated the allelopathic effects of *T. diversifolia* on the germination, growth and chlorophyll contents of maize. It was reported that aqueous extract of fresh shoot of *T. diversifolia* significantly stimulated fresh weight, dry weight, leaf area and ratio of maize seedling. Ademiluyi (2012) reported that leachate of *T. diversifolia* inhibited the total germination percentage and the speed of emergence of *Abelmoschus esculentus*. It was further demonstrated that growth parameters and yield of okra were substantively increased by the application of *T. diversifolia* extracts.

Musyimi *et al*. (2012) also reported that aqueous extract of fresh *T. diversifolia* shoot stimulated the germination and growth of spider plants *Cleome gynandra* seeds. They suggested that further studies should be conducted to identify the exact allelochemicals in *T. diversifolia*. Ademuluyi (2013) reported that aqueous extract of *T. diversifolia* shoot suppressed the germination of *Tridax procumbens* and that the number of secondary root of *T. procumbens* decreases as the concentration of the extract increases. Musyimi *et al*. (2015) also discovered that aqueous shoot extract of *T. diversifolia* stimulated growth of *Vigna sinensis*.

From this literature review, inhibitory and stimulatory allelopathic effects of *T. diversifolia* have been documented mostly in laboratory and non-field experiments. However, the allelopathic potential of *T. diversifolia* in biological weed control on the field had been rarely reported. Moreso, within the contexts of this review, no studies have been

conducted on investigating the potential of utilizing the allelopathic property of *T. diversifolia* in biological weed control in cropping system.

2.7.3 Shelf life of aqueous extract of *Tithonia diversifolia* in allelopathy

Past study indicated that phytotoxicity of aqueous extracts of *T. diversifolia* towards annual ryegrass generally increased, at 25°C over a 32 day period (Vyvyan 2002; Haig, 2005). Aqueous extracts have a limited shelf life of about 12 days (Wu *et al*., 2003).

2.8 ALLELOCHEMICALS AND THEIR POSSIBLE PATHWAYS

Allelochemicals are found in different concentrations in plant parts and their pathways of release into the environment vary among species (Kruse *et. al.*, 2000). Rice (1984) and Putnam (1998) observed that allelochemicals are present in plant roots, rhizomes, stems, leaves, flowers, influorescences, pollens, fruits and seeds. Several researchers had further stated that the leaves are the major sources of these allelochemicals (Singh *et al*., 2003a; Singh *et al*., 2003b). Their possible pathways are: exudation and deposition on the leaf surface with subsequent washing off by rainfall; exudation of volatile compounds from living green parts of the plants; decay of plant residues such as litterfall and dead roots and root exudation (Rasmussen 1993; Dudai, 1999; Chon and Kim 2002; Olofsdotter *et al*., 2002; Chou, 2006; Saffari and Torabi, 2011; Ilori and Ilori, 2012).

2.8.1 Effects of Allelochemicals

Allelopathic activities are usually measured using seed germination, radicle and plumule elongation, shoot and root growth, microbial numbers and other plant functions (Einhellig, 1995). Allelochemicals usually interfere with major physiological processes such as respiration, photosynthesis, water balance and stomatal functions, stem conductance of water, xylem element flux, membrane permeability, cell-division, changes in protein

synthesis and inhibition or stimulation of specific enzymes (Carroll, 1994; Siddiqui *et al*., 2009; Uniyat and Chhetri, 2010).

Several allelochemicals such as sorgoleone, juglone, quercetin, ferulic acid and cineone have been found to affect respiration. Einhellig (1995) found that the production of ATP in mitochondria was inhibited by a variety of flavonoids. It was also discovered that the respiration of wheat plants was inhibited by quackgrass that was grown in the same pot. Patterson (1981) discovered that cinnamic acid, benzoic acid, scopoletin and chlorogenic acid inhibit photosynthesis. Artemisinnin was shown to reduce photosynthesis in *Lemna minor* (Carroll, 1994). Mersie and Singh (1993) observed that ferulic, p-coumaric, chlorogenic and vanillic acids inhibited photosynthesis from 33-65% in enzymatically isolated leaf cells of velvetleaf. Substances extracted from quackgrass rhizomes caused decreased transpiration, water content and cell sap osmotic pressure as well as degree of stomatal opening when applied to flax grown in a pot. These effects were caused by a water deficit possibly due to restricted water uptake by the root (Vicherkova, 1996).

It has been observed that potatoes produce toxic substances that inhibit tree growth. In a study, when potatoes were cultivated between rows of young apple trees, the phytotoxins inhibited the growth of the apple. Reduced total nitrogen contents were observed in the branches and root of apple trees. Consequently, there was a change in the composition of proteins in the bark of the branches, increased amount of soluble albumins and decreased quantity of residual proteins (Rice, 1984). Cinnamic acid has been found to interfere with the mechanism of protein synthesis (Carroll, 1994; Macias *et al*., 1998).

2.8.2 Allelochemicals as bioherbicides

The increasing incidence of herbicide resistance and environmental cum health concerns are creating a demand for new herbicides. The need for new herbicides becomes obvious

to solve the dilemma of need to remove the older herbicides from the production fields for environmental, toxicological or economical purposes (Ilori, 2013). Allelochemicals are products of secondary metabolism and are non-nutritional metabolites (Chung and Miller, 1995; Welch *et al*., 2004; Iqbal and Fry, 2012). These compounds belong to numerous chemical groups including alkaloids, flavonoids, phenols, coumarins, steroids and terpenoids. They are released into the environment by plant organs such as roots, rhizomes, leaves, stems, bark, flowers, fruits and seeds (Nasir *et al*., 2005a; Solyts *et al*., 2013). A wide range of these biochemicals are synthesized during the shikimate pathway or in the case of essential oils from the soprenoid pathway (Hosseini, 2011). Allelochemicals affect germination and growth of neighbouring plants by disruption of various physiological processes including photosynthesis, respiration, water and hormonal balance (Mann, 1987; Hussain *et al*., 2007; Shajie and Saffari, 2007; Tanveer *et al*., 2008; Solyts *et al*., 2013). Plant producing allelochemicals are referred to as donor plants while the plants to which the allelochemicals are directed to are referred to as target plants or acceptors. Most of the allelochemicals penetrate the soil as already plant-active compounds such as phenolic acids, cyanide, momilactones etc while others have to be modified by microorganisms or by specific environmental conditions e.g Juglone benzoxazolin 2-one (BOA), 2-amino-3-H-phenoxazin-3-one (APO) (Solyts *et al*., 2013).

The best known examples of natural bioherbicides are phytotoxic water extract from herbage of sorghum (*S. bicolor*) and sunflower (*Helianthus annum*) which can be effectively used in plant protection without yield loss (Narwal, 2004; Mahmood *et al*., 2009; Dayan *et al*., 2010; Solyts *et al*., 2013). The effect of sorgaab on weeds is time and dose-dependent, but it is typically used at 5% or 10% (w/v) concentrations as double spray applied at 20 and 30 days after sowing (DAS) or after seedling transplantation in wheat.

Sorgaab may also be applied at 40 and 60 DAS (Cheema *et al*., 2003; Irshad and Cheema, 2004).

Sunfaag has been widely used in wheat cropping system as post emergent herbicide usually applied at seven days intervals as from three-four weeks after planting or transplanting. The herbicidal efficiency calculated as the effectiveness of sunfaag in comparison to synthetic herbicides showed a quite high value 60% efficiency index (Hosseini, 2011). However, weed control requires high concentration of sunflower and sorghum ranging up to 80% and can generate economic losses due to the necessity of cultivating higher amounts of sorghum or sunflower that also required an appropriate cultivation system (Anjum and Bajwa, 2007; Mahmood *et al*., 2009).

Fenwick *et al*. (1983) and Peterson *et al*. (2001) have reported high allelopathic potential conditioned by glucosinolates and isothyocyanates in *Brassica*. Isothiocyanates are known inhibitors of germination of spiny sowthistle (*Sonchus asper* L. Hill), smooth pigweed (*A. hybridus* L.), barnyard grass, black grass and wheat (Peterson *et al*., 2001). Examples of allelochemicals isolated from plants are listed in Table 1.

Plants phytotoxic extracts can be successfully used in integrated weed control. A purified allelochemical may act on target plant with much higher or much lower strength (Shahrokhi *et al*., 2011). Solyts *et al*. (2013) observed that in a situation, when an allelochemical is active at unprofitably high doses but a favourable environmental profile, it may still be a source to explore due to several reasons such as biodegradability. They further suggested that modification of chemicals structure of such allelochemicals can make them more active on target plants while preserving desire properties.

Table 1: List of natural herbicides (Allelochemicals) and their sources

Allelochemicals	**Plant source**	**Sensitive weeds**
Glucosinolates	Mustard plant *(Brassica sp.)*	Pigweed *(Amaranthus hybridus)* Barnyard grass *(Echinochloa cruss gali*. L.), Black grass (*Alopecurus suroides*), Morning glory *(Convolvulus arvensis* L.) and Dodders (*Cuscuta* spp.)
Sorgoleone	Sorghum (*Sorghum bicolor* L.)	Canary grass (*Phalaris minor* Retz), Blacknight shade (*Solanum nigrum.* L.), purple nutsedge (*Cyperus rotundus*. L.), Redroot pigweed (*Amaranthus retroflexus* L.)
Momilactone	Rice (*Oryza sativa*. L.)	Barnyard grass (*E. colonum* L.), Meadow grass (*Poa annua* L.) and Hairy crabgrass (*Digitaria sanguinalis*)
Essential oils	Eucalyptus (*Eucalyptus* sp.)	Barnyard grass (*E. colonum.* L.) and Ryegrass (*Lolium rigidum*)

Source: Soltys *et al.* (2013)

Sorgoleone, an allelochemical from the root hair of sorghum has enormous potential as an herbicide due to its high activity against various weed species. Studies conducted under laboratory conditions have shown that low doses of sorgoleone 100 µm inhibited growth of black night shade (*Solanum nigrum* L.), red root pigweed and common ragweed by 80%. However, sickpod (*Senna obtusifolia* L.), hairy crabgrass (*Digitaria sanguinalis* L.), and velvet leaf (*Abutilon theophrasti* Medik) growth was reduced by 40% (Nimbal *et al*., 1996; Bhowmik and Inderjit, 2003).

Momilactones from rice inhibited the growth of typical weeds in rice e.g. barnyard grass and awnless barnyard grass at concentration higher than I μm and 10 μm respectively (Dayan *et al*., 2009). The phytotoxic abilities of momilacton A and B were also demonstrated on livid pig weed (*Amaranthus lividus* L.), hairy crabgrass and annual blue grass (*Poa annua* L.) at a concentration higher than 60 μm and 12 μm respectively. The experiment revealed that momilactone A and B is secreted by rice root into the rhizosphere has a profound effect on the entire life cycle (Katonoguchi *et al*., 2008). Samentine isolated from long pepper piper fruits has been shown to be suppressive to lettuce (Huang *et al*., 2010). Higher concentrations of sarmentine caused almost 100% mortality of red root pigweed, barnyard grass, bind weed, hairy crabgrass, animal blue grass, wild mustard, curly dock with impaired effects on horse weed (*Conyza canadensis* L.) growth under laboratory conditions (Fukuda *et al*., 2004; Lederer *et al*., 2004). As an herbicide, sarmentine and its derivatives may be obtained from fruits of long pepper and successfully synthesized chemically (Huang *et al*., 2010).

2.8.3 Advantages of allelochemicals as bioherbicides

Chemical weed control is an integral part of plant protection which is effective but rather costly and problematic due to environmental pollution and other issues. However, the

exploration of the allelochemicals allows the introduction of alternative technique for biological weed control. The application of extract from allelopathic plants as foliar spray decreases the cost of herbicide application and more importantly improves crop production and protect the environment (Putnam, 1998; Dudai *et al*., 1999).

The mode of action of some allelochemicals is similar to synthetic herbicide (Solyts *et al*., 2013). Most allelochemicals are totally or partially water soluble which makes them easier to apply without surfactants (Vyvyan 2002; Dayan *et al*., 2009; Dayan *et al*., 2010). Their chemical structure is more environment friendly than synthetic ones. They have higher oxygen and nitrogen-rich molecules with relatively few so-called heavy atoms. They are also characterized by absence of unnatural rings (Solyts *et al*., 2013). These properties decrease their environmental half-life, prevent accumulation of the compounds in the soil and eventually reduce their influence on non-target organisms.

2.8.4 Limitations of allelochemicals as bioherbicides

There are enormous numbers of factors that limit the use of allelochemicals as bioherbicides. Allelochemicals are characterized by multisite-action in plant without high specificity which is achieved in the case of synthetic herbicides. Thus, they can rarely be supplied as selective herbicides. Consequently, allelochemicals have to be first isolated from plant extract (Duke *et al*., 2000). The amount of compound recovered is usually low in comparison to chemical synthesis. Moreso, extraction is followed by purification, selection of the most active compound and determination of its mode of action in plants (Solyts *et al*., 2013).

The use of allelopathic crop extract may not be economical when the crops have to be grown on the farm. Growing these crops within the farm would take both space and time. More so, the effects of the allelochemicals might be influenced by environmental factors

thus, rendering them ineffective in natural settings (Inderjit and Duke, 2003; Inayat *et al*. 2009).

2.9 *Vigna unguiculata* (COWPEA)

Vigna unguiculata (L.) Walp. (cowpea) is one of the most ancient human food sources and has probably been used as a crop plant since Neolithic times. It is a multipurpose crop that has the potential to function as a key integrating factor in provision of protein in human diet and fodder for livestock as well as bringing nitrogen into the farming system through biological fixation (Giller, 2001). Cowpea is grown extensively in 16 African countries with the continent producing two-third of the world total cowpea production. World production of cowpea was estimated to be 2.27 million tonnes of which Nigeria produces the highest of about 850,000 tonnes (FAO, 2001; Adaji *et al*., 2007). Cowpea is of major importance to the livelihoods of millions of relatively poor people in less developed countries of the tropics (FAO, 2001). Islam *et al*. (2006) emphasized that all parts of the plant used as food are nutritious providing protein and vitamins: immature pods and peas are used as vegetables while several snacks and main dishes are prepared from the grains. It has been reported that Nigeria is the second greatest consumer of cowpea in the whole world (Egho, 2009). Cowpea forms a major staple food in the diet of African and Asian countries. Also, cowpea has been regarded as the poor man's major source of protein (Awe, 2008).

2.9.1 Botany of Cowpea

Cowpea, *Vigna unguiculata* belongs to the family Fabaceae. A lack of archeological evidence has resulted in contradicting views supporting Africa, Asia and South America as origin. Cowpea is an annual herb with varying growth forms which ranges from erect, sub-erect and prostrate to climbing habits. The root system comprises a main tap root with many lateral roots that develop near the soil surface. The stems may be striated, smooth or

slightly hairy, and are usually tinged with purple pigment (Ugborogho and Agomo, 1989). The first pair of leaves above the cotyledonary node is simple and opposite but they exhibit considerable variations in size and shape. The trifoliolate leaves arise alternately and the terminal leaflet is frequently longer and of greater area than the asymmetrical and lateral leaflet. The shape of the terminal leaflet ranges from ovate, lanceolate, globular, linears, hastate, subhastate to globose (Ng, 1990).

Reproductive structures are solitary flowers borne on racemose inflorescence at the end of long succulent peduncle. Each flower is bisexual, zygomorphic and papillionaceous: the petals vary in colour from white, yellow, purple to mauve (Ugborogbo and Agomo, 1989). The length of the peduncle ranges from less than 5 cm to more than 50 cm. Pods are coiled; round or crescent usually yellow when ripe but may also be brown or purple in colour (Ugborogbo and Agomo, 1989). The seeds vary considerably in shape, colour and size. The seed shape range from globular, oblong to kidney shape with intermediate oval or ovoid forms. The seed has marked white hilum 2-3 mm long which may or may not be surrounded by a pigmented eye. The different shapes of this pigmented area form the basis for the eye patterns (Porter *et al*., 1974). The number of seeds per pod may vary from 8-20. The seeds are relatively large 2-12 mm long and weigh 5-30 g / 100 seeds. The testa may be smooth, rough, white, green, brown, red, black or speckled (Ugborogbo and Agomo, 1989).

2.9.2 Economic Importance of Cowpea

Cowpea is a major staple food crop in tropical Africa especially in West Africa. The seeds are a major source of plant protein and vitamins for man, feed for livestock and also a source of cash income. The young leaves and immature pods are eaten as vegetable (Dugje *et al*., 2009). It is a protein-rich legume with very high potential to improve the standard of living of peasant farmers in Africa where the cost of animal protein is high (Babaleye,

1993). According to the USDA food database leaves of the cowpea plant have the highest percentage of calories from protein among vegetarian foods (Duke, 1981).

In West Africa, cowpea is grown in some places mainly for its edible leaves and if such varieties are pruned regularly they continue to produce leaves. The leaves are boiled, drained, sun-dried and used for animal feeding during off-seasons such leaves are good source of minerals including phosphorus, zinc, iron and vitamins such as ascorbic acid, B carotene and folic acid (Imungi and Potter, 1985). In the United States of America, green seeds of *V. unguiculata* are sometimes roast like peanuts and scorched seeds are occasionally used as coffee substitute (Duke, 1990). Some cowpea varieties are also used as pasture plants: such varieties are characterized by fleshy tender leaves, fast growth rate and ability to produce a considerable amount of forage within a relatively short time (Duke, 1990).

Cowpea is also used by peasant farmers as cover crops in various countries, thus, useful in checking erosion (Duke, 1981). Cowpea also fixes atmospheric nitrogen through symbiotic relationship with bacteria in its nodule, an attribute which makes the plant to enhance the soil nitrogen level. Cowpea seeds are also used for cultural and traditional purposes. The seeds are sacred to the Hausa and Yoruba people of Nigeria. Cooked beans are prescribed for sacrifices to evil spirit and to pacify the spirit of twins and sick children (Duke, 1981). There is a big market for the sale of cowpea grain and fodder in West Africa. In Nigeria, farmers who cut and store cowpea fodder for sale at the peak of dry season have been found to increase their annual income by 25 % (Dugje *et al*., 2009).

2.9.3 Cultivation of cowpea

Cowpea is grown mostly for their edible seeds. It thrives in poor dry conditions growing well in soils up to 85% sand. It is a drought tolerant and warm weather crop as it is well

adapted to drier regions of the tropics where other food legumes do not perform well. It is shade tolerant so is compatible as intercrop with maize, millet, sorghum, sugarcane and cotton (Ajeigbe *et al*., 2010). It is a summer crop which grows best when the minimum temperature is above 10° C. Its flowers open in the early day and close at approximately mid- day. After blooming, the flowers wilt and collapse.

2.9.3.1 Land selection and preparation

Cowpea is well adapted to sandy and poor soils but best yields are obtained in well drained sandy loam to clay soil with a pH between six and seven. It can tolerate drought but not waterlogged areas (Duke, 1990). All vegetation must be cleared and the field prepared manually with a hoe or tractor. Cowpea can be planted on ridges or on a flat seed bed. Well prepared land ensures good germination, reduces weed infestation and prevents water-logging which may damage the plants (Dugje *et al*., 2009).

2.9.3.2 Planting time

The important criteria for determining when to plant include the onset and duration of rain, the maturity period of the cowpea variety, and the growth habit of the variety. Most of the semi-erect and prostrate varieties are photosensitive, thus, they will not flower when planted early (Ajeigbe *et al*., 2005; Dugje *et al*., 2009). The recommended planting time for cowpea is given in Table 2.

Table 2: Recommended planting date for cowpea

Commencement of rain	Duration	Cowpea type	Maturity time	When to plant
May	May-Oct.	Erect Semi-erect Prostrate	Early and Extra-early maturity Medium Maturity Late Maturity	August, week 2 August week 1 August week 2
June	June-Oct.	Erect Semi-erect Prostrate	Early and Extra-early maturity Medium Late	August week 3 August week 1 Mid-August
June – July	July –Oct.	Erect Semi Erect Prostrate	Early and Extra-early maturity Medium Late	July Ending July Ending August week 1

Source: Dugje *et al*. (2009)

Sowing is usually manual at a depth of 2.5 to 5 cm for most varieties. For sole cropping spacing should be 50 cm between row and 20 cm within rows for erect varieties (Dugje *et al*., 2009). However, spacing of 75 cm between row and 30 cm within row has been found to have positive influence on the growth and yield parameters (Duke, 1990). Dugje *et al*. (2009) suggested that, for semi erect varieties spacing should be 75 cm between rows and 25-30 cm within row while for prostrate varieties, spacing should be 75 cm between rows and 50 cm within rows. Maximum of three seeds per hole and thinned to two per plants at two weeks.

2.9.3.3 Fertilizer rate and application.

Cowpea does not require too much nitrogen fertilizer as it fixes its own nitrogen from the air using the root nodules in its roots. However, it requires more phosphorous in form of single super phosphate or SUPA. About 30 kg of P/ha in the form of SUPA is recommended for better yield. Compost and manure should be applied three-four weeks before planting (at least 1 ton/ha) is important for better yield (Korimawa *et al*., 2002; *Ajeigbe et al*., 2010).

2.9.3.4 Weed control

Weeds constitute a serious problem in cowpea production and if not well managed, can harbour other pests and reduce both yield and the quality of the grain. Cowpea is not a strong competitor with weeds especially at the early stage of growth. Awodoyin (2010) reported that the critical period for removal of *Sclerocarpus africanus* in cowpea field is between two-four weeks after planting. The type of weed control to be adopted depends on the nature of infestation and the available resources. Minimum of two weedings is recommended for manual weed control, first at three weeks after planting and second at five to six weeks after planting. Poor weed control or delay in weeding causes a drastic

reduction in yield (Dugje *et al*., 2009). Awodoyin (2010) reported that interference of *S. africanus* with cowpea throughout the life cycle resulted in 47.9% yield loss. Ajeigbe *et al*. (2010) and Adigun (2014) identified diseases, insect pests and parasitic weeds as the major constraints to cowpea grain and fodder production. Chemical weed control is effective and glyphosate is recommended where there are troublesome weeds such as sedges and spear grass. Application of paraquat and pendimethalin within two days of planting is recommended (Ajeigbe *et al*., 2010; Yadav, 2017).

2.9.3.5 Cowpea pests and diseases

Insects are a major factor in the lower yields of cowpea in Africa. They affect each tissue component and developmental stage of the plant. In severe cases, insects are responsible for over 90% loss in yield (Jackai and Daoust, 1986). The legume pod borer *Maruca vitriata* is the main field pest of cowpea (Sharma, 1998). It damages the flower buds, flowers and pods of the plant. Other important pests include pod sucking bugs thrips and post-harvest weevil (*Callosobruchus maculatus*) (Jackai and Daoust, 1986).

Cowpea diseases include bacterial blight, anthracnose, brown blotch, brown rust, soft stem rot, charcoal rot and nematode rot (Ajeigbe *et al*., 2008). Both pest and diseases can be controlled by cultural, preventative, chemical and biological methods (Umeozor, 2005).

2.9.3.6 Harvesting

Harvesting should be done when 80-90% of the pods are dry. The dry pods can be manually beaten and winnowed. More than one picking may be needed in some varieties. Ajeigbe *et al*. (2010) suggested that first harvesting should be done when about 70% of the pods are dry while the next harvesting occurs seven to ten days after. Harvested pods

should be spread out to dry in the sun or under shade. Timely harvesting and proper drying of grains are essential for quality grains (Ajeigbe *et al*., 2010).

2.10 SIGNIFICANCE OF FIELD WORK IN ALLELOPATHIC STUDIES

Allelopathy is a dynamic process that involves more than just donor and target plants (Jabran *et al*., 2008; Jabran *et al*., 2010; Jabran *et al*., 2011). Variation in the type of soil, water and nutrients availability and climatic conditions are also determinants of the occurrence of effective allelopathic activity. Laboratory and green house studies in most cases focus on allelopathic effects of a particular plant on a given weed species in Petri dish or pot experiment, however it is expected that allelopathy will be used under field conditions. Perceived allelopathy effects that were measured in the greenhouse and Petridish experiments may be tempered by the soil environment. It has been stated that further screening of allelopathic toxins in field situation is essential before allelopathy can be a factor in weed control (Jabran *et al*., 2008; Jabran *et al*., 2011).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 PROCEDURE FOR THE BASELINE STUDY

Jatropha curcas shoot and *Tithonia diversifolia* plant were collected from the wild at different locations in Ede and Osogbo of Osun State while *Sorghum bicolor* plant residues were collected from farmers in Iwo, Osun State, Nigeria. Crude extracts of *Jatropha curcas* shoot, *Tithonia diversifolia* plant and *Sorghum bicolor* plant residues were prepared according to the procedure described by Ilori (2013). 10% and 20% w/v concentrations of each extracts were applied at 2, 21 and 35 days after planting Ife Brown accession of cowpea singly in a pot containing 5 kg of loamy soil into which 5 g of seeds of weeds of different species have being mixed (Arif *et al*., 2015). There were three replicates for the two different concentrations for each of the extracts. Weedy checks were maintained as the control. Weed density at 30 and 65 days after planting were enumerated and the weed control efficiency of each extract was calculated at 65 days after planting using the procedure of Arif *et al*. (2015).

3.2 DESCRIPTION OF THE EXPERIMENTAL SITE

The field experiments were conducted in the experimental farm located at Owode, Ede, (latitude 7^{o} 43'08'' N; longitude 4^{0} 29' 45'' E; altitude 230 m above the sea level), Osun State, in the rainforest agro-ecozone of Nigeria. The geographical location is 7.89 km Southwest of Osogbo and 185.91 km Northeast of Lagos (Figure 1).

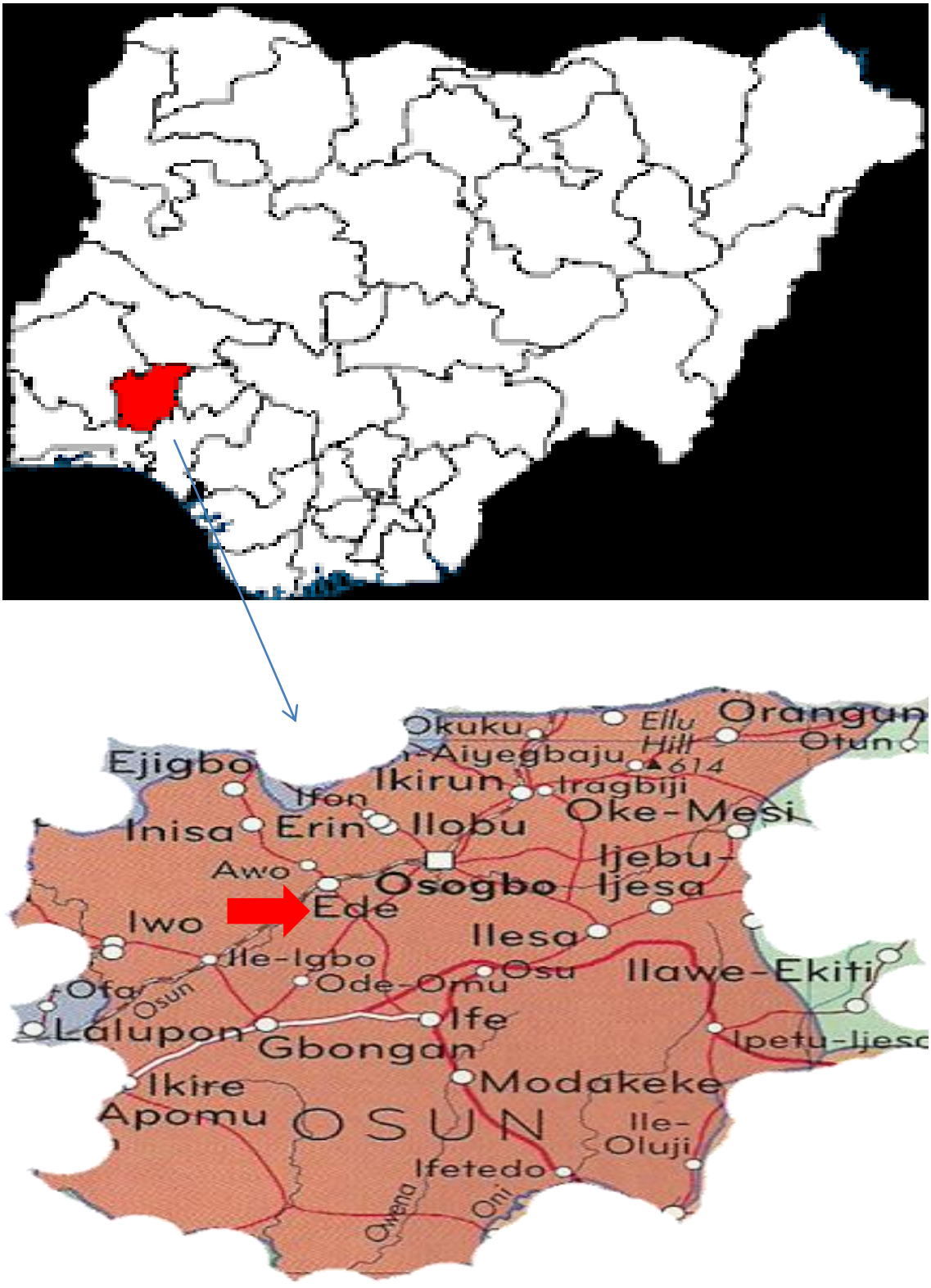


Figure I: Map of Nigeria showing Osun State (red coloured) and the location of the experimental site (arrowed)

3.3 PRE-PLANTING PHYSICOCHEMICAL ANALYSIS OF THE EXPERIMENTAL SOIL

3.3.1 Collection of soil sample for the baseline study of the experimental site

Soil samples were collected from the top 0 – 15 cm in each of the plots in field experiments I and II respectively. The samples were mixed to obtain a composite sample for each of the fields. The composite soil sample of each of the fields were air-dried, sieved with a 2-mm mesh and taken to the Analytical Service Laboratory, International Institute of Tropical Agriculture (IITA), Ibadan for physicochemical soil analysis.

3.3.2 Soil texture analysis

Determination of grading and particle size distribution of experimental soil sample from each of the fields was carried out at the Analytical Service Laboratory of the IITA, Ibadan using the method specified by the British Standard Institution (BSI). Sieves of 2.36 mm, 1.18 mm, 600 micron, 425 micron, 300 micron, 212 micron, 150 micron and 63 micron arranged on top of one another in descending order were used.

3.3.3 Determination of soil pH

The pH of each of the soil samples was determined using the procedure of Mucha *et al*. (2004). A suspension of the sieved soil sample was prepared by mixing 2 g of the soil with 4 ml of deionized water (1:2 w/v). The pH of the suspension was determined with a pre-calibrated pH meter (Model 215).

3.3.4 Determination of soil moisture content

The moisture content of each of the soil sample was measured using the procedure of Mucha *et al*. (2004). 15 g of the sieved soil sample was weighed (initial weight) using an analytical balance, and inserted into moisture can. The sample in the can was then heated in the oven to a temperature of 105° C for 12 h. Thereafter, the sample was removed from

the oven, cooled in desiccators for 1 h, and the final weight was recorded. The analysis was done in triplicates.

3.3.5 Determination of total organic carbon

The total organic carbon of each of the soil samples was determined according to the procedure of Benard *et al*. (2004). The sieved sample was first oven-dried at 60° C for 12 h. Thereafter, 1.5 g of sample was mixed with 2 ml of 1 M HCl to eliminate inorganic carbon, and then further dried at 105^{o}C for 10 h to remove HCl. Subsequently, the total organic carbon was analyzed using a carbon analyzer.

3.3.6 Determination of organic matter content

The organic matter content of each of the soil samples was determined, using the loss-on-ignition (LOI) method as described by Mucha *et al*. (2004). 15 g of the sample was weighed (initial weight) on an analytical weighing balance, and inserted into crucible cups. The sample in the crucible cup was then placed in a furnace and heated at a temperature of 500° C for 4 h. After heating, the samples were left to cool in desiccators for 1 h, and the final weight of the sample was later taken. The organic matter content was determined by the percentage loss of sample weight (that is, initial weight minus final weight) after combustion at 500° C for 4 h.

3.3.7 Determination of mineral content

Soil minerals were extracted using the procedure of De-Fillippo and Ribeiro (1997). 5.0 g of the sieved soil was placed in a flask and 20 ml of the extracting solution (0.05 N HCL + 0.025 N H_2S0_4) was added to it. Then the sieve soil mixture was placed in a magnetic stirrer and stirred for 20 minutes. The resulting solution was filtered through a Whatman filter paper into a plastic vial and diluted to 50 ml with the extracting solution. A reagent blank containing only the acids was prepared along with the samples. Thereafter, the

mineral content of the sample was analyzed using the Atomic Absorption Spectrophotometer (Model A Analyst 200; Perkim Elmer, USA), the calibration curves of the different minerals were generated by first analyzing standard solutions of the individual minerals before the sample analysis.

3.4 COLLECTION OF PLANT SAMPLES AND TEST CROP

3.4.1 Collection of *T. diversifolia* and *S. bicolor* plant materials

Mature *T. diversifolia* plants were collected from the wild where there were large populations at different locations in Ede and Osogbo, Osun State, Nigeria. The identification of the plants was confirmed at the Herbarium Unit of the Department of Botany, Obafemi Awolowo University, Ile - Ife with voucher number IFE 17597. *S. bicolor* plant residues were collected from farmers in Iwo, Osun State and Oko, Oyo State immediately after harvesting. Plate 2 show the research materials.

3.4.2 Collection of the Test Crop

Two accessions of cowpea (*V. unguiculata*) were used as the test crop. Seeds of cowpea accession (IT 84E-124) were collected from the Seed Bank of International Institute of Tropical Agriculture (IITA), Ibadan, Oyo State while the seeds of Ife Brown variety were collected from farmer Ayoade in Erin Ijesa, Osun State, Nigeria.

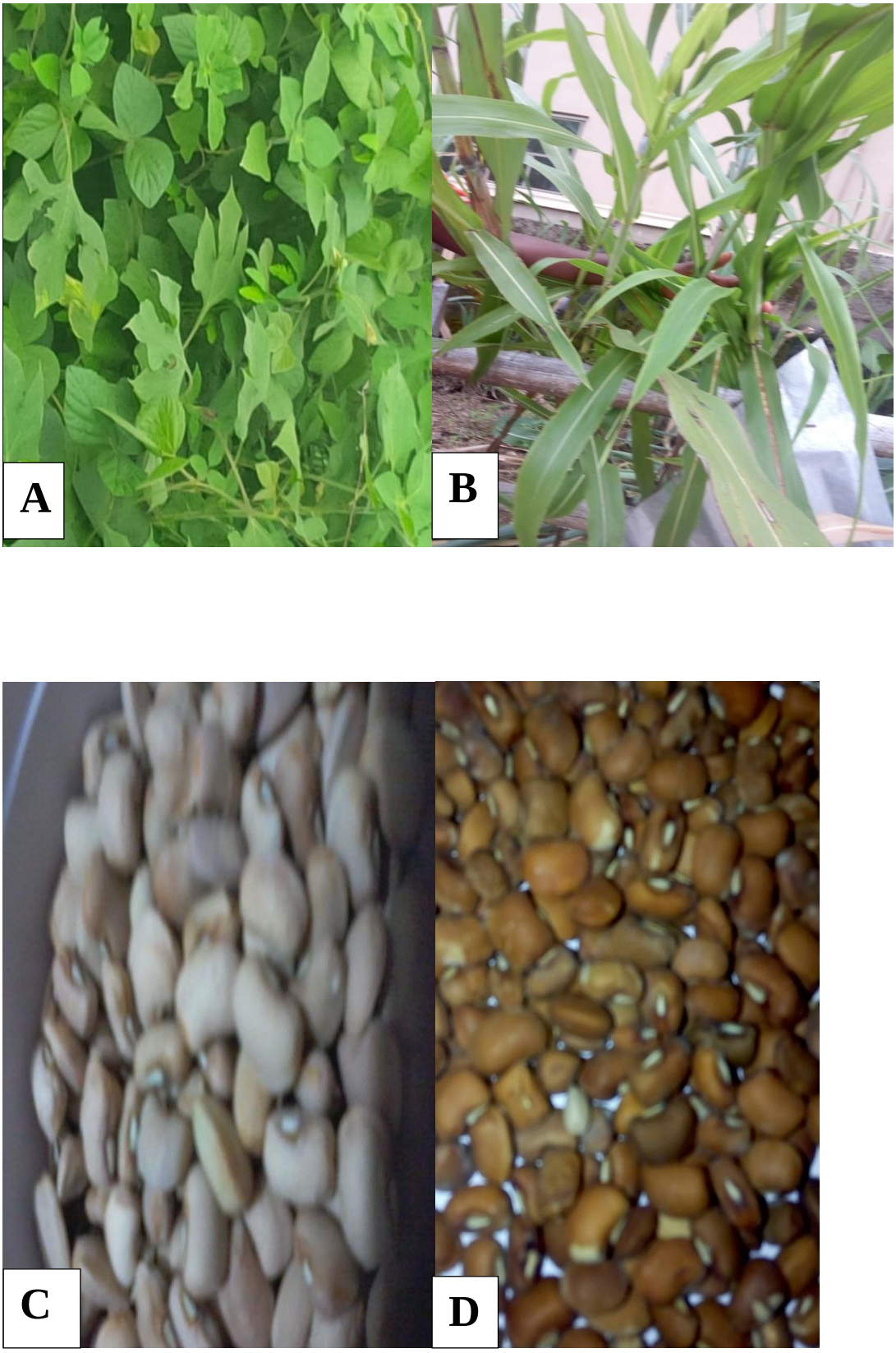


Plate 2: Research Materials used for the study

A: *Tithonia diversifolia* B: *Sorghum bicolor*

C: Cowpea seeds (IT 84E-124) D: Cowpea seeds (Ife Brown)

3.5 DETERMINATION OF THE ALLELOCHEMICAL CONSTITUENTS OF THE AQUEOUS EXTRACTS OF *T. diversifolia*

The allelochemical constituents of the aqueous extracts of *T. diversifolia* were determined by spectrophotometric method at the Biochemistry Laboratory, Obafemi Awolowo University, Nigeria as described in the subsequent sections.

3.5.1 Preparation of the aqueous extracts for the biochemical analysis

Aqueous extracts from the root, stem and leaf of *T. diversifolia* were prepared using the procedure of Olajire and Azeez (2011), by soaking 0.5 g of the dried plant parts in 25 ml of distilled water for 24 hours. The mixture was centrifuged at 3,000 revolutions per minute (rpm) for ten minutes and the supernatant was collected and stored at -4 ^{o}C for the analyses.

3.5.2 Determination of total alkaloid content

The total alkaloid content of the aqueous extract from separate plant parts was measured using 1, 10-phenanthroline method as described by Singh *et al*. (2004). A separate aliquot (1 ml) of each extract was mixed with 1 ml of 0.025M $FeCl_3$ in 0.5M HCl and 1 ml of 0.05M of 1, 10- phenanthroline. The mixture was incubated for 30 minutes in water bath with temperature maintained at 70° C. The absorbance of the red-coloured complex was measured at 510 nm against a reagent blank. Alkaloid content was expressed as mg quinine per g of the sample dry weight. The experiment was done in triplicates.

3.5.3 Determination of total flavonoid contents

Total flavonoid content of the aqueous extract from separate plant part was determined using $AlCl_3$ method as reported by Kale *et al*. (2010). A (0.5 ml) of each extract was dispensed into test tube, followed by 1.5 ml of methanol, 0.1 ml of 10% aluminium chloride, 0.1 ml of 1 M potassium acetate and 2.8 ml of distilled water. The mixture was

shaken and allowed to stay at room temperature for 30 minutes, after which the absorbance was measured at 514 nm. Total flavonoid content was expressed as mg flavonoid/mg quercetin. This assay was carried out in triplicate.

3.5.4 Determination of total phenol content

The total phenol content of the aqueous extact from separate plant parts was determined by using Folin-Ciocalteus method as modified by Olajire and Azeez (2011). A 0.5 ml of each extract was added to ten ml of deionized distilled water and 2.5 ml of 0.2 N Folin-Ciocalteu's phenol reagent. The mixture was allowed to stand for five minutes at room temperature before adding two ml of sodium carbonate. The absorbance was measured at 780 nm after ten minutes using quercetin as standard for calibration curve. This assay was carried out in triplicate.

3.5.5 Determination of total saponin content

Total saponin content of the aqueous extract from separate plant parts was determined by the method described by Makkar *et al*. (2007). An aliquot **(**0.25 ml) of each extract was mixed with 0.25 ml vanillin reagent (8% vanillin in ethanol) and 2.5 ml of 72% aqueous H_2SO_4 in test tubes. The test tubes mixtures were heated in a water-bath at 60° C for ten minutes, cooled in ice for four minutes and then, allowed to acclimatize to room temperature. Subsequently, the absorbance was measured at 544 nm. Diosgenin was used as a standard and the results obtained were expressed as mg diosgenin equivalent per g of extract dry weight. The experiment was done in triplicate.

3.5.6 Determination of total tannin content

Total tannin content of the aqueous extract of separate plant part was determined according to the method of Padmaja (1989). An aliquot (0.1 ml) of each extract was mixed with 7.5 ml of distilled water, 0.5 ml of Folin-Denis reagent, and one ml of 35% sodium

carbonate solution, and diluted to ten ml with distilled water. The mixture was shaken well and allowed to stay at room temperature for 30 minutes, after which the absorbance was measured at 760 nm. A blank was prepared with water instead of the extract. Tannin content was expressed as tannic acid equivalent in mg/g of extract dry weight. The experiment was done in triplicate.

3.6 IDENTIFICATION AND QUANTIFICATION OF PHENOLIC COMPOUNDS IN *T. DIVERSIFOLIA* BY HPLC

The identification and quantification of some of the phenolic compounds in *T. diversifolia* were done by using Agilent HPLC 1100 series with an online degasser, a variable wave length detector (VWD), autosampler, radwag analytical balance, Hama H13220 pH Meter, Uniscope SM800M Centrifuge and Thermostated Water-Bath MIC WTB.

3.6.1 Preparation of the extract of *T. diversifolia* for the HPLC analysis

Approximately one g each of the freeze-dried crude extract from the root, stem and leaf of *T. diversifolia* was weighed and transferred to a flask. A 25 ml (A) of 70% ethanol was added to the sample in the flask and refluxed for four hours at 80° C. The residue left in the flask after drying was re-constituted with three ml (C) HPLC-grade methanol, centrifuged and transferred to vials for HPLC.

3.6.2 HPLC Conditions

HPLC was conditioned according to the procedure of Gupta *et al*. (2012). Ten milligrammes (10 mg) of each of the standards was weighed, and transferred to a 50 ml volumetric flask and made up to the mark with methanol to give a stock solution containing 0.2 mg/ml concentration (200 µg/ml). Calibration working standards of 20 µg/ml, 10 µg/ml, 5 µg/ml and 2.5 µg/ml were prepared by dilution of the stock solution

and transferred to HPLC vials for HPLC analysis. The standard free phenol compounds used for HPLC analyses were p–hydroxybenzoic acid, vanillic acid, resorcinol and p-benzoquinone. The amount on the chromatogram represents the amount in three ml of the reconstituted sample and was calculated as follows:

Amount per gm of sample = amount µg/ml × C × A/W × B,

where: A = volume of ethanol in water used (25 ml),

B = volume of clear layer evaporated (20 ml),

C = volume of HPLC Grade Methanol used to reconstitute (3 ml) and

W = weight of sample taken.

3.7 PREPARATION OF AQUEOUS EXTRACTS

3.7.1 Preparation of aqueous extracts of *T. diversifolia*

Aqueous extracts were prepared according to the procedure of Hua *et al*. (2005) with little modification. Fresh *T. diversifolia* plants were collected, cleaned and separated into root, stem and leaves. The plant parts were chopped into three-five cm pieces and air-dried at room temperature (27 ± 2° C) to constant weight. The dried plant materials were milled into fine powder with A2 grinder and sieved through a ten-mm sieve. One thousand grams (1000 g) of the powder of plant parts were extracted in ten litres of distilled water for 24 hours at room temperature (27 ± 2° C) to obtain 10% (w/v concentration). The resulting mixtures were sieved through four layers of Muslin cloth and reserved for use. The extracted filtrates were designated as 100% strength. These full-strength filtrates were either used directly as 10% (w/v) concentration or diluted with distilled water to produce 5% (w/v) concentration.

3.7.2 Preparation of aqueous extract of *Sorghum bicolor*

Aqueous extract of *Sorghum bicolor* was prepared according to the procedure of Hussain and Gadoon (1981). Mature whole *Sorghum* plant residues were collected from farmers' plots after harvesting and air-dried for seven days. The dried *Sorghum* plant residues were chopped into about five cm pieces with a fodder cutter. Chopped plant materials were air-dried at room temperature to a constant weight, milled with A2 grinder into fine powder and sieved through a ten-mm sieve. The powder was soaked in the ratio of 1000 g: 10 l of distilled water to obtain 10% (w/v) concentration. The water extract was obtained by filtering the mixture through four layers of Muslin cloth.

3.8 FIELD EXPERIMENTS I and II

3.8.1 Experimental Design

The experimental field was laid out in randomized complete block design (RCBD) with three replications and a net plot size of 3 m × 3 m. There were ten treatments for each of the two cowpea accessions (IT 84E-124, Ife Brown) in the field I experiment as shown in Figure 2.

A	TRE 10 3m 3m	1m	TSE 5		TLE 10		GLY		SE 10		TSE 10		HW		TRE5		WC		TLE5
	1m	1m																	
B	HW 3m 3m	1m	TSE 10		SE 10		TSE 5		TRE 10		GLY		TLE 5		TLE 10		TRE 5		WC
	1m																		
C	TRE 5 3m 3m	1m	HW		TSE 5		TRE 10		TLE 5		TSE 10		WC		GLY		TLE 10		SE10

Figure 2: Experimental lay-out of Field Experiment I
Key: TRE = *Tithonia* Root Extract, TSE = *Tithonia* Stem Extract, TLE = *Tithonia* Leaf Extract, SE *Sorghum* Extract, WC = Weedy Check, GLY= Glyphosate, HW = Hand weeding, 10 = 10% (w/v) concentration, 5 = 5% (w/v) concentration.

The treatments were:

1. TRE 10 *Tithonia* Root Extract at 10.0% (w/v) concentration
2. TRE 5 *Tithonia* Root Extract at 5.0% (w/v) concentration
3. TSE 10 *Tithonia* Stem Extract at 10.0% (w/v) concentration
4. TSE 5 *Tithonia* Stem Extract at 5.0% (w/v) concentration
5. TLE 10 *Tithonia* Leaf Extract at 10.0% (w/v) concentration
6. TLE 5 *Tithonia* Leaf Extract at 5.0% (w/v) concentration
7. SE 10 *Sorghum* Extract at 10.0% (w/v) concentration
8. WC Weedy Check
9. GLY Herbicide (Glyphosate)
10. HW Hand weeding (Weed-Free)

However, in field experiment II, there were eight treatments for Ife Brown accession as shown in Figure 3. The treatments were:

1. TSE 10.0 *Tithonia* Stem Extract at 10% (w/v) concentration
2. TSE 7.5 *Tithonia* Stem Extract at 7.5% (w/v) concentration
3. TLE 10 *Tithonia* Leaf Extract at 10% (w/v) concentration
4. TLE 7.5 *Tithonia* Leaf Extract at 7.5% (w/v) concentration
5. SE 10 Sorghum Extract at 10% (w/v) concentration
6. WC Weedy Check
7. GLY Herbicide (Glyphosate)
8. HW Hand weeding

A	TSE 10 3m 3m 1m		TLE 7.5		SE 10		GLY		WC		TLE 10		HW		TSE 7.5
	1m	1m													
B	WC 3m 3m	1m	TLE 10		TSE 7.5		HW		TSE 10		SE 10		TLE 7,5		GLY
	1m														
C	GLY 3m 3m	1m	SE 10		TLE 10		TSE 7.5		TLE 7.5		WC		TSE 10		HW

Figure 3: Experimental lay-out of Field Experiment II
Key: TSE = *Tithonia* Stem Extract, TLE = *Tithonia* Leaf Extract, SE = Sorghum Extract, 7.5 = 7.5% (w/v) concentration, 10 = 10% (w/v) concentration, GLY = Glyphosate, WC = Weedy Check, HW = Hand weeding.

3.8.2 Cultivation of cowpea

3.8.2.1 Land Preparation

In Field Experiment I, six hundred (600 m) by 600 m of land was cleared and ploughed manually to produce flat weed-free (no debris of fallow weeds) seed beds. The land was fenced with net and divided into 3 m by 3 m plots to give ten plots per block. The ten treatments were randomly allocated to the ten plots in each of the three blocks. There were 1-m alleyways between the plots and between the blocks as shown in Figure 2. The plots were also labelled appropriately based on the treatments applied. While in Field Experiment II, 240 m × 240 m piece was cleared and ploughed manually into to produce flat weed-free seed beds. The land was fenced with net and divided into plots of 3 m × 3 m to give eight plots per block. Also, there were 1-m alleyways between the plots and between the blocks. The plots were labelled appropriately based on the treatments applied. The eight treatments were randomly allocated to the eight plots (Figure 3) and there were three replicates.

3.8.2.2 Sowing of cowpea

In Field Experiment I, two cowpea accessions (IT 84E-124 and Ife Brown) were sown at a seed rate of 25 kg/ha and 75 cm × 30 cm spacing (Dugje *et al*., 2009; Aladejimokun *et al*., 2014) while Ife Brown was sown at the same rate in the Field Experiment II. Each plot comprised of 100 seeds (one seed per stand).

3.8.2.3 Application of the aqueous plant extracts and herbicide

In Field Experiment I, 10% and 5% (w/v) concentrations of aqueous extracts from the root, stem and leaves of *T. diversifolia* were applied at the rate of 20 l/ha at 2, 21 and 35 days after planting (DAP) using a knapsack sprayer on different plots as indicated in the experimental lay out (Figure 2). *Sorghum* extract (SE 10) was also applied at the same rate

on the same date on SE 10 treated plots as indicated in the experimental lay out (Figure 6). However, for the herbicide-treated plots, glyphosate was carefully applied on the same date at 3 l/ha while the weeds were removed from the hand weeded plots by hand pulling. The weedy check plots were left untreated. The extracts and the herbicides were carefully applied in between the cowpea stands in each plot as indicated in the experimental lay out (Figure 2). The cowpea stands were protected by directing the nostle away from them. The plants were protected from insect attack by applying Lambdacyhalothrin (Karate) at the rate of 2 ml/l starting from four weeks after planting (WAP) and at seven-day intervals till crop harvest. On the other hand, in Field Experiment II, 7.5% 10% (w/v) concentrations of the aqueous extracts from the stem and leaf of *T. diversifolia* were applied at the rate of 20 l/ha at 2, 21 and 35 DAP for weed control as indicated in the experimental lay out (Figure 3). However, for the herbicide-treated plots, glyphosate was applied on the same date at the rate of 3 l/ha while, the weeds were removed from hand weeded plots by hand-pulling as indicated in the experimental lay out (Figure 3). The weedy check plots were left untreated. The plants were also protected from the extracts and herbicides, and insect pest attack accordingly.

3.8.3 Investigation of the allelopathic effects of *T. diversifolia* on germination and seedling growth of cowpea

The allelopathic effects of *T. diversifolia* extracts on germination and seedling development of the two accessions of cowpea were investigated by collecting data on germination and seedling growth parameters as described below.

3.8.3.1 Germination

Germination percentage was recorded from each plot by physically counting the number of seeds that germinated at seven DAP.

3.8.3.2 Seedling growth

Data on plant height, number of leaves per plant, root length, shoot dry weight and root dry weight were recorded from five seedlings randomly sampled from each plot. Plant height and root length were measured with a 30-cm ruler. Leaves per seedling were counted and recorded. Thereafter, the whole seedling were carefully uprooted with a ball of earth and lowered into a bucket of water to loosen the soil and ensure full recovery of the root system (Awodoyin and Ogunyemi, 2005). Each of the seedlings was separated into shoot and root, packaged separately in paper envelopes and oven-dried to a constant weight at 70^{o} C in a Uniscope SM 9053 Laboratory Oven. The dried plant parts were then weighed on a mettler balance (model P1210) to obtain dry weight.

3.8.4 Assessment of weed suppressive effects of aqueous extracts of *T. diversifolia* on weeds of cowpea cropping system

The weed suppressive effect of the aqueous extracts of *T. diversifolia* on weeds in the cropping systems of the two cowpea accessions and one accession in the Field Experiments I and II respectively, were assessed by estimating the total weed densities at 30 and 65 DAP. At 30 DAP, the weed species were enumerated from two 0.5 m × 0.5 m quadrat samples randomly placed in each plot. The data obtained were used for computing weed density. However, at 65 DAP, (after the enumeration), weeds were harvested by clipping the stands at soil level and packed in separate paper envelopes. The weeds harvested from each plot were dried to a constant weight at 70° C in a Uniscope SM9053 Laboratory Oven. The dried weeds were then weighed on a mettler balance (model P1210) to obtain dry weight. The weed flora harvested from the weedy check plots were separated by species and packed in separate envelopes for identification at the Herbarium Unit of the Botany Department, Obafemi Awolowo University, Ile-Ife, Osun State, Nigeria.

3.8.5 Evaluation of the allelopathic effects of aqueous extracts of *T. diversifolia* on yield of cowpea

The allelopathic effects of the aqueous extracts of *T. diversifolia* on yield of cowpea were evaluated by collecting data on plant height, total number of pods per plant, total number of seeds per pod, grain yield and 1000-seeds weight. Data on plant height was recorded at six WAP while data on pods per plant and seeds per pod were recorded from ten randomly selected plants from each plot. The plant height was measured using 30-cm ruler while pods per plant and seeds per pod were recorded after physical counts. The first major harvesting was done on the 65 DAP for accession IT 84E-124 and on the 75 DAP for Ife Brown when about half of the pods had dried. Subsequent harvests were made at 7-days intervals until 120 DAP. The pods from each plot were spread and sun-dried for two weeks, shelled manually and the shelled grain packed in paper envelopes. The grains from each plot were weighed on a mettler balance and the weight recorded. The weights of one thousand-seeds (1000-seeds weight) from each plot were also recorded.

3.9 STATISTICAL ANALYSES

The data obtained from the field and laboratory experiments were subjected to one-way Analysis of Variance (ANOVA) using the Statistical Package for Social Sciences (SPSS 20). The mean differences were compared using pairwise comparison and Duncan's New Multiple Range Test (DMRT) at 5% level of probability (Steel and Torrie, 1984). The mean values were presented in tables and figures. The percentage decrease in relation to the WC for each parameter was calculated from the difference between the treatments (T) and WC using the equation WC-T/ WC (100). On the other hand, the percentage increase was calculated from the difference between the treatment and the control using the equation T-WC/WC (100).

CHAPTER FOUR

4.0 RESULT

4.1 BASELINE STUDY

The result of the baseline study is presented in Table 3. The dominant weed species in the experimental pots comprised of *Talinum triangulare, Chromolaena odorata, Ageratum conyzoides* and *Phalaris minor*. The highest weed density at 30 DAP was recorded from the weedy check. WC = 15.00 ± 2.67. This was significantly higher than the WD at 30 DAP (p = 0.01) recorded from each of the experimental pots. Within the aqeous extract treated pots, the least WD at 30 DAP was recorded from the pots treated with TE 10 = 3.34 ± 2.32, however, this was not significantly different from the WD at 30 DAP (p = 0.35) recorded from the pots treated with TE 20 = 3.67 ± 2.12. This was followed by the WD at 30 DAP recorded from the pots treated with SE 20 = 6.34 ± 1.21 which was not significantly different from the WD at 30 DAP recorded from the pots treated with SE 10 = 6.67 ± 1.36. Similarly, the same trend was observed in the WD at 65 DAP.

Likewise at 65 DAP, the highest WDW was recorded from the weedy check pots WC = 11.67 ± 2.84 g/pot. This was significantly higher than the WDW at 65 DAP (p = 0.02) recorded from each of the entire experimental pots. Within the aqueous extract treated pots, the least WDW at 65 DAP was recorded from the pots treated with TE 10 = 3.79 ± 0.94 g/pot. This was not significantly different from the WDW at 65 DAP (0.51) recorded from the pots treated with TE 20 = 4.08 ± 0.98 g/pot. This was followed by the WDW at 65 DAP recorded from the pots treated with SE 10 = 5.25 ± 1.02 g/pot which was not significantly different from the WDW at 65 DAP (p = 0.32) recorded from the pots treated with SE 20 = 5.28 ± 1.04 g/pot. The highest weed control efficiency (WCE) was recorded from the pots treated with TE 10 = 67.52%. This was not significantly different from the WCE (p = 0.35) recorded in the pots treated with TE 20 = 65.03%. This was

Table 3: Weed suppressive effects of aqueous extracts of *J.curcas, S. bicolor residue* and *T. diversifolia* in the baseline study

TREATMENTS	WD at 30 DAP (Number/ pot)	WD at 65 DAP (Number/pot)	WDW at 65 DAP (g/pot)	WCE (%)
JSE 20	9.00 ± 1.23[c]	15.67 ± 1.67[c]	7.34 ± 1.45[c]	37.10
JSE 10	9.34 ± 1.15[c]	14.34 ± 1.54[c]	7.67 ± 1.32[c]	34.27
TE 20	3.67 ± 2.12[a]	7.32 ± 2.71[a]	4.08 ± 0.94[a]	65.03
TE 10	3.34 ± 2.32[a]	8.00 ± 2.35[a]	3.79 ± 0.90[a]	67.52
SE 20	6.34 ± 1.21[b]	12.67 ± 1.13[b]	5.28 ± 1.04[b]	54.75
SE 10	6.67 ± 1.36[b]	12.34 ± 1.42[a]	5.25 ± 1.02[b]	55.01
WC	15.00 ± 2.67[d]	24.00 ± 5.21[d]	11.67 ± 2.84[d]	0

JSE = *Jatropha* Shoot Extract, TE = *Tithonia* Extract, SE *Sorghum* Extract WC = Weedy check, DAP = Days after Planting, WD = Weed density, WDW = Weed Dry Weight, WCE = Weed Control Efficiency, 20 = 20% (w/v) concentration, 10 = 10% (w/v) concentration.

Values in a column followed by the same letter are not significantly different by DMRT at $p > 0.05$.

followed by the WCE observed in the pots treated SE 10 = 55.01%. This was not significantly different from WCE (p = 0.51) obtained with the application of SE 20 = 54.75%.

4.2 ALLELOCHEMICAL CONSTITUENTS OF AQUEOUS EXTRACTS OF *T. diversifolia*

The results of the allelochemical constituents of the aqueous extracts from the different parts of *T. diversifolia* as determined by the spectrophotometric method are presented in Table 4. The screening of the aqueous extracts of *T. diversifolia* indicated the presence of tannins, phenols, alkaloids, flavonoids and saponins. The result indicated that TLE had the highest quantity (mg/g) of all the allelochemicals quantified. TLE had 2.42 ± 0.59 mg/g total phenol, 0.60 ± 0.09 mg/g flavonoid, 1.75 ± 0.31 mg/g tannin 1.82 ± 0.50 mg/g saponin and 1.50 ± 0.45 mg/ alkaloids. These were significantly higher than the quantities obtained in TRE and TSE (p = 0.00).

The differences in the concentration of phenols in the TLE and SE were statistically significant (p = 0.02) while the difference observed in the concentration of phenols in TRE and TSE was not statistically significant (p = 0.12). The concentrations of tannins in the extracts were the next to that of phenols in TSE, while TRE and SE have tannins as the highest followed by phenols. However, TLE has saponins as the next to phenols followed by tannins. TLE also had the highest concentration of tannin (1.75 ± 0.01 mg/g). This was significantly higher (p = 0.00) than the concentrations in TRE and TSE. Consequently, the concentration of saponin in TLE was significantly higher (p = 0.02) than the concentration in TRE and TSE. The concentration of saponin in SE was 0.67 ± 0.08 mg/g. Flavonoids had the least concentration in TLE (0.60 ± 0.09 mg/g) while alkaloids had the least

Table 4: Allelochemical constituents (mg/g) aqueous extracts of *T. diversifolia*

Allelochemicals	TRE	TSE	TLE	SE
Phenols	0.76 ± 0.24^{b}	0.84 ± 0.20^{b}	2.42 ± 0.59^{a}	0.95 ± 0.15^{b}
Flavonoids	0.34 ± 0.04^{c}	0.29 ± 0.07^{c}	0.60 ± 0.09^{a}	0.47 ± 0.02^{b}
Tannins	0.90 ± 0.11^{c}	0.82 ± 0.15^{c}	1.75 ± 0.31^{a}	1.04 ± 0.04^{b}
Saponins	0.42 ± 0.20^{c}	0.37 ± 0.23^{c}	1.82 ± 0.50^{a}	0.67 ± 0.08^{b}
Alkaloids	0.19 ± 0.21^{c}	0.17 ± 0.22^{c}	1.50 ± 0.45^{a}	0.54 ± 0.03^{b}

Key: TRE = *Tithonia* Rooot Extract, TSE = *Tithonia* Stem Extract, TLE = *Tithonia* Leaf Extract, SE = Sorghum Extract.
Values in a row followed by the same letter are not significantly different by DMRT at $p > 0.05$.

concentration in TRE and TSE (0.19 ± 0.21 mg/g and 0.17 ± 0.22 mg/g) respectively (Table 4).

4.3 QUANTIFICATION OF FREE PHENOLIC COMPOUNDS IN AQUEOUS EXTRACT OF *T. diversifolia* BY HPLC

Table 5 shows the quantities of resorcinol, vanillic acid, p-hydroxybenzoic acid and p-benzoquinone that are present in the extracts of *T.diversifolia* as determined by HPLC. The most abundant phenolics in the extracts from all the plant parts was p-hydroxybenzoic acid. The concentration in TLE was 666.15 µg/g. However, resorcinol and vanillic acid were found in lesser amounts in TLE (44.07 µg/g and 41.02 µg/g) respectively, but absent in TRE and TSE.

The chromatograms of the free phenolic compounds in *T. diversifolia* extracts as detected by HPLC are presented in Figures 4-10.

Table 5: Phenolic composition (µg/g) aqueous extracts of *T. diversifolia* by HPLC

Phenolic compound	**TRE**	**TSE**	**TLE**	**SE**
Resorcinol (µg/g)	ND	ND	44.07	7.32
Vanillic acid (µg/g)	3.33	9.20	41.02	22.51
p-hydroxybenzoic acid (µg/g)	36.84	291.11	666.15	576.39
p-benzoquinone (µg/g)	8.18	46.92	237.18	58.82

Key: TRE = *Tithonia* Root Extract, TSE = *Tithonia* Stem Extract, TLE = *Tithonia* Leaf Extract, SE = Sorghum Extract, ND = Not detected

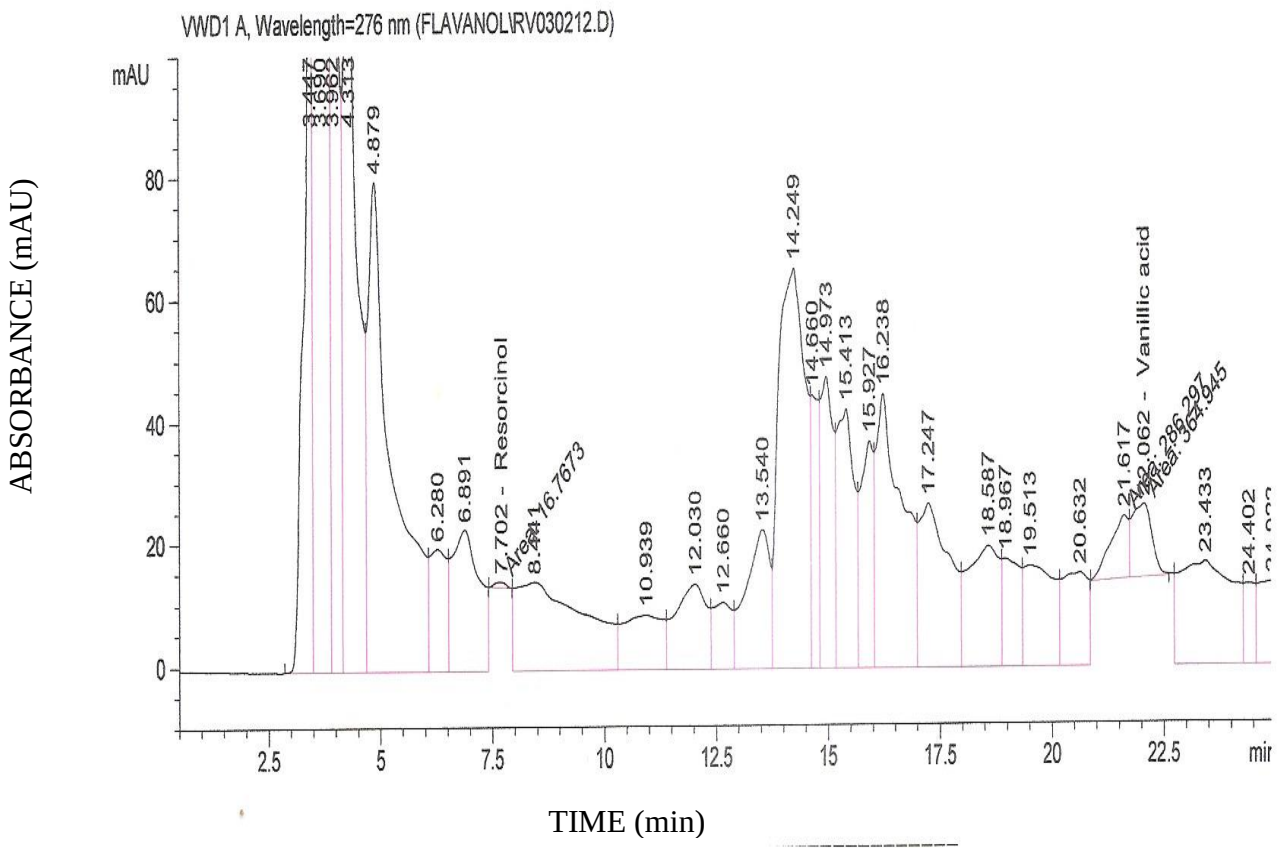


Figure 4: HPLC chromatogram of *T.diversifolia* leaf extract showing resorcinol and vanillic acid

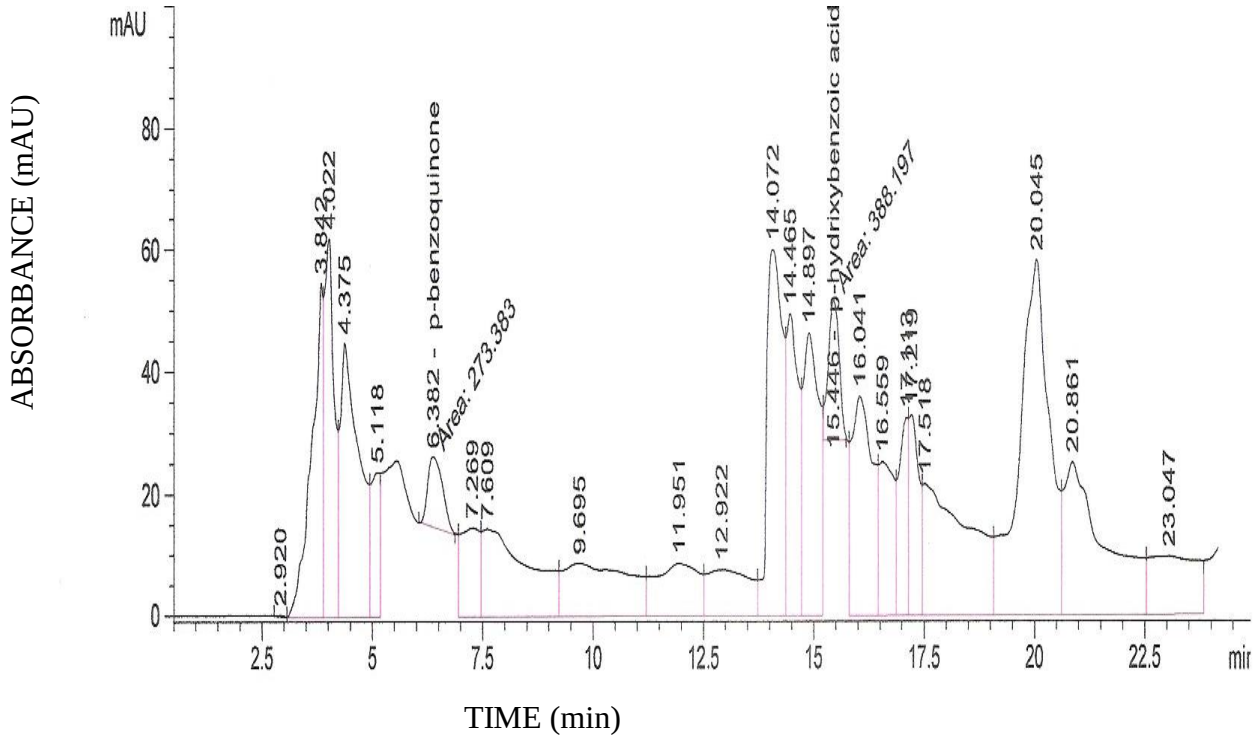


Figure 5: HPLC chromatogram of *S. bicolor* extract showing p-benzoquinine and p-hydroxybenzoic acid

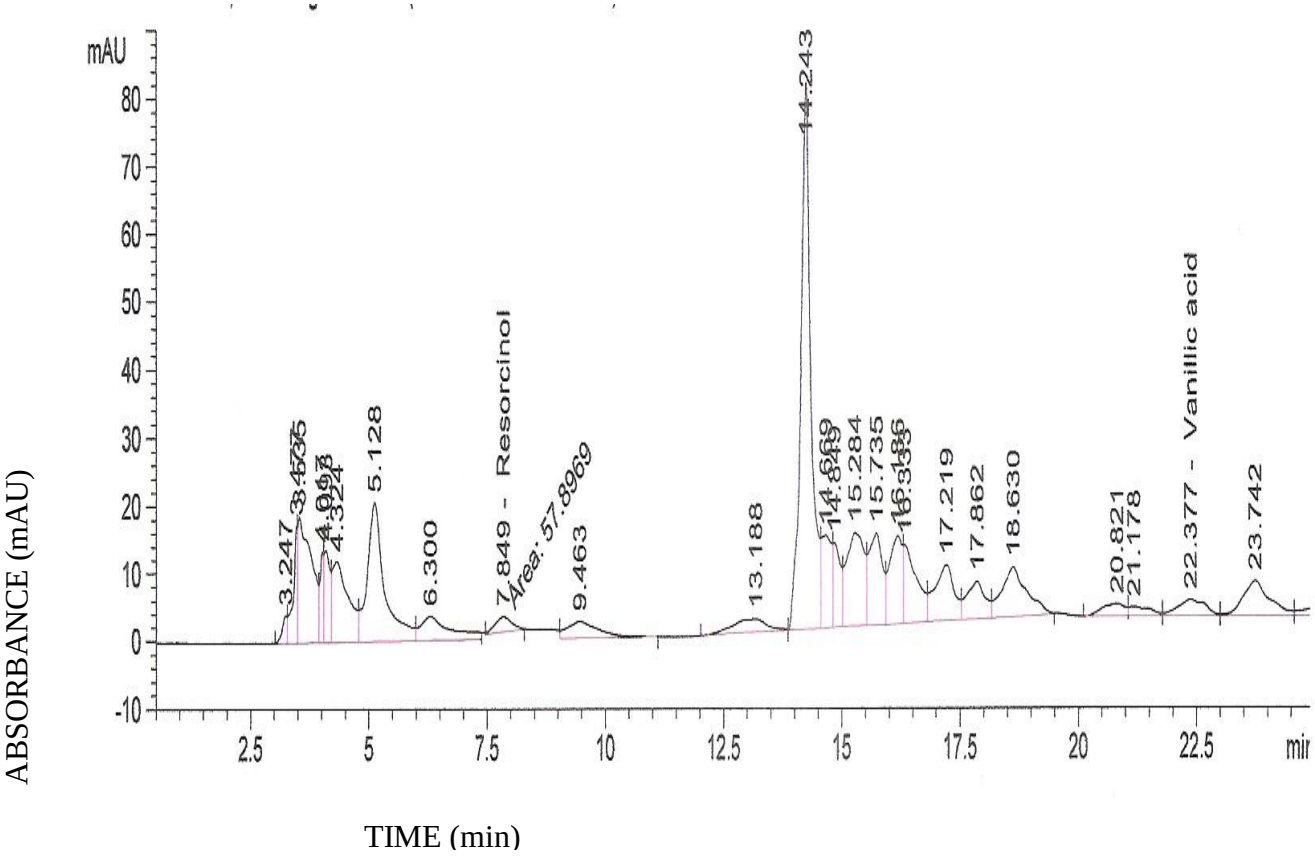


Figure 6: HPLC chromatogram of *S. bicolor* extract showing resorcinol and vanillic acid

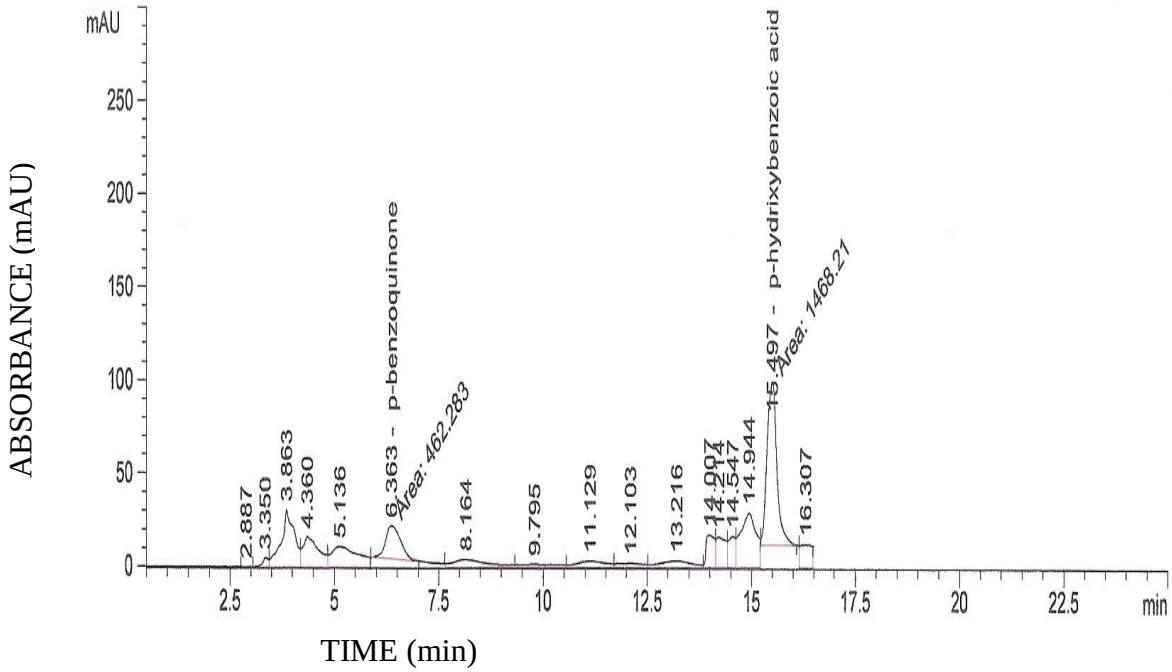


Figure 7: HPLC chromatogram of *T. diversifolia* stem extract showing p-benzoquinone and p-hydroxybenzoic acid

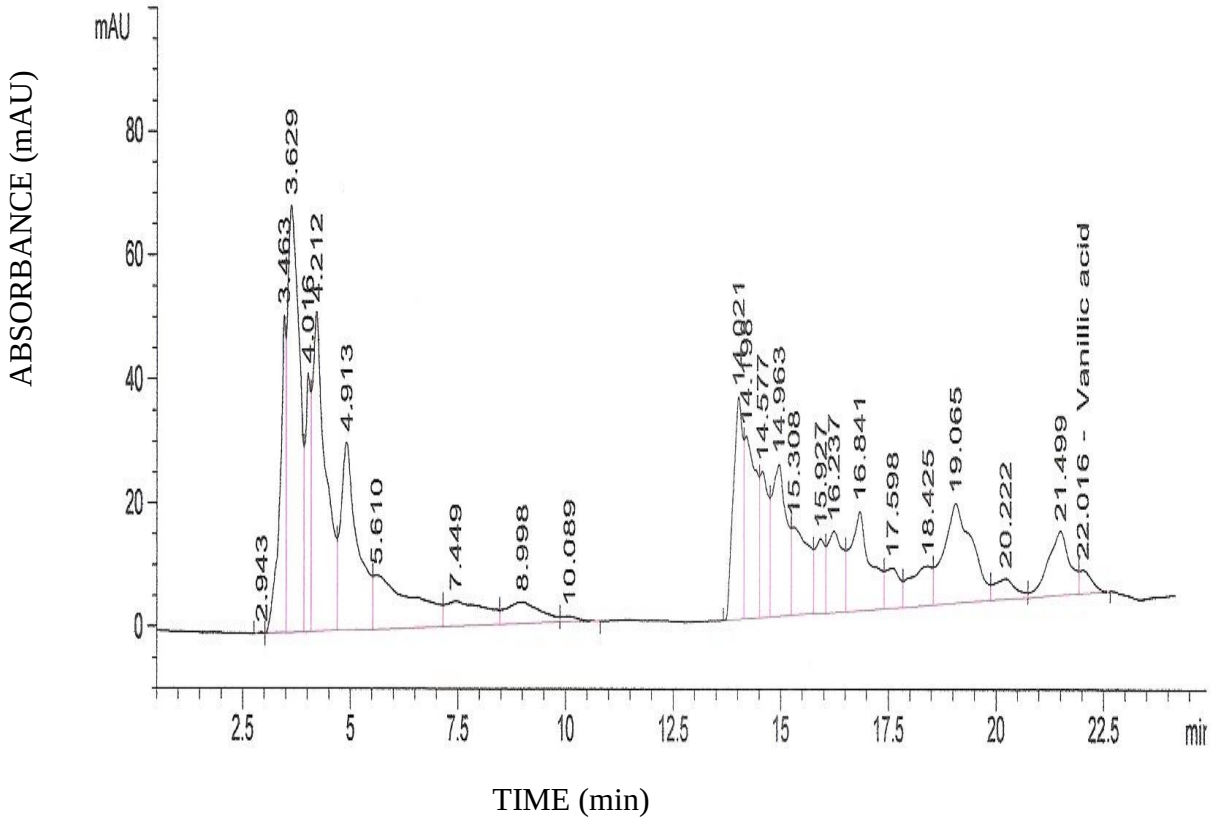


Figure 8: HPLC chromatogram of *T. diversifolia* stem extract showing vanillic acid

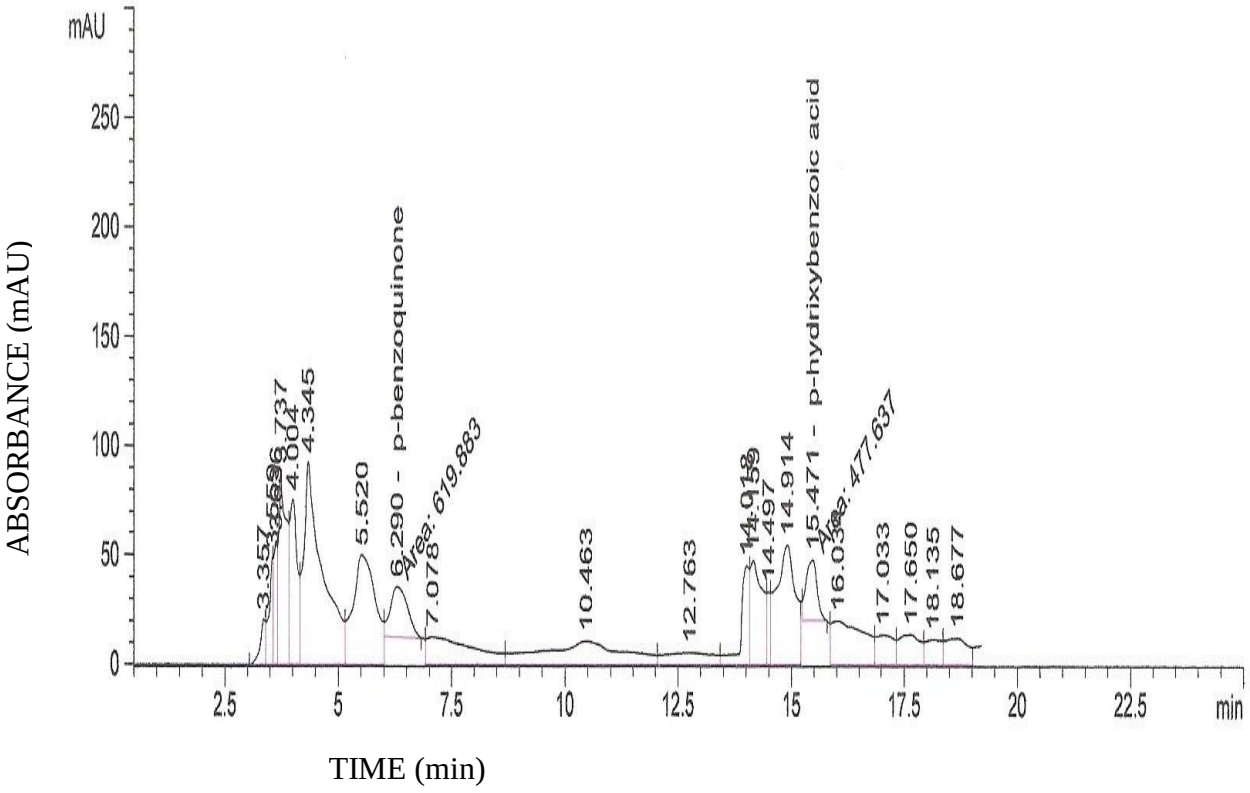
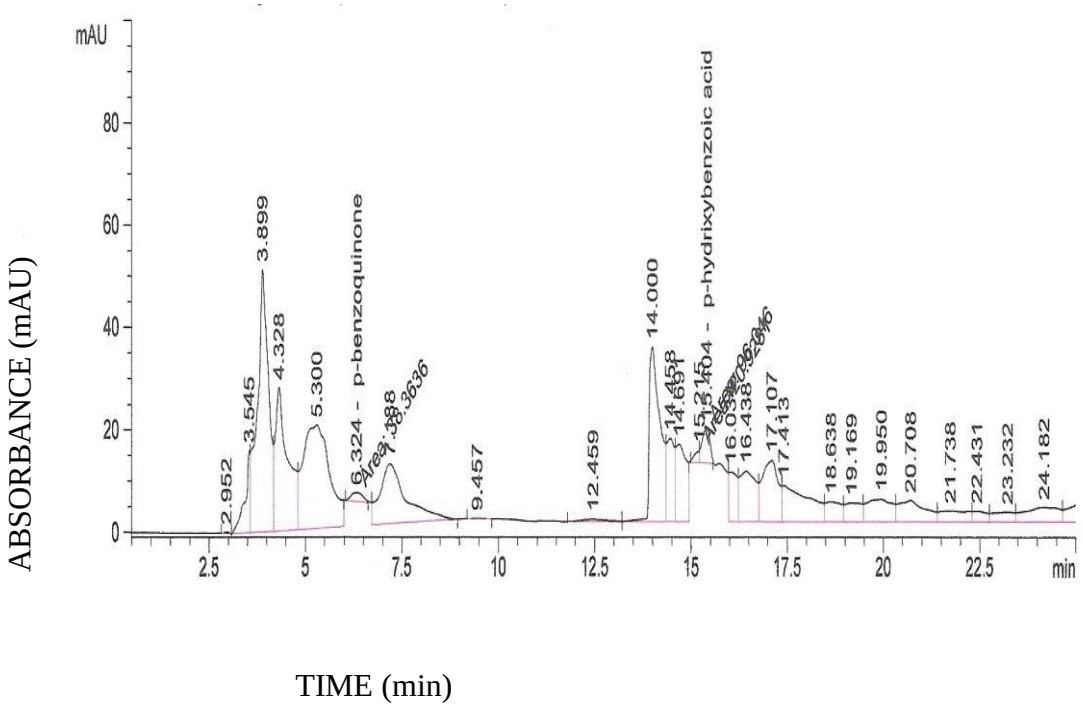


Figure 9: HPLC chromatogram of *T.diversifolia* leaf extract showing p-benzoquinone and p-hydroxybenzoic acid



ABSORBANCE (mAU)

TIME (min)

Figure 10: HPLC chromatogram of *T.diversifolia* root extract showing p-benzoquinone and p-hydroxybenzoic acid

4.4 BACKGROUND SOIL PHYSICOCHEMICAL PROPERTIES

The results of the baseline physicochemical analysis of the air – dried soil are presented in Tables 6 and 7. The results showed that the soil of the Field Experiment I was made up of sand 75%, silt 5% and clay 20% and total nitrogen was 0.3% and available phosphorus was 20.93 mg/kg. The soil is loamy sand, slightly acidic and marginally fertile. The soil also contained low amounts of Ca, Mg and Na (Table 6).

Also, the soil of the Field Experiment II was made up of sand 74%, silt 6% and clay 20% and total nitrogen was 0.40% and available phosphorus was 21.93 mg/kg. The soil is loamy sand, slightly acidic and marginally fertile with low amounts of Ca, Mg and Na (Table 7).

Table 6: Baseline physicochemical properties of the soil (Field Experiment I)

Property	**Value (%)**
Sand	74
Silt	6
Clay	20
Textural class	Loamy sand
pH	6.45
Total organic carbon	2.01
Total Nitrogen	0.30
Moisture content	16.47
Soil organic matter	3.47
Available Phosphorus (mg/kg)	20.93
Calcium (mg/kg)	1.02
Magnesium (mg/kg)	115.81
Sodium (mg/kg)	31.53

Table 7: Baseline physicochemical properties of the soil (Field Experiment II)

Property	**Value (%)**
Sand	75
Silt	5
Clay	20
Textural class	Loamy sand
pH	6.49
Total organic carbon	2.05
Total Nitrogen	0.40
Moisture content	16.57
Soil organic matter	3.45
Available Phosphorus (mg/kg)	21.93
Calcium (mg/kg)	1.05
Magnesium (mg/kg)	116.38
Sodium (mg/kg)	32.23

4.5 FIELD EXPERIMENT 1

4.5.1 The allelopathic effects of the aqueous extracts of *T. diversifolia* on germination and seedling growth of the two cowpea accessions.

The results of the allelopathic effects of the aqueous extracts from the different parts of *T. diversifolia* on germination, plant height, and root length at four weeks after planting (4 WAP) of the two accessions of cowpea are presented in Table 8. While the results of the allelopathic effects of the aqueous extracts from the different parts of *T. diversifolia* on the leaves per plants, shoot dry weight and root dry weight at 4 WAP are presented in Table 9.

Table 8: The allelopathic effects of aqueous extracts of *T. diversifolia* on germination and seedling growth of the two cowpea accessions

Treatments	Germination %		Shoot Length at 4 WAP (cm)		Root Length at 4 WAP (cm)	
	IT 84E-124	IFE BROWN	IT 84E-124	IFE BROWN	IT 84E-124	IFE BROWN
TRE10	97.00 ± 0.24^{a}	98.33 ± 0.05^{a}	17.59 ± 0.72^{d}	19.81 ± 0.63^{d}	13.50 ± 0.46^{d}	14.30 ± 0.40^{d}
TRE5	97.33 ± 0.13^{a}	98.00 ± 0.05^{a}	17.07 ± 0.88^{d}	19.23 ± 0.81^{d}	13.32 ± 0.52^{d}	14.17 ± 0.44^{d}
TSE10	98.33 ± 0.17^{a}	98.00 ± 0.05^{a}	19.70 ± 0.05^{c}	21.90 ± 0.02^{c}	14.60 ± 0.12^{c}	15.20 ± 0.12^{c}
TSE5	97.33 ± 0.13^{a}	98.00 ± 0.05^{a}	17.96 ± 0.60^{d}	19.47 ± 0.74^{d}	13.13 ± 0.58^{d}	14.03 ± 0.48^{d}
TLE10	97.67 ± 0.03^{a}	97.67 ± 0.02^{a}	24.93 ± 1.60^{a}	26.23 ± 1.39^{a}	17.13 ± 0.67^{a}	18.30 ± 0.86^{a}
TLE5	97.00 ± 0.24^{a}	97.67 ± 0.02^{a}	17.48 ± 0.75^{d}	19.78 ± 0.64^{d}	13.30 ± 0.53^{d}	14.37 ± 0.38^{d}
SE10	98.33 ± 0.03^{a}	98.00 ± 0.05^{a}	20.78 ± 0.28^{c}	21.39 ± 0.13^{c}	14.70 ± 0.09^{c}	15.24 ± 0.11^{c}
WC	98.00 ± 0.07^{a}	98.00 ± 0.05^{a}	15.23 ± 1.46^{e}	15.07 ± 1.81^{e}	12.27 ± 0.85^{e}	12.73 ± 0.89^{e}
GLY	98.67 ± 0.28^{a}	98.66 ± 0.02^{a}	19.18 ± 0.21^{c}	21.02 ± 0.25^{c}	14.64 ± 0.10^{c}	15.34 ± 0.07^{c}
HW	98.67 ± 0.28^{a}	99.00 ± 0.26^{a}	22.05 ± 1.69^{b}	23.12 ± 0.41^{b}	15.57 ± 0.19^{b}	16.74 ± 0.37^{b}

TRE = *Tithonia* Root Extract, TSE = *Tithonia* Stem Extract, TLE = *Tithonia* Leaf Extract, SE *Sorghum* Extract WC = Weedy check, GLY= Glyphosate, HW = Hand weeding, WAP = Weeks after Planting, 10 = 10% (w/v) concentration, 5 = 5% (w/v) concentration.
Values in a column followed by the same letter are not significantly different by DMRT at $p > 0.05$.
Values = mean value ± standard error

Table 9: The allelopathic effects of aqueous extracts of *T. diversifolia* on number of leaves/plant, shoot dry weight and root dry weight of the two cowpea accessions

Treatments	Leaves/plant at 4 WAP		Shoot dry weight at 4 WAP (g)		Root dry weight at 4 WAP (g)	
	IT 84E-124	IFE BROWN	IT 84E-124	IFE BROWN	IT 84E-124	IFE BROWN
TRE10	16.83 ± 0.24^{d}	17.83 ± 0.05^{d}	3.42 ± 0.19^{d}	3.43 ± 0.04^{d}	0.74 ± 0.023^{d}	0.74 ± 0.054^{d}
TRE5	16.53 ± 0.34^{d}	17.33 ± 0.21^{d}	3.40 ± 0.20^{d}	3.41 ± 0.06^{d}	0.72 ± 0.030^{d}	0.76 ± 0.048^{d}
TSE10	17.00 ± 0.20^{c}	19.34 ± 0.42^{c}	3.77 ± 0.08^{c}	3.85 ± 0.07^{b}	0.86 ± 0.045^{c}	0.82 ± 0.030^{c}
TSE5	16.55 ± 0.34^{d}	17.55 ± 0.14^{d}	3.42 ± 0.19^{d}	3.60 ± 0.01^{c}	0.76 ± 0.016^{d}	0.78 ± 0.042^{d}
TLE10	19.97 ± 0.75^{a}	22.67 ± 1.47^{a}	4.24 ± 0.06^{a}	4.16 ± 0.17^{a}	1.14 ± 0.104^{a}	1.10 ± 0.059^{a}
TLE5	16.02 ± 0.50^{d}	17.82 ± 0.05^{d}	3.78 ± 0.08^{c}	3.64 ± 0.01^{c}	0.73 ± 0.030^{d}	0.74 ± 0.054^{d}
SE10	17.33 ± 0.09^{c}	19.83 ± 0.58^{c}	3.92 ± 0.04^{b}	3.88 ± 0.08^{b}	0.87 ± 0.018^{c}	0.85 ± 0.020^{c}
WC	13.17 ± 1.40^{d}	15.17 ± 0.89^{e}	2.93 ± 0.35^{e}	2.97 ± 0.20^{d}	0.62 ± 0.061^{e}	0.63 ± 0.089^{e}
GLY	17.91 ± 0.10^{c}	19.67 ± 0.42^{c}	3.82 ± 0.07^{c}	3.65 ± 0.01^{c}	0.85 ± 0.012^{c}	0.84 ± 0.023^{c}
HW	18.83 ± 0.39^{b}	20.34 ± 0.74^{c}	3.93 ± 0.03^{b}	3.89 ± 0.04^{b}	0.93 ± 0.006^{b}	0.98 ± 0.021^{a}

TRE = *Tithonia* Root Extract, TSE = *Tithonia* Stem Extract, TLE = *Tithonia* Leaf Extract, SE *Sorghum* Extract WC = Weedy check, GLY= Glyphosate, HW = Hand weeding, WAP = Weeks after Planting, 10 = 10% (w/v) concentration, 5 = 5% (w/v) concentration.
Values in a column followed by the same letter are not significantly different by DMRT at $p > 0.05$.
Values = mean value ± standard error

4.5.1.1. The allelopathic effects of the aqueous extracts of *T. diversifolia* on germination of the two cowpea accessions

The germination percentages ranged from 97% to 99%. There were no significant differences in the germination percentages (p = 0.51) among the various experimental plots (Table 8).

4.5.1.2 The allelopathic effects of the aqueous extracts of *T. diversifolia* on shoot lengths of two cowpea accessions at four WAP.

In accession IT 84E-124, the highest mean shoot length (SL) was observed from the regime of plants in the plots treated with TLE 10 = 24.93 ± 1.60 cm. This was significantly different (p = 0.00) from the mean SL observed from the other regimes of plants in the entire experimental plots for the accession. This was followed by the mean SL observed from the regimes of plants in the hand weeding plots HW = 22.05 ± 0.69. The mean SL recorded from the regimes of plants treated with SE 10 = 20.78 ± 0.28 cm was not significantly different from the mean SL (p = 0.65) observed from the regimes of plants in plots treated with TSE 10 = 19.70 ± 0.05 and herbicide GLY = 19.18 ± 0.21 (Table 8). However, it was significantly higher (p = 0.01) than the mean SL observed from the regimes of plants in the plots treated with TRE 10 = 17.59 ± 0.72 cm; TRE 5 = 17.07 ± 0.88 cm, TSE 5 = 17.96 ± 0.60 cm and TLE 5 = 17.48 ± 0.75 cm. The lowest mean SL was observed from the regime of plants in the weed check (control) plots WC = 15.23 ± 1.46 cm; this was significantly lower than the SL (p = 0.01) observed from the other regimes of plants in the entire experimental plots for this accession (Table 8).

Similarly, in Ife Brown accession, the highest mean SL was recorded from the regime of plants in the plots treated with the TLE 10 = 26.23 ± 1.39 cm. This was significantly different from the mean SL (p = 0.00) recorded from the other regimes of plants in the

entire experimental plots in the accession (Table 8). This was followed by the mean SL observed from the regime of plants in the hand weeding plots HW = 23.12 ± 0.41. The mean SL observed in the regime of plants in the plots treated with SE 10 = 21.39 ± 0.13 cm, was not significantly different from the SL (p = 0.52) recorded from the regimes of plants in the plots treated with TSE 10 = 21.90 ± 0.02 and herbicide GLY = 21.82 ± 0.25 (Table 8). The lowest mean SL was recorded from the regime of plants in the weedy check plots WC = 15.07 ± 1.81 cm, this was significantly different from the mean SL (p = 0.02) recorded from the other regimes of plants in the entire experimental plots in the accession (Table 8).

4.5.1.3 The allelopathic effects of the aqueous extracts of *T. diversifolia* on root length at four WAP in the two cowpea accessions

In accession IT 84E -124, the highest mean root length (RL) was observed in the regime of plants in the plots treated with TLE 10 (17.13 ± 0.67 cm). This was significantly higher than the mean RL (p < 0.00) obtained from the other regimes of plants in the entire experimental plots for this accession. This was followed by the mean RL recorded from the regime of plants in the hand weeding plots HW = 15.57 ± 0.19 cm (Table 8). The mean RL observed from the regime of plants in the herbicide-treated plots GLY = 14.64 ± 0.10 cm was not significantly different from the mean RL (p = 0.55) recorded from the regimes of plants in the plots treated with SE 10 = 14.70 ± 0.90 cm and TSE 10 = 14.60 ± 0.12 cm. The lowest RL was observed from the regime of plants in the weedy check plots WC = 12.27 ± 0.85 cm. This was significantly lower than the mean RL (p = 0.01) observed from the other regimes of plants in the entire experimental plots for this accession (Table 8).

Similarly, in Ife Brown accession, the highest mean RL was observed in the regime of plants from the plots treated with TLE 10 = 18.30 ± 0.86 cm. This was significantly higher than the mean RL (p = 0.02) observed from the orther regimes of plants in the entire experimental plots in the accession. This was followed by the mean RL recorded from the regime of plants in the hand weeding plots HW = 16.74 ± 0.37 cm (Table 8). The mean RL observed in the regime of plants in the herbicide-treated plots GLY = 15.34 ± 0.07 cm was not significantly different from the mean RL (p = 0.75) observed from the regimes of plants in the plots treated with TSE 10 = 15.20 ± 0.12 cm and SE 10 15.24 ± 0.11 cm. The lowest mean RL was also observed in the regime of plants in the weedy check plots WC = 12.73 ± 0.89 cm. This was significantly lower than the mean RL (p = 0.01) observed from the other regimes of plants in the entire experimental plots in the accession (Table 8).

4.5.1.4 The allelopathic effects of the aqueous extract of *T. diversifolia* on leaves per plant at four WAP in the two cowpea accessions

The highest mean leaves per plant (LPP) were obtained from the regime of plants in the plots treated with TLE 10 = 19.97 ± 0.75. This was significantly different from the mean LPP (p = 0.03) observed from the other regimes of plants in the entire experimental plots in the accession. This was followed by the mean LPP recorded in the regime of plants in hand weeding plots HW = 18.83 ± 0.39 (Table 9). The mean LPP observed from the regime of plants in the herbicide-treated plots GLY = 17.91 ± 0.10 was not significantly different from the mean LPP (p = 0.65) recorded from the regimes of plants in the plots treated with TSE 10 = 17.00 ± 0.20 and SE 10 = 17.33 ± 0.09 (Table 9). The lowest mean LPP was obtained from the regime of plants in the weedy check plots WC = 13.17 ± 1.40. This was significantly lower than the mean LPP (p = 0.04) observed from the other regimes of plants in the entire experimental plots in the accession (Table 9).

Similarly in Ife Brown accession, the highest mean LPP was observed from the regime of plants in the plots treated with TLE 10 = 22.67 ± 1.47. This was significantly higher than the mean LPP (p = 0.02) observed from the other regimes of plants in the entire experimental plots in the accession. This was followed by the mean LPP recorded in the regime of plants in the hand weeding plots HW = 20.34 ± 0.74 (Table 9). The mean LPP observed from the regime of plants in the herbicide-treated plots GLY = 19.67 ± 0.42 was not significantly different from the mean LPP (p = 0.51) recorded from the regimes of plants in the plots treated with TSE 10 = 19.34 ± 0.42 and SE 10 = 19.83 ± 0.58. The lowest mean LPP was also obtained from the regime of plants in the weedy check plots WC =15.17 ± 0.89. This was significantly lower than the mean LPP (p = 0.02) observed from the other regimes of plants in the entire experimental plots in the accession (Table 9).

4.5.1.5 Allelopathic effects of aqueous extracts of *T. diversifolia* on shoot dry weight at four WAP in two cowpea accessions

In accession IT 84E-124, the highest mean shoot dry weight (SDW) was observed from the regime of plants in the plots treated with TLE 10 = 4.24 ± 0.06 g. This was significantly different from the mean SDW (p = 0.01) obtained from the other regimes of plants in the entire experimental plots in the accession. This was followed by the mean SDW observed from the regime of plants in the hand weeding plots HW = 3.93 ± 0.03 g (Table 9). The mean SDW observed in the regime of plants in the herbicide-treated plots GLY = 3.82 ± 0.07 g was not significantly different from the mean SDW (p = 0.51) observed from the regimes of plants in the plots treated with TSE 10 = 3.77 ± 0.08 g and SE 10 = 3.92 ± 0.04 g. The lowest mean SDW was obtained from the regime of plants in the weedy check plots WC = 2.93 ± 0.35 g. This was significantly different from the mean SDW (p = 0.00) obtained from the other regimes of plants in the entire experimental plots in the accession (Table 9).

Similarly in Ife-Brown accession, the highest mean SDW was observed from the regime of plants in the plots treated with TLE 10 = 4.16 ± 0.17 g. This was significantly higher than the mean SDW ($p = 0.01$) obtained from the other regimes of plants in the entire experimental plots in the accession. This was followed by the mean SDW observed from the regimes of plants in the hand weeding plots HW = 3.89 ± 0.04 g and closely followed by SE 10 = 3.88 ± 0.08 and TSE 10 = 3.85 ± 0.07 (Table 9). The mean SDW observed in the regime of plants in the herbicide-treated plots GLY = 3.65 ± 0.01 g was not significantly different from the mean SDW ($p = 0.12$) observed from the regimes of plants in the plots treated with TSE 5 = 3.60 ± 0.01 g and TLE 5 = 3.64 ± 0.01 g. The lowest mean SDW was obtained from the regime of plants in the weedy check plots WC = 2.97 ± 0.20 g (Table 9).

Figure 11 shows the percentage increase in SDW in relation to the weedy check in the two cowpea accessions. The regime of plants in the plots treated with TLE 10 had 44.71% and 40.07% increases in SDW in the two accessions respectively (Figure 11). However, the regime of plants in the hand weeding plots had 34.13% and 30.97% increases in SDW while the regime of plants in the herbicide treated plots had 30.38% and 28.89% increases in SDW. The regime of plants in the plots treated with SE 10 also had 33.79% and 30.64% increases in SDW (Figure 11).

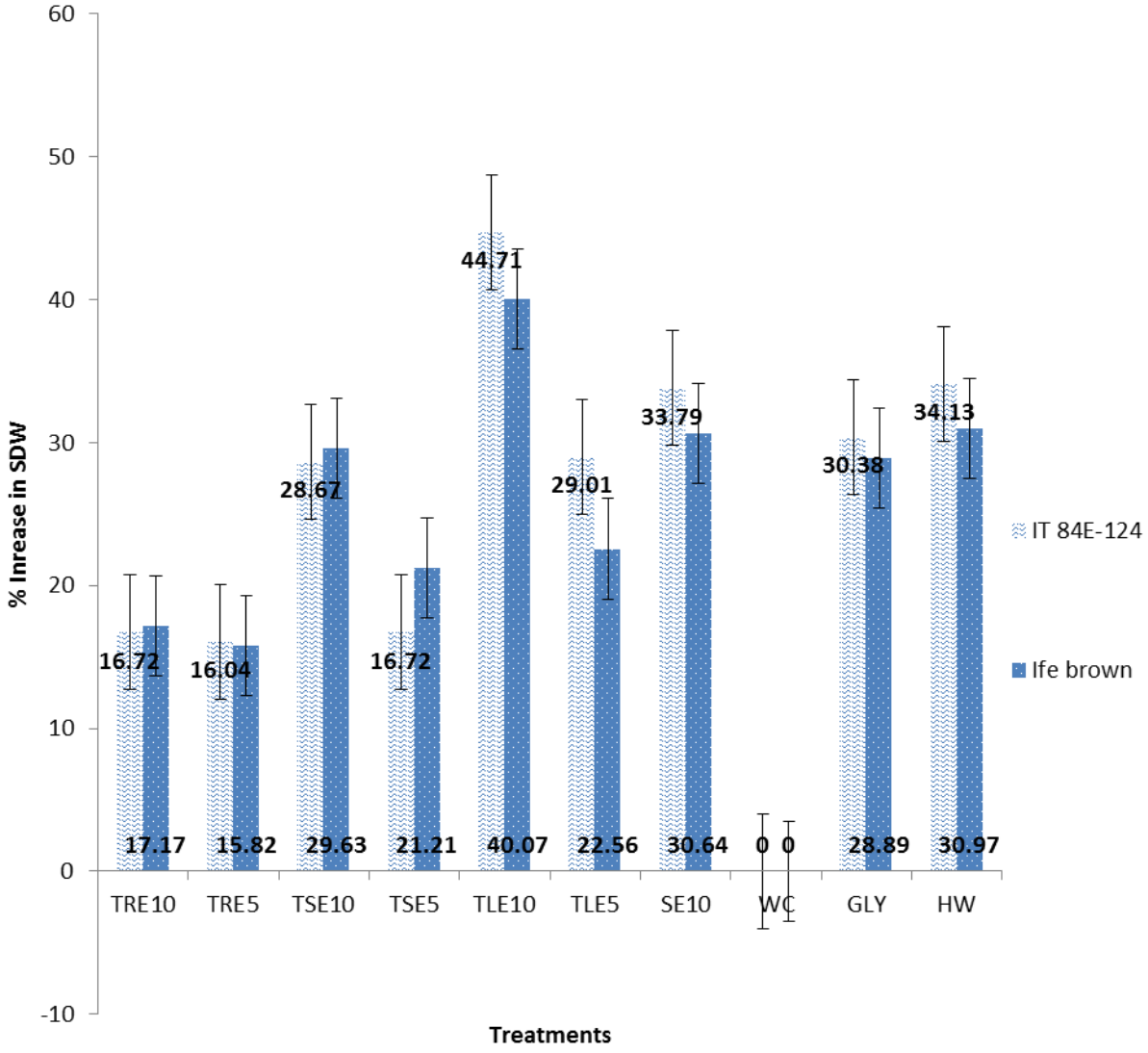


Figure 11: Percentage increase in shoot dry weight in relation to the weedy check in the two cowpea accessions

TRE = *Tithonia* Root Extract, TSE = *Tithonia* Stem Extract, TLE = *Tithonia* Leaf Extract, SE *Sorghum* Extract WC = Weedy check, GLY= Glyphosate, HW = Hand weeding, SDW = Shoot Dry Weight, 10 = 10% (w/v) concentration, 5 = 5% (w/v) concentration.
Bars indicate standard error of the mean.

4.6.1.6 The allelopathic effects of the aqueous extracts of *T. diversifolia* on root dry weight at four WAP in the two cowpea accessions

In accession IT 84E-124, the highest mean root dry weight (RDW) was observed from the regime of plant in the plots treated with TLE 10 = 1.14 ± 0.104 g. This was significantly higher than the mean RDW ($p = 0.02$) obtained from the other regimes of plants in the entire experimental plots in the accession (Table 9). This was followed by the mean RDW recorded from the regime of plants in the hand weeding plots HW = 0.93 ± 0.006 g. The mean RDW observed from the regimes of plants in the herbicide-treated plots GLY = 0.85 ± 0.012 g was not significantly different from the mean RDW ($p = 0.34$) observed from the regimes of plants in the plots treated with TSE 10 = 0.86 ± 0.045 g and SE 10 = 0.87 ± 0.018 g. The lowest mean RDW was obtained from the regime of plants from the weedy check plots WC = 0.62 ± 0.061 g. This was significantly lower than the mean RDW ($p = 0.00$) observed from the other regimes of plants in the entire experimental plots for this accession (Table 9).

Similar trend was observed in Ife Brown accession with the highest mean RDW obtained from the regime of plants in the plots treated with TLE 10 = 1.10 ± 0.059 g. This was significantly different from the mean RDW ($p = 0.02$) observed from the other regimes of plants in the entire experimental plots. This was followed by the mean RDW recorded from the regime of plants in the hand weeding plots HW = 0.98 ± 0.021 g (Table 9). The mean RDW observed from the regime of plants in the herbicide-treated plots GLY = 0.84 ± 0.023 g was not significantly different from the mean RDW ($p = 0.45$) observed from the regimes of plants in the plots treated with TSE 10 = 0.82 ± 0.030 g and SE 10 = 0.85 ± 0.020 g. The lowest mean RDW was observed from the regime of plants in the weedy check plots WC = 0.63 ± 0.089 g. This was also significantly different from the mean

RDW ($p = 0.01$) observed from the other regimes of plants in the entire experimental plots for the accession (Table 9).

Figure 12 shows the percentage increase in RDW in relation to the weedy check in the two accessions of cowpea. The regimes of plants in the plots treated with TLE 10 had 62.90 % and 69.23% increases in RDW in the two accessions respectively (Figure 12). The regime of plants in the hand weeding plots had 50% and 50.70% increases in RDW in the two accessions correspondingly. The regime of plants in the herbicide treated plots had 37.09% and 29.23% increases in RDW. The regime of plants in the plots treated with SE 10 also had 40.32% and 30.77% increases in RDW in the two accessions in that order (Figure 12).

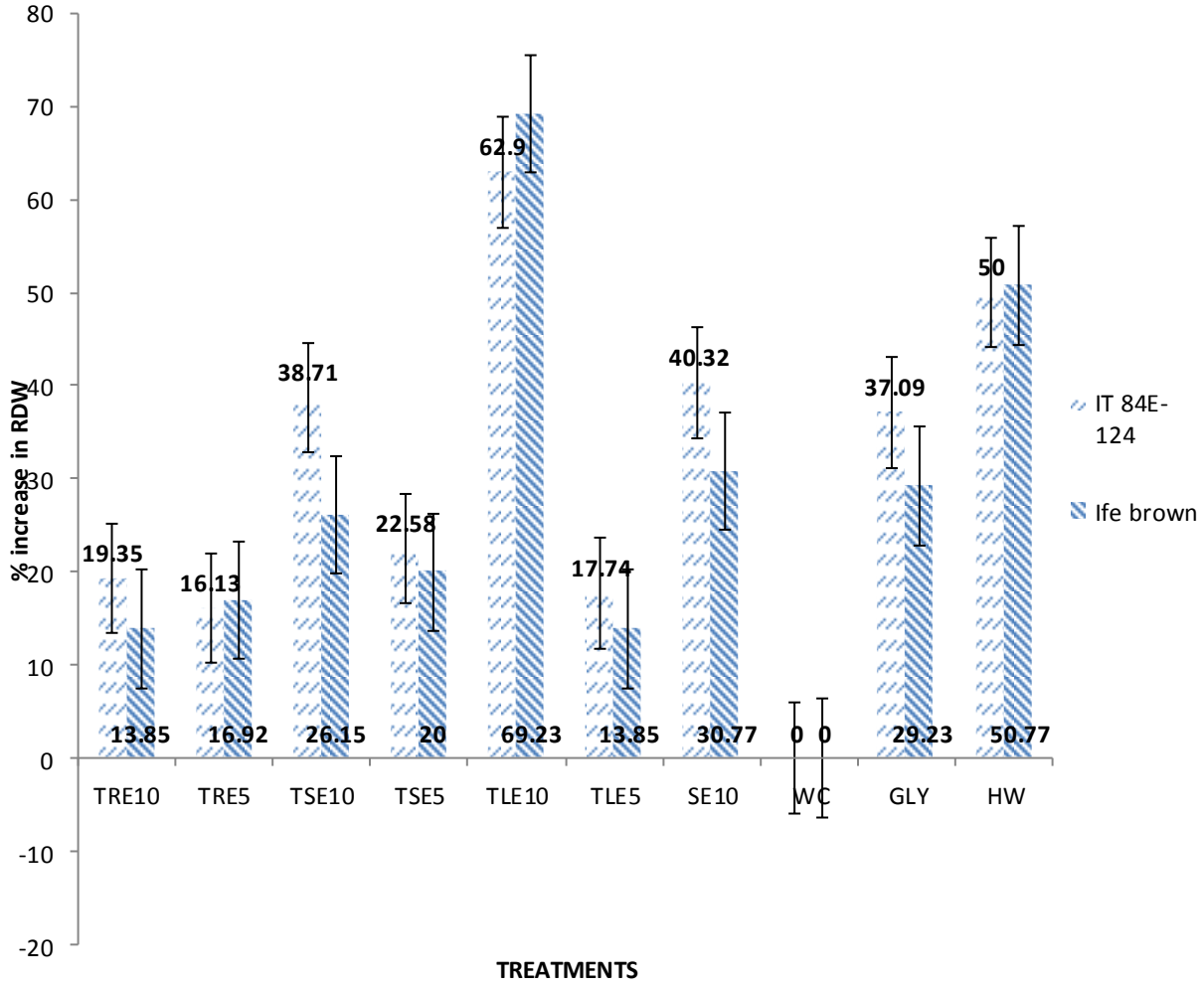


Figure 12: Percentage increase in root dry weight in relation to the weedy check in two cowpea accessions

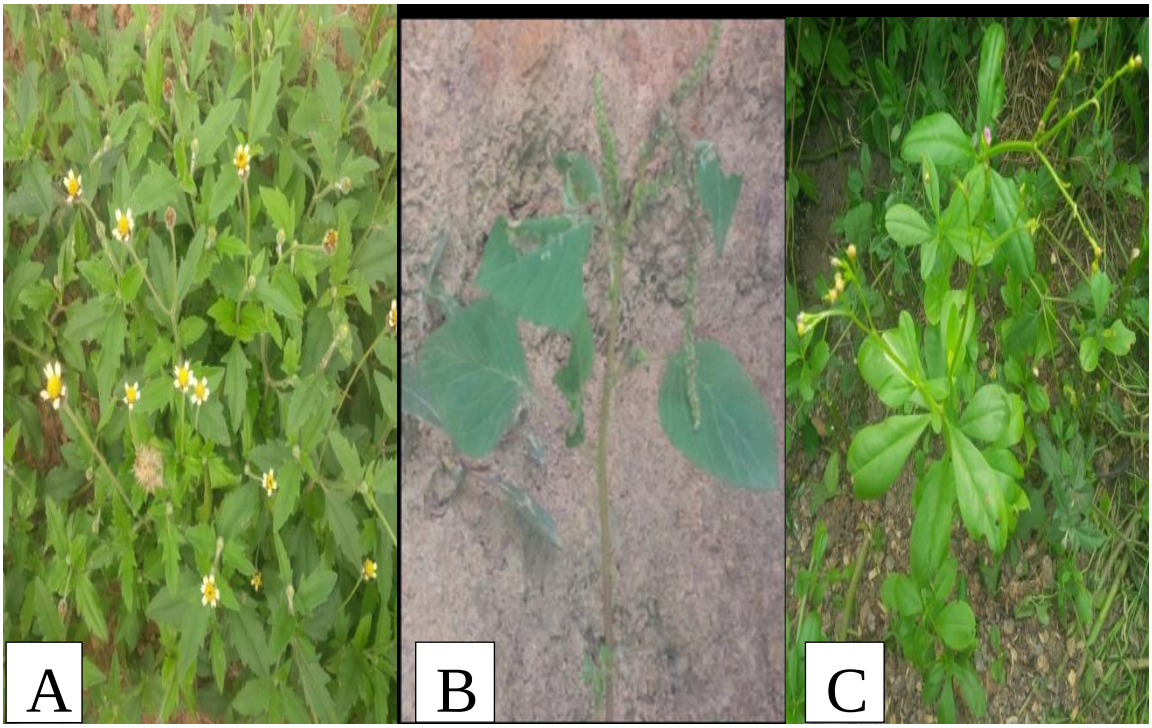
TRE = *Tithonia* Root Extract, TSE = *Tithonia* Stem Extract, TLE = *Tithonia* Leaf Extract, SE *Sorghum* Extract WC = Weedy check, GLY= Glyphosate, HW = Hand weeding, RDW = Root Dry Weight, 10 = 10% (w/v) concentration, 5 = 5% (w/v) concentration.
Capped bar indicate standard error of the mean

4.5.2 Weed suppressive effects of aqueous extracts of *T. diversifolia* on weeds of the cropping system of the two cowpea accessions

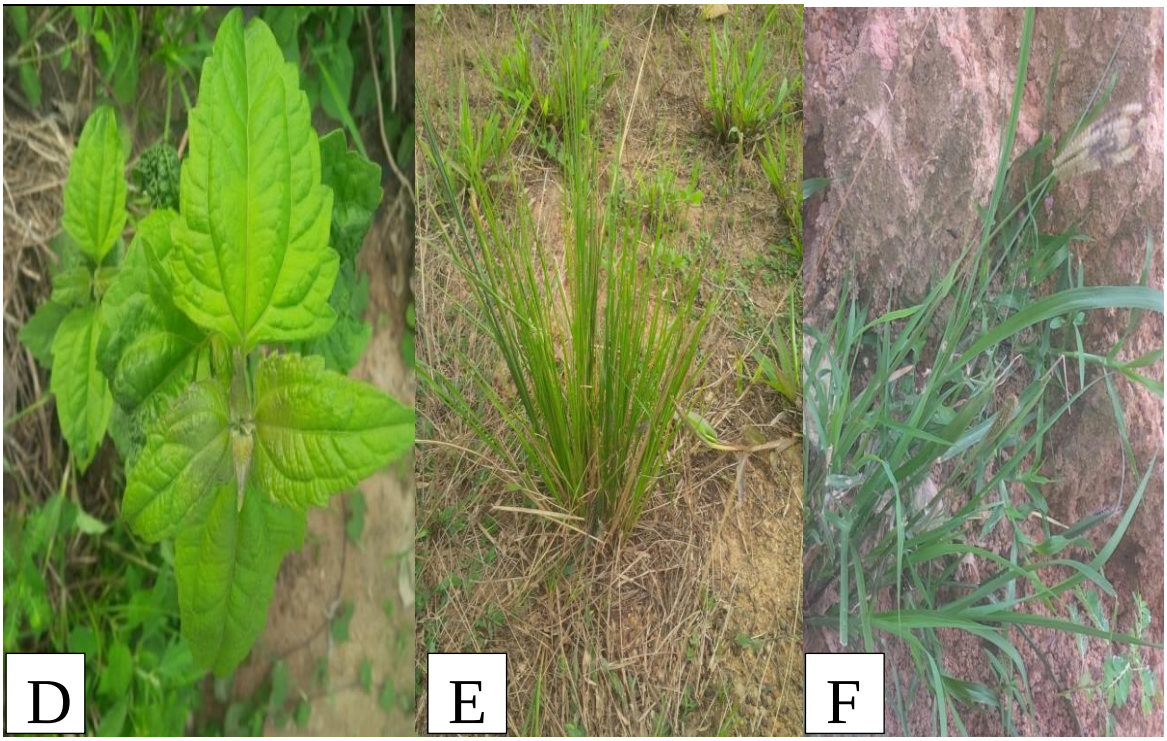
The weed flora of the experimental site comprised *Phalaris minor* Retz. (little seed canary grass), *Chenopodium album* L. (lambsquarters), *Amaranthus viridis* L. (slender amaranth), *Tridax procumbens* L. (coat button), *Talinum triangulare* Jacq. (water leaf), *Chromolaena odoratata* L. (siam weed), *Digitaria* sp (crabgrass), *Ageratum conyzoides* L. (goat weed) and *Convolvulus arvensis* (field bind weed). Plate 3 show the pictures of the dominant weed species in the experimental sites, while the weed density at 30 and 65 days after planting (DAP) are presented in Table 10.

4.5.2.1 Weed suppressive effects of aqueous extracts of *T. diversifolia* on weed density of cropping system of the two cowpea accessions at 30 DAP

In accession IT 84E-124, the highest mean weed density at 30 DAP was recorded from the weedy check plots, WC= 40.27 ± 5.34/m^2 (Table 10). This was not significantly different from the mean weed density at 30 DAP ($p = 0.55$) observed from the plots treated with TRE 5= 38.53 ± 4.79/m^2 and TRE 10 = 36.53 ± 4.16/m^2. The lowest mean WD was recorded from the hand weeding plots, HW= 1.53 ± 6.91/m^2 (Table 10).This was not significantly different from the mean WD at 30 DAP ($p = 0.51$) recorded in the herbicide-treated plots GLY=2.79 ± 6.51/m^2. Considerable reduction in the mean WD at 30 DAP was observed from the aqueous extract-treated plots in which the least was recorded from the plots treated with TLE 10 = 12.80 ± 3.34/m^2. This was significantly different from the mean WD at 30 DAP ($p = 0.01$) recorded from all other plots in the accession (Table 10).



B



Pl B 3: Some of the dominant weed species of the experimental site
B

A B *ridax procumbens* **B:** ***Amaranthus viridis*** **C:** ***Talinum triangulare***

D: ***Chromolaena odorata*** **E:** ***Heteropogon contortus*** **F:** ***Phalaris minor***

Table 10: Weed suppressive effects of aqueous extracts of *T. diversifolia* on weed density at 30 and 65 DAP in the cropping systems of the two cowpea accessions

Treatments	Weed density at 30 DAP (no./m^2)		Weed density at 65 DAP (no./m^2)	
	IT 84E-124	**Ife Brown**	**IT 84E-124**	**Ife Brown**
TRE10	36.53 ± 4.16^{a}	29.67 ± 3.59^{a}	78.83 ± 5.86^{b}	62.33 ± 6.49^{b}
TRE5	38.53 ± 4.79^{a}	30.4 ± 3.81^{a}	100.64 ± 12.75^{a}	67.50 ± 8.12^{b}
TSE10	20.8 ± 0.81^{c}	16.2 ± 0.67^{b}	48.17 ± 6.50^{c}	33.70 ± 2.56^{e}
TSE5	30.13 ± 2.14^{b}	28.8 ± 3.31^{a}	96.33 ± 11.39^{a}	53.5 ± 3.70^{c}
TLE10	12.80 ± 3.34^{d}	11.73 ± 2.09^{c}	34.5 ± 8.16^{d}	27.5 ± 5.79^{f}
TLE5	28.67 ± 1.68^{b}	30.67 ± 3.90^{a}	72.83 ± 3.96^{b}	45.66 ± 1.22^{d}
SE10	21.67 ± 0.54^{c}	16.67 ± 1.47^{b}	40.17 ± 6.37^{d}	35.00 ± 2.15^{e}
WC	40.27 ± 5.34^{a}	32.27 ± 4.41^{a}	106.51 ± 14.61^{a}	75.67 ± 10.71^{a}
GLY	2.79 ± 6.51^{e}	1.73 ± 5.25^{d}	18.33 ± 13.28^{e}	13.33 ± 9.00^{g}
HW	1.53 ± 6.91^{e}	1.83 ± 5.22^{d}	16.83 ± 13.75^{e}	15.50 ± 8.32^{g}

TRE = *Tithonia* Root Extract, TSE = *Tithonia* Stem Extract, TLE = *Tithonia* Leaf Extract, SE *Sorghum* Extract WC = Weedy check, GLY= Glyphosate, HW = Hand weeding, DAP = Days after Planting, 10 = 10% (w/v) concentration, 5 = 5% (w/v) concentration.
Values in a column followed by the same letter are not significantly different by DMRT at $p > 0.05$.
Values = mean value ± standard error

Similarly in Ife Brown accession, the highest mean WD at 30 DAP was recorded from the weedy check plots WC = 32.27 ± 4.41/m^2, this was not significantly different from the mean WD at 30 DAP (p = 0.12) observed from the plots treated with TRE 10 = 29.67 ± 3.59/m^2; TRE 5 = 30.40 ±3.81/m^2; TSE 5 = 28.80 ± 3.31/m^2 and TLE 5 = 30.67 ± 3.90/m^2 (Table 10). The lowest mean WD at 30 DAP was recorded from the hand weeding plots, HW = 1.83 ± 5.22/m^2, this was significantly different from the mean WD at 30 DAP (p = 0.00) obtained from each of the entire experimental plots in the accession except herbicide-treated plots, GLY = 1.73 ± 5.25/m^2. However, considerable reductions in the mean WD at 30 DAP were recorded in the aqueous extract-treated plots with the highest reduction recorded from the plots treated with TLE 10 = 11.73 ± 2.09/m^2. This was significantly different from the mean WD at 30 DAP (p = 0.02) observed in the plots treated with SE 10 = 16.67 ±1.47/m^2 and TSE 10 = 16.2 ± 0.67 (Table 10).

Figure 13 shows the percentage decrease in WD at 30 DAP in relation to the weedy check as affected by aqueous extracts of *T. diversifolia* in the cropping systems of the two accessions (IT 84E-124 and Ife Brown) of cowpea. The herbicide-treated plots had GLY 93.07% and 94.64% decreases in WD at 30 DAP while hand weeding plots had 96.20% and 94.33%.in the two accessions respectively. The aqueous extract-treated plots TLE 10 also exhibited 68.21% and 63.65% while SE 10 demonstrated 46.81% and 48.34% decreases in WD at 30 DAP in the cropping systems of the two accessions correspondingly.

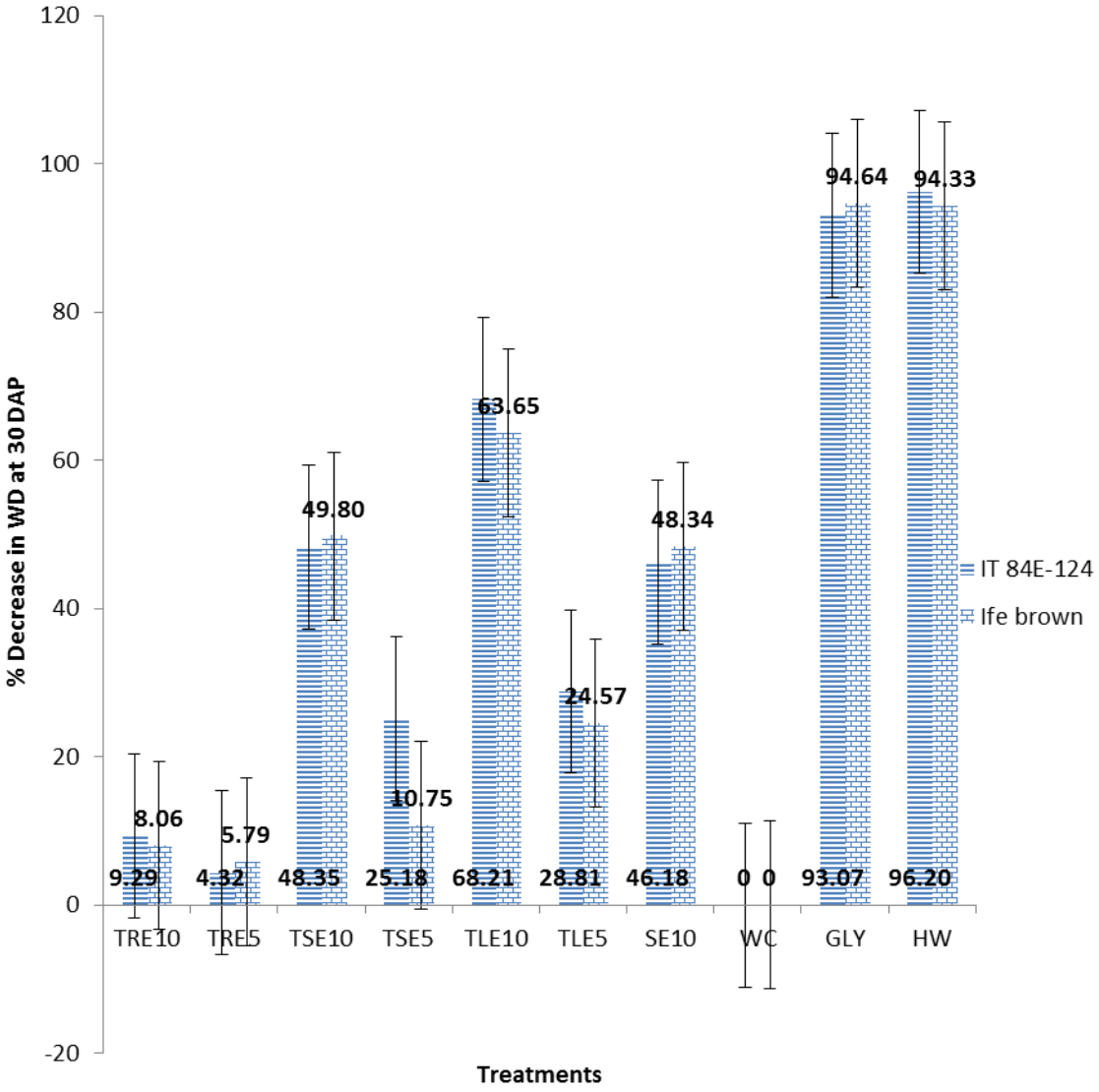


Figure 13: Percentage decrease in weed density at 30 days after planting in relation to the weedy check in the cropping system of the two cowpea accessions

TRE = *Tithonia* Root Extract, TSE = *Tithonia* Stem Extract, TLE = *Tithonia* Leaf Extract, SE *Sorghum* Extract WC = Weedy check, GLY= Glyphosate, HW = Hand weeding, DAP = Days after Planting, WD = Weed Density, 10 = 10% (w/v) concentration, 5 = 5% (w/v) concentration.
Capped bar indicate standard error of the mean

4.5.2.2 Weed suppressive effects of aqueous extracts of *T. diversifolia* on weed density at 65 DAP in the cropping system of the two cowpea accessions

In accession IT 84E-124, the highest mean weed density (WD) at 65 DAP was recorded from the weedy check plots WC = 106 ± 14.61/m^2. This was significantly different from the mean WD at 65 DAP (p = 0.03) recorded from each of the entire experimental plots in the accession except the plots treated with TRE 5 = 100.64 ± 12.75/m^2 and TSE 5 = 96.33 ± 11.39 (Table 10). This was followed by the mean WD at 65 DAP recorded from the plots treated with TRE 10 = 78.83 ± 5.86/m^2 and TLE 5 = 72.83 ± 3.96/m^2. The lowest mean WD was recorded from the hand weeding plots, HW = 16.83 ± 3.41/m^2. This was significantly different from the mean WD at 65 DAP (p = 0.03) recorded from each of the experimental plots for the accession except the herbicide-treated plots GLY = 18.33 ± 13.28/m^2. In the aqueous extract-treated plots, there was significant reduction in the mean WD at 65 DAP, the highest reduction was recorded from the plots treated with TLE 10 = 34.50 ± 8.16/m^2. This was not significantly different from the mean WD at 65 DAP (p = 0.51) recorded in the plots treated with SE 10 = 40.17 ± 6.37/m^2 (Table 10)

Likewise in Ife Brown accession, the highest mean WD at 65 DAP was recorded from the weedy check plots WC = 75.67 ± 10.71/m^2. This was significantly different from the mean WD (p = 0.00) recorded from the entire experimental plots in the accession. This was followed by the mean WD recorded from the plots treated with TRE 5 = 67.50 ± 6.12/m^2 and TRE 10 = 62.33 ± 6.49/m^2 (Table 10). The least mean WD at 65 DAP was recorded from the herbicide-treated plots, GLY = 13.33 ± 9.02/m^2. However, this was not significantly different from the mean WD at 65 DAP (p = 0.51) recorded from the hand weeding plots HW = 15.50 ± 8.32/m^2 (Table 10). Higher concentrations of the extracts led to considerable reduction in the mean WD at 65 DAP, the highest reduction was recorded

from the plots treated with TLE 10 = 27.50 ± 4.52/m^2. This was significantly lower than the mean WD at 65 DAP (p = 0.01) recorded from the plots treated with TSE 10 = 33.70 ± 2.56 / $m^2$and SE 10 = 35.00 ± 2.15 / m^2 (Table 10).

Figure 14 shows the percentage decrease in WD at 65 DAP in relation to the weedy check as affected by the aqueous extracts of *T. diversifolia* in the cropping systems of two accessions of cowpea (IT 84E-124 and Ife Brown). The herbicide-treated (GLY) plots exhibited 82.79% and 82.42% while hand weeding plots demonstrated 84.20% and 79.52% decreases in WD at 65 DAP in the two accessions respectively. The aqueous extract-treated plots TLE 10 exhibited 67.61% and 63.66% decreases while SE 10 showed 62.28% and 53.75% decreases in the two accessions consecutively (Figure 14).

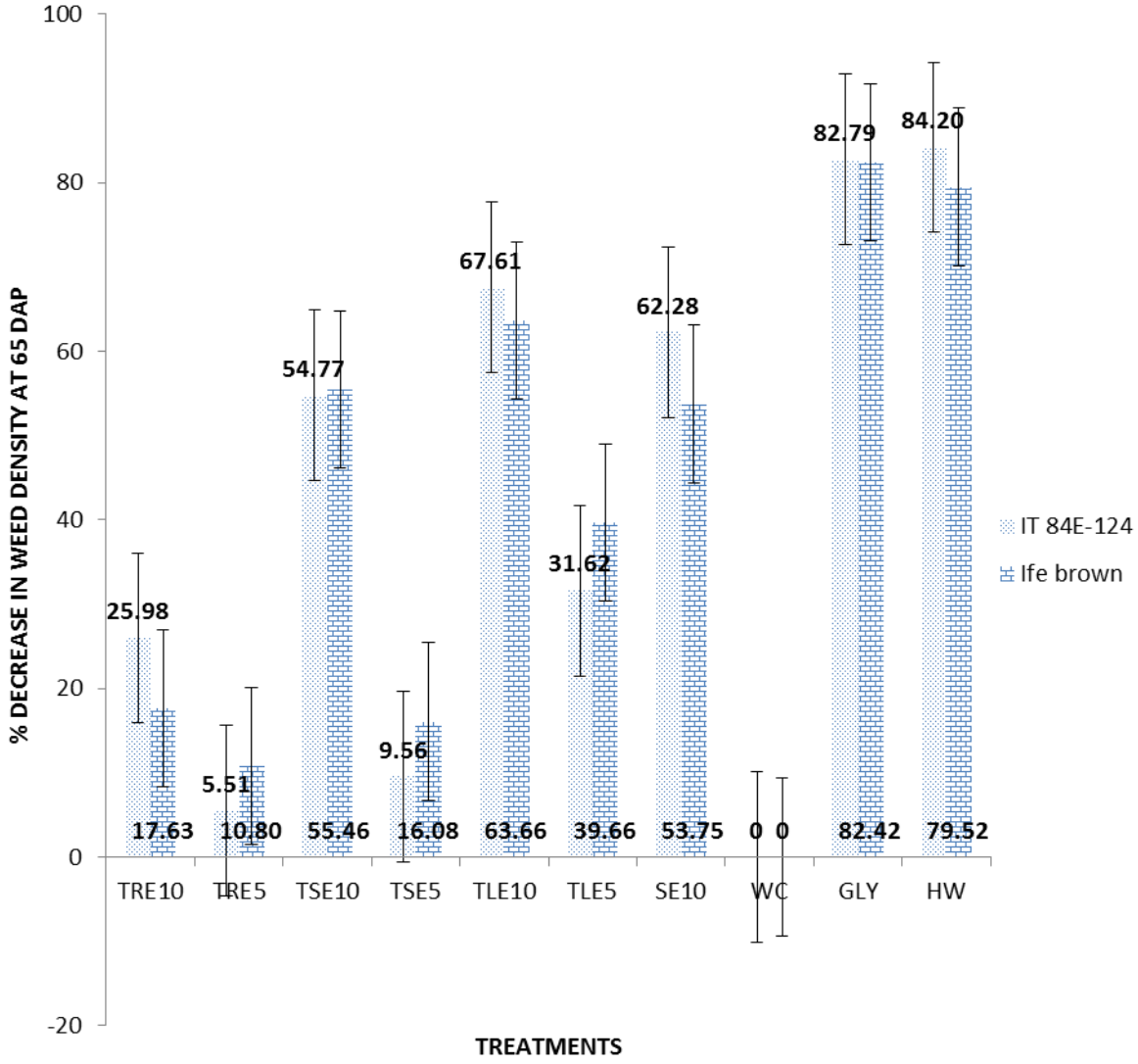


Figure 14: Percentage decrease in weed density at 65 days after planting in relation to the weedy check in the cropping system of the two cowpea accessions.
TRE = *Tithonia* Root Extract, TSE = *Tithonia* Stem Extract, TLE = *Tithonia* Leaf Extract, SE *Sorghum* Extract WC = Weedy check, GLY= Glyphosate, HW = Hand weeding, DAP = Days after Planting, 10 = 10% (w/v) concentration, 5 = 5% (w/v) concentration.
Capped bars indicate standard error.

4.5.2.3 Weed suppressive effects of aqueous extracts of *T. diversifolia* on weed dry weight at 65 DAP in the two cowpea accessions

The effects of aqueous extracts from the different parts of *T. diversifolia* on mean weed dry weight at 65 DAP in the cropping system of the two accessions of cowpea and the weed control efficiencies are presented in Table 11. In accession IT 84E-124, the highest mean WDW was recorded from the weedy check plots WC = 65.67 ± 9.39 g/m^2. This was not significantly different from the mean WDW at 65 DAP (p = 0.55) recorded from the plots treated with TSE 5 = 57.67 ± 6.85 g/m^2 and TRE 10 = 56.67 ±6.54 g/m^2. These were followed by the mean WDW recorded from the plots treated with TRE 5 = 54.67 ± 5.90 g/m^2 and TLE 5 = 50.00 ± 4.43 g/m^2. The lowest mean WDW was recorded from the herbicide -treated plots GLY = 3.00 ± 10.43 g/m^2. This was significantly different from the mean WDW at 65 DAP (p = 0.02) observed from each of the experimental plots in the accession except the herbicide-treated plots GLY = 4.50 ± 9.96 g/m^2 (Table 11).

In the seven aqueous extract-treated plots, the lowest mean WDW was observed from the plots treated with TLE 10 = 18.67 ± 5.47 g/m^2. This was significantly lower than the mean WDW at 65 DAP (p = 0.03) recorded from the plots treated with SE 10 = 28.33 ± 2.42 g/m^2 and other five aqueous extract-treated plots. These were followed by the mean WDW at 65 DAP recorded from the plots treated with TSE 10 = 26.67 ± 2.94 g/m^2 (Table 11).

Table 11: Weed suppressive effects of aqueous extracts of *T. diversifolia* on weed dry weight at 65 DAP in the cropping system of the two cowpea accessions

Treatments	Weed dry weight at 65 DAP (g/m^2)		Weed control efficiency (%)	
	IT 84E-124	Ife Brown	IT 84E-124	Ife Brown
TRE 10	$56.67 \pm 6.54^{a, b}$	55.33 ± 5.92^{a}	13.70	11.21
TRE 5	54.67 ± 5.90^{b}	60.67 ± 7.61^{a}	16.75	2.65
TSE 10	26.67 ± 2.94^{c}	23.33 ± 4.20^{b}	59.39	62.54
TSE 5	57.67 ± 6.85^{a}	55.00 ± 5.82^{a}	12.18	11.74
TLE 10	18.67 ± 5.47^{d}	18.00 ± 5.88^{c}	71.56	71.12
TLE 5	50.00 ± 4.43^{b}	56.33 ± 6.23^{a}	23.86	9.61
SE 10	28.33 ± 2.42^{c}	28.00 ± 2.72^{b}	56.86	55.07
WC	65.67 ± 9.39^{a}	62.32 ± 8.13^{a}	0	0
GLY	3 ± 10.43^{e}	3.67 ± 10.41^{d}	95.43	94.11
HW	4.5 ± 9.96^{e}	3.42 ± 10.49^{d}	93.14	94.50

TRE = *Tithonia* Root Extract, TSE = *Tithonia* Stem Extract, TLE = *Tithonia* Leaf Extract, SE *Sorghum* Extract WC = Weedy check, GLY= Glyphosate, HW = Hand weeding, DAP = Days after Planting, 10 = 10% (w/v) concentration, 5 = 5% (w/v) concentration.
Values in a column followed by the same letter are not significantly different by DMRT at $p > 0.05$.
Values = mean value ± standard error

Similarly, in Ife Brown accession, the highest mean WDW at 65 DAP was recorded from the weedy check plots WC = 62.32 ± 8.13 g/m^2. This was not significantly different from the mean WDW at 65 DAP (p = 0.51) recorded from the plots treated with TRE 10 = 55.33 ± 5.92 g/m^2, TRE 5 = 60.67 ± 7.61 g/m^2, TSE 5 = 55.00 ± 5.82 g/m^2 and TLE 5 = 56.33 ± 6.23 g/m^2. The least mean WDW was observed from the herbicide-treated plots GLY = 3.67 ± 10.41 g/m^2, this was not significantly different from the mean WDW at 65 DAP (p = 0.45) recorded from the hand weeding plots HW = 3.42 ± 10.49 g/m^2. In the seven aqueous extract treated-plots, the lowest mean WDW was recorded from the plots treated with TLE 10 = 18.00 ± 5.88 g/m^2. This was significantly different lower than the mean WDW at 65 DAP (p = 0.02) observed from the plots treated with TSE 10 = 23.33 ± 4.20 g/m^2) and SE 10 (28.00 ± 2.72 g/m^2 (Table 11).

The weed control efficiencies (WCE) of the herbicide-treated plots were 95.43% and 94.11% in the two accessions respectively. The WCE of the hand weeding plots were 93.14% and 94.50% in the two accessions correspondingly (Table 11). However in the seven aqueous extract-treated plots, the highest WCE, 71.56% and 71.12%, were recorded in the plots treated with TLE 10 in the two accessions respectively. The plots treated with SE 10 had 56.86% and 55.07% WCE in the two accessions respectively (Table 11).

4.5.3 The allelopathic effects of aqueous extracts of *T. diversifolia* on yield of the two cowpea accessions

The allelopathic effects of aqueous extracts of *T. diversifolia* on yield parameters of the two cowpea accessions are presented in Table 12.

4.5.3.1 The allelopathic effects of aqueous extracts of *T. diversifolia* on plant height at six WAP in the two cowpea accessions

In IT 84E-124 accession, the highest mean plant height (PH) was observed from the regime of plants in the plots treated with TLE 10 = 34.93 ± 2.72 cm at six WAP. This was significantly different from the mean PH ($p = 0.01$) obtained from the other regimes of plants in the entire experimental plots for the accession. This was followed by the mean PH observed from the regime of plants in the hand weeding plots HW = 30.76 ± 1.81 cm (Table 12). The lowest mean PH was observed from the regime of plants in the weedy check plots WC = 19.52 ± 2.14 cm. This was significantly lower than the mean PH ($p = 0.00$) obtained from the other regimes of plants in the entire experimental plots for the accession. The mean PH observed from the regime of plants in the herbicide-treated plots GLY = 27.73 ± 0.44) was not significantly different from the mean PH ($p = 0.55$) recorded the regimes of plants in the plots treated with TSE 10 = 28.13 ± 0.57 cm and SE 10 = 28.65 ± 0.73 cm (Table 12).

Similarly in Ife Brown accession, the highest mean PH at 6 WAP was recorded from the regime of plants in the plots treated with TLE 10 = 38.48 ± 1.63 cm. This was significantly higher than the mean PH ($p = 0.01$) observed from the other regimes of plants in the entire experimental plots in the accession. This was followed by the mean PH recorded from the regime of plants in the hand weeding plots HW = 33.67 ± 0.89 cm. The mean PH observed from the regime of plants in the herbicide-treated plots, GLY = 30.24 ± 0.60 cm, was not significantly different from the mean PH ($p = 0.15$) observed from the

Table 12: The allelopathic effects of aqueous extracts of *T. diversifolia* on yield of the two cowpea accessions

Treatments	Plant height at 6 WAP (cm)		Pods/plant (no.)		Grain yield (kg/ha)	
	IT 84E-124	Ife brown	IT 84E-124	Ife Brown	IT 84E-124	Ife Brown
TRE10	24.33 ± 0.62^{d}	28.76 ± 0.50^{d}	20.32 ± 0.78^{d}	24.27 ± 0.88^{d}	350.86±22.84^{e}	377.43 ± 8.44^{d}
TRE5	23.06 ± 1.03^{d}	27.47 ± 0.90^{d}	19.70 ± 1.29^{d}	23.42 ± 0.70^{d}	344.84±24.11^{e}	375.34 ± 9.10^{d}
TSE10	28.13 ± 0.57^{c}	30.60 ± 0.72^{c}	26.95 ± 0.99^{c}	27.90 ± 0.42^{c}	399.89 ± 6.62^{c}	434.87 ± 5.92^{c}
TSE5	23.67 ± 0.83^{d}	27.74 ± 0.81^{d}	19.14 ± 1.47^{d}	24.02 ± 0.50^{d}	360.33± 4.03^{d}	374.32 ± 3.73^{d}
TLE10	34.93 ± 2.72^{a}	38.48 ± 1.63^{a}	33.20 ± 2.97^{a}	34.08 ± 2.68^{a}	446.47±21.04^{a}	485.57±21.58^{a}
TLE5	24.4 ± 0.60^{d}	27.63 ± 0.85^{d}	19.20 ± 1.45^{d}	24.20 ± 0.63^{d}	358.02±3.39^{d}	396.64 ± 2.37^{d}
SE10	28.65 ± 0.73^{c}	33.13± 0.89^{c}	25.97 ± 0.69^{c}	27.21 ± 0.43^{c}	397.21 ± 6.46^{c}	440.67 ± 8.02^{b}
WC	19.52 ± 2.14^{e}	23.87± 2.03^{e}	20.01 ± 1.19^{d}	20.26 ± 1.69^{e}	270.82±32.34^{e}	280.58 ±39.07^{e}
GLY	27.73 ± 0.44^{c}	30.24± 0.60^{c}	25.92 ± 0.67^{c}	27.80 ± 0.40^{c}	401.20± 8.89^{c}	432.67 ± 9.02^{c}
HW	30.76 ± 1.81^{b}	33.67 ± 0.89^{b}	29.81 ± 2.21^{b}	30.62 ± 2.23^{b}	416.29±13.66^{b}	456.25±16.48^{b}

TRE = *Tithonia* Root Extract, TSE = *Tithonia* Stem Extract, TLE = *Tithonia* Leaf Extract, SE *Sorghum* Extract WC = Weedy check, GLY= Glyphosate, HW = Hand weeding, WAP = Weeks after Planting, 10 = 10% (w/v) concentration, 5 = 5% (w/v) concentration.
Values in a column followed by the same letter are not significantly different by DMRT at $p > 0.05$.
Values = mean value ± standard error

regimes of plants in the plots treated with TSE10 = 30.60 ± 0.72 cm and SE 10 = 33.13 ± 0.89 cm (Table 12).

4.5.3.2 The allelopathic effects of aqueous extracts of *T. diversifolia* on pods per plant in the two cowpea accessions

In accession IT 84E-124, the mean highest pods per plant (PPP) was recorded from the regime of plants in the plots treated with TLE 10 = 33.20 ± 2.97. However, this was significantly different from the mean PPP (p = 0.02) observed in the other regimes of plants in the entire experimental plots. This was followed by the meanPPP recorded from the regime of plants in the hand weeding plots HW = 29.81 ± 2.21 (Table 12). The PPP recorded from the regime of plants in the plots treated with TSE 10 = 26.95 ± 0.99, was not significantly different from the PPP (p = 0.51) observed in the regimes of plants in the plots treated with SE 10 = 25.97 ± 0.69 and herbicide-treated plots GLY = 25.92 ± 0.67 (Table 12). The lowest mean PPP was recorded from the regime of plants in the plots treated with TSE 5 = 19.14 ± 1.47, however, this was not significantly different (p = 0.65) from the mean PPP recorded in the regimes of plants in the plots treated with TRE 5 = 19.70 ± 1.29; TRE 10 = 20.32 ± 0.78 and TLE 5 = 19.20 ± 1.45 and the weedy check WC = 20.01± 1.19 (Table 12).

Equally, in Ife Brown accession, the highest mean PPP was recorded from the regime of plants in the plots treated with TLE 10 = 34.08 ± 2.68. This was significantly different from the mean PPP (p = 0.01) observed in the other regimes of plants in the entire experimental plots for the accession. This was followed by the mean PPP recorded from the regime of plants in the hand weeding plots HW = 30.62 ± 2.23. The mean PPP recorded from the regime of plants in the herbicide-treated plots GLY = 27.80 ± 0.40, was not significantly different from the PPP (p = 0.51) observed in the regime of plants in the plots treated with SE 10 = 27.21 ± 0.43. However, the mean lowest PPP was recorded

from the regime of plants in the weedy check plots WC = 20.26 ± 1.69. This was significantly lower (p = 0.03) than the mean PPP observed from the other regimes of plants in the entire experimental plots for the accession (Table 12).

4.5.3.3 The allelopathic effects of aqueous extracts of *T. diversifolia* seeds per pod in the two cowpea accessions

The allelopathic effects of the aqueous extracts from the different parts of *T. diversifolia* on the mean seeds per pod (SPP) in the two accessions of cowpea (IT 84E-124 and Ife Brown) are presented in Figure 15. In IT 84E-124, the mean highest SPP was observed from the pods harvested from the regime of plants in the plots treated with TLE 10 = 14.43 ± 0.21. This was significantly different from the mean SPP (p = 0.04) observed in the pods harvested from the other regimes of plants in the entire experimental plots in the accession. The mean SPP observed in the pods harvested from the regime of plants in the weedy check, WC = 8.56 ± 0.21, was the least. This was significantly different from the mean SPP (p = 0.04) observed in the pods harvested from the other regimes of plants in the entire experimental plots for the accession. The mean SPP recorded in the pods harvested from the regime of plants in the herbicide-treated plots, GLY = 13.21 ± 0.21, was not significantly different (p = 0.55) from the mean SPP observed in the pods harvested from the regimes of plants in the plots treated with TSE 10 = 13.63 ± 0.21; SE 10 = 13.60 ± 0.21 and hand weeding plots HW = 13.42 ± 0.21 (Figure 15).

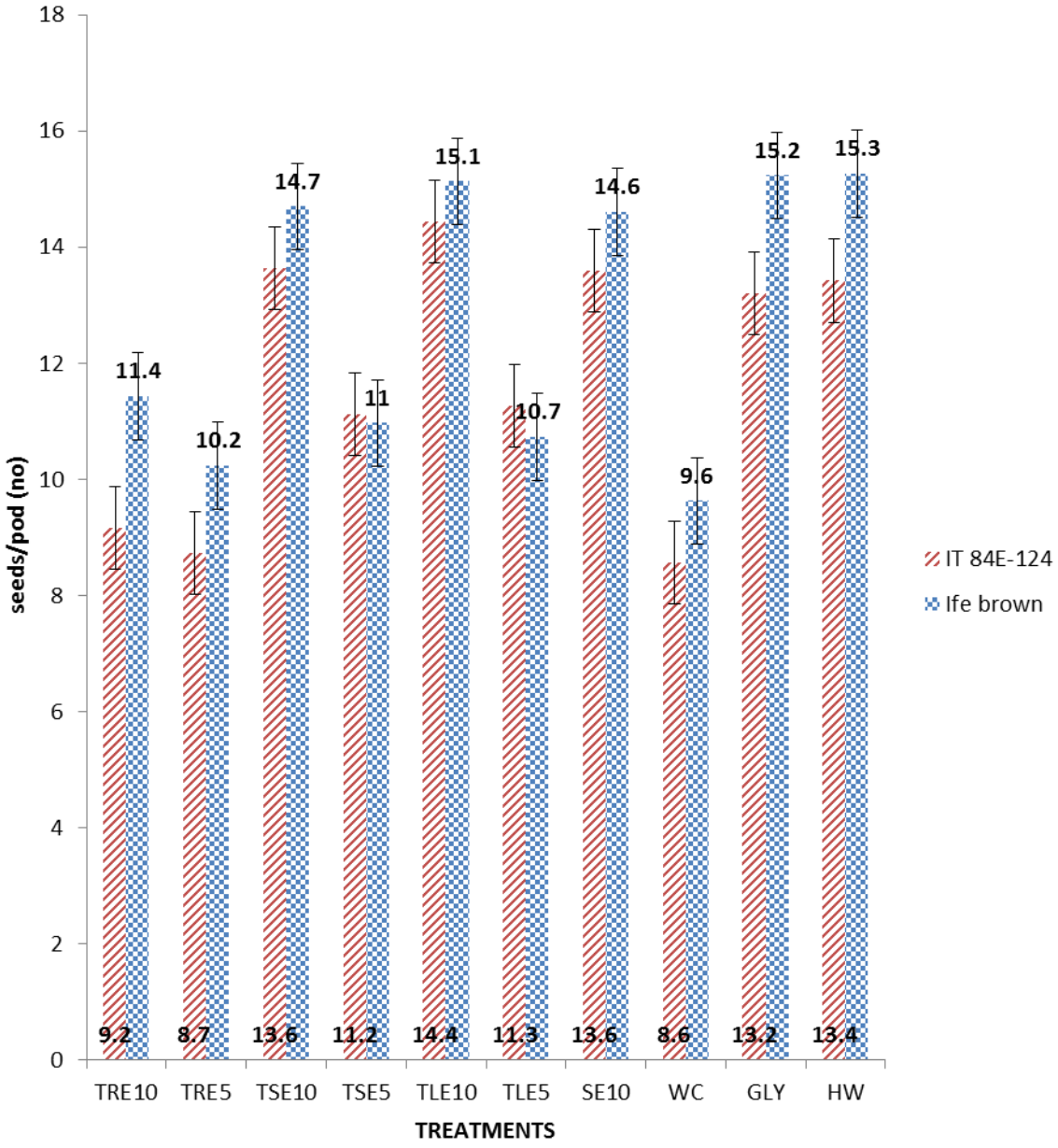


Figure 15: Allelopathic effects of the aqueous extracts of *T. diversifolia* on seeds per pods (SPP) in the two cowpea accessions

TRE = *Tithonia* Root Extract, TSE = *Tithonia* Stem Extract, TLE = *Tithonia* Leaf Extract, SE *Sorghum* Extract WC = Weedy check, GLY= Glyphosate, HW = Hand weeding, 10 = 10% (w/v) concentration, 5 = 5% (w/v) concentration.
Capped bars indicate standard error of the mean.

In Ife Brown accession, the highest mean SPP was observed from the pods harvested from the regime of plants in the hand weeding plots HW = 15.26 ± 0.19. However, this was not significantly different from the mean SPP (p = 0.51) observed in the pods harvested from the regimes of plants in the plots treated with TLE 10 = 15.13 ± 0.19 and herbicide GLY = 15.23 ± 0.19. These were followed by the mean SPP recorded from the pods harvested from the regimes of plants in the plots treated with TSE 10 = 14.70 ± 0.19 and SE 10 = 14.60 ± 0.19. The lowest mean SPP was observed from the pods harvested from the regime of plants in the weedy check plots WC = 9.63 ± 0.19. This was significantly different (p = 0.04) from the SPP observed in the pods harvested from the other regimes of plants in the entire experimental plots in the accession (Figure 15).

4.5.3.4 The allelopathic effects of aqueous extracts of *T. diversifolia* on grain yield of the two cowpea accessions

In accession IT 84E-124, the highest mean grain yield (GY) was recorded from the plots treated with TLE 10 = 446.47 ± 21.04 kg/ha. This was significantly higher than the mean GY (p = 0.00) recorded from the each of the other entire experimental plots. This was followed by the mean GY recorded from the hand weeding plots HW = 416.29 ±13.66 kg/ha (Table 12). The lowest mean GY was observed from the weedy check plots WC = 270.82 ± 32.34 kg/ha, this was significantly different (p = 0.01) from the mean GY recorded from each of the other entire experimental plots in the accession (Table 12). The mean GY observed from the herbicides-treated plots GLY = 401.20 ± 8.89 kg/ha was not significantly different (p = 0.06) from the mean GY recorded from the plots treated with TSE 10 = 399.89 ± 6.62 kg/ha and SE 10 = 397.21 ± 6.46 kg/ha (Table 12).

Likewise in Ife Brown accession, the highest mean GY was observed from the plots treated with TLE 10 = 485.57 ± 21.58 kg/ha. This was significantly different from the

mean GY ($p = 0.01$) obtained from each of the other experimental plots for the accession. This was followed by the mean GY recorded in the plots treated with SE 10 = 440.67 ± 8.02 kg/ha and hand weeding HW = 456.25±16.48 kg/ha. The lowest mean GY was recorded from the weedy check plots WC = 280.58 ± 39.07 kg/ha. This was significantly different ($p = 0.02$) from the mean GY observed from each of the other entire experimental plots (Table 12). The mean GY obtained from the herbicides-treated plots, GLY = 432.67 ± 9.02 kg/ha, was not significantly different from the mean GY ($p > 0.05$) recorded from the plots treated with TSE 10 = 434.87 ± 5.92 kg/ha (Table 12).

Figure 16 shows the percentage increase in GY in relation to the GY of the weedy check (control) in the two accessions of cowpea (IT 84E-124 and Ife Brown) as affected by the aqueous extracts of *T. diversifolia*. The highest percentage increase was recorded in the plots treated with TLE 10 which exhibited 64.86% and 73.06% increase in GY in the two accessions respectively. However, SE 10 demonstrated 46.67% and 57.06% increase in GY in the two accessions respectively. Herbicide-treated plots exhibited 48.14%, and 54.21% increases in GY while hand weeding demonstrated 53.71% and 62.61% increase in GY in the two accessions respectively (Figure 16).

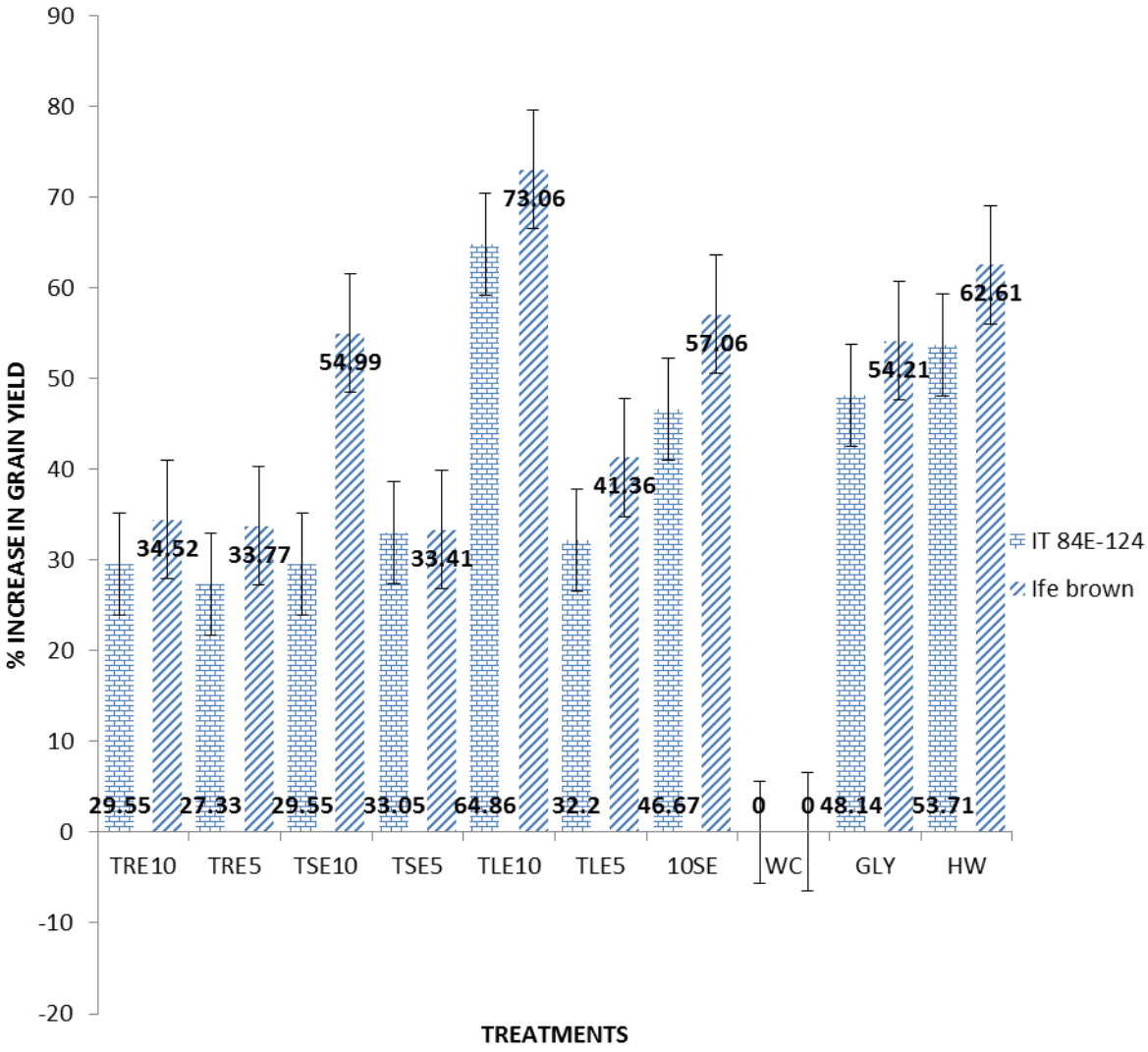


Figure 16: Percentage increase in grain yield in relation to the weedy check (WC) in the two cowpea accessions
TRE = *Tithonia* Root Extract, TSE = *Tithonia* Stem Extract, TLE = *Tithonia* Leaf Extract, SE *Sorghum* Extract WC = Weedy check, GLY= Glyphosate, HW = Hand weeding, 10 = 10% (w/v) concentration, 5 = 5% (w/v) concentration.
Capped bars indicate standard error of the mean

4.5.3.5 The allelopathic effects of aqueous extracts from the different parts of *T. diversifolia* on 1000-seeds weight of the two cowpea accessions

The allelopathic effects of the aqueous extracts of *T. diversifolia* on 1000-seeds weight in the two accessions (IT 84E-124 and Ife Brown) of cowpea are presented in Figure 17. In accession IT 84E-124, the mean highest 1000-seeds weight was recorded from the seeds harvested from the regime of plants in the plots treated with TLE 10 = 197.60 ± 5.24 g. However, this was not significantly different from the mean 1000-seeds weight ($p = 0.51$) recorded from the seeds harvested from the other regimes of plants in the entire experimental plots (Figure 17). The lowest mean 1000-seeds weight was recorded from the seeds harvested from the regimes of plants in the weedy check plots WC = 182.00 + 5.22 g. This was not significantly different from the mean 1000-seeds weight ($p = 0.12$) recorded from the seeds harvested from the regimes of plants in the other entire experiment plots in the accession (Figure 17).

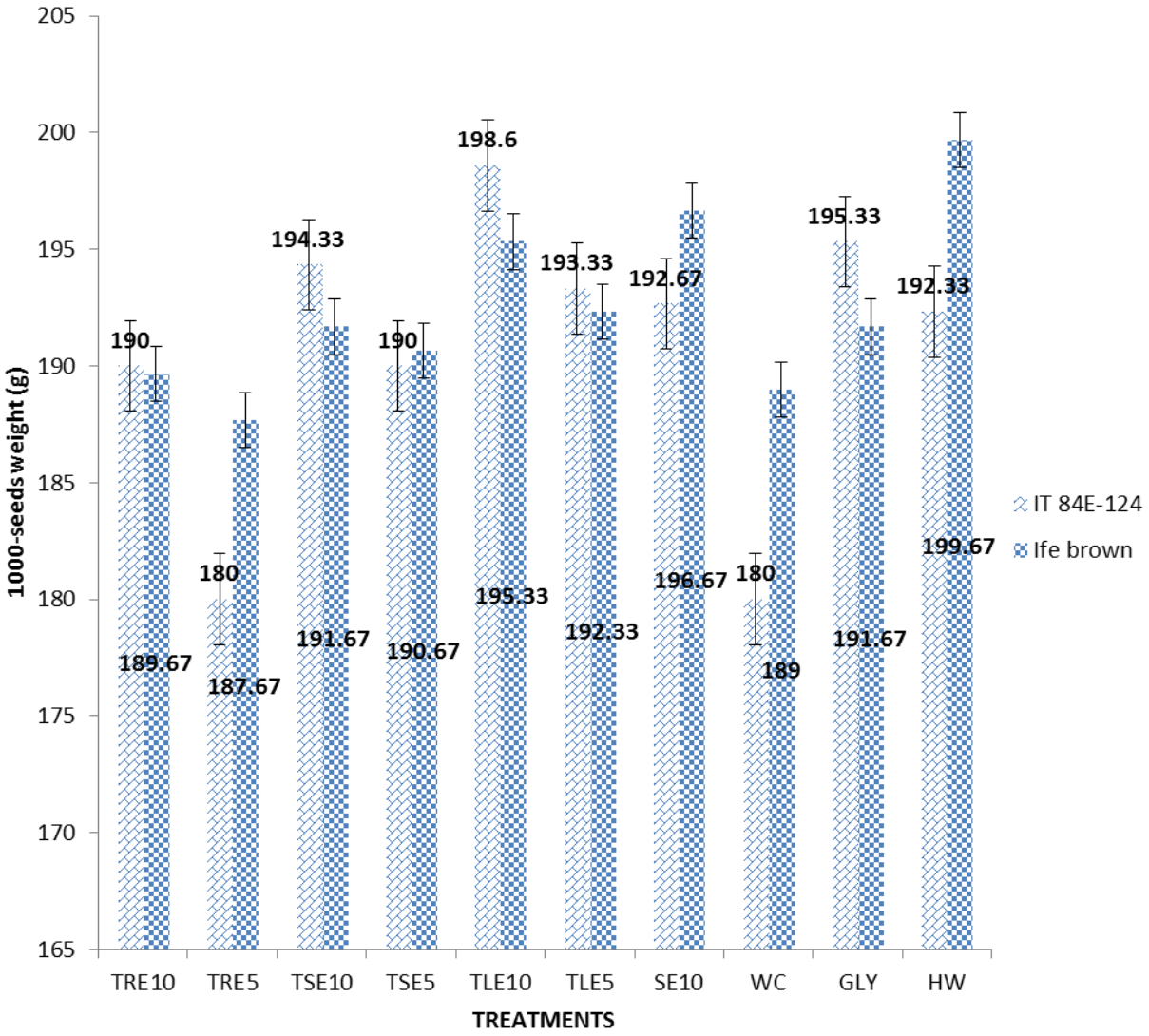


Figure 17: Allelopathic effects of aqueous extracts of *T. diversifolia* on 1000-seed weight in the two cowpea accessions

TRE = *Tithonia* Root Extract, TSE = *Tithonia* Stem Extract, TLE = *Tithonia* Leaf Extract, SE *Sorghum* Extract WC = Weedy check, GLY= Glyphosate, HW = Hand weeding, 10 = 10% (w/v) concentration, 5 = 5% (w/v) concentration.
Capped bars indicate standard error of the mean.

In Ife Brown accession, the highest mean 1000-seeds weight was recorded from the seeds harvested from the regimes of plants in the hand weeding plots HW = 199.667 ± 4.66 g. However, this was not significantly different from the mean 1000-seeds weight (p = 0.51) recorded from the seeds harvested from the other entire experimental plots for this accession (Figure 17). Similarly, the lowest mean 1000-seeds weight was recorded from the seeds harvested from the plots treated with TRE 5 = 187.67 ± 4.66 g. This was not significantly different from the mean 1000-seeds weight (p = 0.45) obtained from the other entire experimental plots in the study (Figure 17).

4.6 FIELD EXPERIMENT II

4.6.1 Weed suppressive effects of aqueous extracts of *T. diversifolia* on weeds of cowpea cropping system (Ife Brown)

The effects of aqueous extracts of *T. diversifolia* on weed densities (WD) at 30 and 65 days after planting (DAP), weed dry weight at 65 DAP, percentage decrease in weed densities at 30 and 65 DAP in relation to the weedy check and weed control efficiencies are presented in Table 13.

Table 13: Weed suppressive effects of aqueous extracts of *T. diversifolia* on weeds of cowpea (Ife Brown) cropping system

Treatments	30 DAP		65 DAP		Weed dry weight at 65 DAP (g/m^2)	Weed control efficiency (%)
	Weed density ($no./m^2$)	% Decrease	Weed density ($no./m^2$)	% Decrease		
TSE 10	16.17 ± 0.28^{d}	59.62	53.00 ± 0.97^{b}	55.21	65.71 ± 6.74^{b}	36.14
TSE 7.5	17.67 ± 0.81^{c}	58.37	54.33 ± 1.44^{b}	54.08	68.16 ± 7.61^{b}	33.76
TLE 10	14.00 ± 0.49^{e}	65.04	40.83 ± 3.34^{c}	65.49	30.95 ± 5.55^{e}	69.92
TLE 7.5	15.15 ± 0.08^{f}	62.17	43.83 ± 2.27^{c}	62.05	$41.92 \pm 1.67^{,d}$	59.26
SE 10	19.38 ± 0.92^{b}	51.61	52.12 ± 0.66^{b}	55.95	49.82 ± 1.13^{c}	51.58
WC	40.05 ± 8.72^{a}	0	118.33 ± 24.07^{a}	0	102.9 ± 19.89^{a}	0
GLY	2.83 ± 4.44^{g}	92.93	19.5 ± 10.88^{d}	83.52	7.24 ± 13.93^{f}	92.96
HW	3.50 ± 4.20^{g}	91.26	20.17 ± 10.64^{d}	82.95	6.39 ± 14.23^{f}	93.79

Key: TSE = *Tithonia* Stem Extract, TLE = *Tithonia* Leaf Extract, SE = Sorghum Extract, WC = Weedy Check, GLY = Glyphosate, HW = Hand weeding, 7.5 = 7.5% (w/v) concentration, 10 = 10% (w/v) concentration, DAP = Days after Planting.
Values in a column followed by the same letter are not significantly different by DMRT at $p > 0.05$.
Values = mean value ± standard error

4.6.1.1 Weed suppressive effects of the aqueous extracts of *T. diversifolia* on WD at 30 DAP in cowpea (Ife Brown) cropping system

The highest mean WD at 30 DAP was recorded from the weedy check plots WC = 40.05 ± 8.72/m^2. This was significantly higher than the mean WD at 30 DAP (p = 0.01) recorded from each of the entire experimental plots. The lowest mean WD at 30 DAP was recorded from the herbicide treated plots GLY = 2.83 ± 4.44/m^2. This was not significantly different from the mean WD at 30 DAP (p = 0.31) recorded from the hand weeding plots HW = 3.50 ± 4.20/m^2). In the five aqueous extract-treated plots, the lowest mean WD was recorded from the plots treated with TLE 10 = 14.00 ± 0.49/m^2. This was significantly different from the mean WD at 30 DAP (p = 0.02) recorded in the plots other four aqueous extract-treated plots. The mean WD at 30 DAP recorded in the plots treated with SE 10 = 19.38 ± 0.92 was significantly higher than the mean WD at 30 DAP (p = 0.00) observed from the plots treated with TLE 10 (14.00 ± 0.49/m^2) and TLE 7.5 (17.67 ± 0.81/m^2) (Table 13). The plots treated with GLY had the highest percentage decrease in weed density at 30 DAP (92.93%), this was followed by the hand weeding plots which had (91.26%) decrease. The plots treated with TLE 10 had 65.04% decrease while the plots treated with SE 10 had 51.61% decrease in weed density at 30 DAP (Table 13).

4.6.1.2 Weed suppressive effects of the aqueous extracts of *T. diversifolia* on weed density at 65 days after planting in cowpea (Ife Brown) cropping system

The highest mean weed density (WD) at 65 DAP was recorded from the weed check plots WC = 118.33 ± 24.07/m^2. This was significantly higher than the mean WD at 65 DAP (p = 0.00) recorded from each of the other entire experimental plots (Table 13). The lowest mean WD was recorded from the herbicide-treated plots GLY = 19.50 ± 10.88/m^2. This was not significantly different from the mean WD at 65 DAP (p = 0.15) observed from hand weeding plots HW = 20.17 ± 10.64/m^2. In the five aqueous extract-treated plots, the

lowest mean WD was recorded from the plots treated with TLE 10 = 40.83 ± 3.34/m^2. However, this was not significantly different from the mean WD at 65 DAP (p = 0.12) recorded from the plots treated with TLE 7.5 = 43.83 ± 2.27/m^2 but was significantly lower (p = 0.01) than the mean WD recorded from the plots treated with SE 10 = 52.12 ± 0.66/m^2; TSE 10 = 53.00 ± 0.97 and TSE 7.5 = 54.33 ± 1.44 (Table 13).

The highest percentage decrease in WD at 65 DAP was observed from the herbicide-treated plots GLY = 83.52%, followed by the hand weeding plots HW = 82.95%. The plots treated with TLE 10 and TLE 7.5 had 65.49% and 62.05% decrease in WD at 65 DAP respectively. While the plots treated with SE 10 had 55.95% (Table 13).

4.6.1.3 Weed suppressive effects of the aqueous extracts of *T. diversifolia* on weed dry weight at 65 DAP in the cropping system of cowpea

The highest mean WDW at 65 DAP was recorded from the weedy check plots WC = 102.90 ±19.89 g/m^2. This was significantly higher (p = 0.02) than the mean WDW recorded from each of the entire experimental plots. The lowest mean WDW at 65 DAP was observed from the weeds collected from the hand weeding plots HW = 6.39 ± 14.23 g/m^2, this was not significantly different from the mean WDW at 65 DAP (p = 0.51) recorded in the herbicide-treated plots GLY = 7.24 ± 13.93 g/m^2 (Table 13).

Within the five aqueous extract-treated plots, the lowest mean WDW at 65 DAP was recorded from the plots treated with TLE 10 = 30.95 ± 5.55 g/m^2. This was significantly different from the mean WDW at 65 DAP (p = 0.00) recorded from each of the entire experimental plots. This was followed by the mean WDW at 65 DAP recorded from the plots treated with TLE 7.5 = 41.92 ± 1.67 g/m^2. The mean WDW at 65 DAP recorded from the plots treated with SE 10 = 49.82 ±1.13 g/m^2 was also significantly different from

the mean WDW at 65 DAP (p = 0.02) recorded from each of the entire experimental plots (Table 13). The highest weed control efficiency was achieved with the hand weeding which gave 93.79% WCE. The herbicide (GLY) resulted in 92.96% WCE. However, TLE 10 demonstrated 69.92% WCE while TLE 7.5 exhibited 59.26% WCE. The plots treated with SE 10 exhibited 51.58% WCE (Table 13).

4.6.2 Allelopathic effects of aqueous extracts of *T. diversifolia* on yield of cowpea (Ife Brown).

The allelopathic effects of aqueous extracts of *T. diversifolia* on yield parameters of cowpea are presented in Table 14.

4.6.2.1 Allelopathic effects of aqueous extracts of *T. diversifolia* on plant height at six weeks after planting in cowpea (Ife Brown)

The highest mean PH was recorded from the regime of plants in the plots treated with TLE 10 = 36.67 ± 1.64 cm. However, this was not significantly different from the mean PH (p = 0.15) observed from the regime of plants in the plots treated with TLE 7.5 = 36.00 ± 1.40 cm. This was followed by the mean PH recorded in the regime of plants from the hand weeding plots HW = 34.14 ± 0.90 (Table 14). The lowest mean PH was observed from the regime of plants in the weedy check plots WC = 24.10 ± 0.80 cm. This was significantly different from the mean PH (p = 0.00) observed from the other regimes of plant in the entire experimental plots. Also, the mean PH observed from the regime of plant in the herbicide-treated plots GLY = 32.62 ± 0.21cm, was not significantly different from the mean PH (p = 0.51) observed in the regimes of plants in the plots treated with TSE 10 = 32.60 ± 0.60 cm, TSE 7.5 = 32.33 ± 0.46 and SE 10 = 32.63 ± 0.20 cm (Table 14).

Table 14: Allelopathic effects of aqueous extracts of *T. diversifolia* on yield parameters of cowpea (Ife Brown)

Treatments	Plant height at 6 WAP (cm)	Pods/plant (no.)	Seeds/pod (no.)	Grain yield (kg/ha)	% Increase in grain yield
TSE 10	32.60 ± 0.22^{c}	28.32 ± 0.54^{d}	13.67 ± 0.10^{c}	424.24 ± 1.70^{c}	44.51
TSE 7.5	32.33 ± 0.46^{c}	27.92 ± 0.68^{d}	13.34 ± 0.21^{c}	423.56 ± 8.54^{c}	44.27
TLE 10	36.67 ± 1.64^{a}	35.63 ± 2.05^{a}	15.03 ± 0.40^{a}	488.65 ± 23.66^{a}	66.45
TLE 7.5	36.00 ± 1.40^{a}	35.61 ± 2.04^{a}	14.98 ± 0.10^{a}	485.34 ± 23.20^{a}	65.32
SE 10	32.63 ± 0.20^{c}	29.95 ± 0.03^{c}	14.69 ± 0.27^{b}	425.22 ± 1.24^{c}	44.84
WC	24.10 ± 0.80^{d}	21.62 ± 2.91^{e}	10.33 ± 1.27^{c}	293.58 ± 45.30^{d}	0
GLY	32.62 ± 0.21^{c}	30.12 ± 0.10^{c}	14.70 ± 0.27^{b}	426.49 ± 1.68^{c}	45.27
HW	34.14 ± 0.90^{b}	33.96 ± 1.47^{b}	14.66 ± 0.27^{b}	457.65 ± 16.01^{b}	59.12

Key: TSE = *Tithonia* Stem Extract, TLE = *Tithonia* Leaf Extract, SE = Sorghum Extract, WC = Weedy Check, GLY = Glyphosate, HW = Hand weeding, WAP = Weeks after Planting 7.5 = 7.5 % (w/v) concentration, 10 = 10 % (w/v) concentration.
Values in a column followed by the same letter are not significantly different by DMRT at $p > 0.05$.
Values = mean value ± standard error

4.7.2.2 Allelopathic effects of aqueous extracts of *T. diversifolia* on pods per plant in cowpea (Ife Brown)

The highest mean pods per plant (PPP) was recorded from the regime of plants in the plots treated with TLE 10 = 35.63 ± 2.05. Nevertheless, this was not significantly different from the mean PPP (p = 0.12) observed from the regime of plants in the plots treated with TLE 7.5 = 35.61 ± 2.04. This was followed by the mean PPP recorded from the regime of plants in the hand weeding plots HW = 33.96 ± 1.47 (Table 14). The mean PPP observed from the regime of plants in the herbicide-treated plots GLY= 30.12 ± 0.10 was not significantly different from the mean PPP (p = 51) recorded from the regime of plants in the plots treated with SE 10 = 29.95 ± 0.03. The lowest mean PPP was recorded from the regimes of plants in the weedy check plots WC = 21.62 ± 2.91. This was significantly different from the mean PPP (p = 0.01) recorded from the other regimes of plants in the entire experimental plots (Table 14).

4.6.2.3 Allelopathic effects of aqueous extracts of *T. diversfolia* on seeds per pod in cowpea (Ife Brown)

The highest mean SPP was observed from the pods harvested from the regime of plants in the plots treated with TLE 10 = 15.03 ± 0.40. This was not significantly different from the mean SPP (p = 0.21) recorded from the pods harvested from the plots treated with TLE 7.5 = 14.98 ± 0.10 (Table 14). This was closely followed by the mean SPP observed from the pods harvested from the regimes of plant harvested from the plots treated with herbicide GLY = 14.70, SE 10 = 14.69 ± 0.27 and hand weeding plots HW = 14.66 ± 0.27. The lowest mean SPP was observed in the pods harvested from the regime of plant in weed check plots WC = 10.33 ± 1.27. The mean SPP observed from other herbicide-treated plots GLY = 14.70 ± 0.27 was not significantly different from the mean SPP (p = 0.51)

recorded from the pods harvested from the regimes of plants in the hand weeding plots WC = 14.66 ± 0.27 (Table 14).

4.6.2.4 Allelopathic effects of the aqueous extracts of *T. diversifolia* on grain yield of cowpea (Ife Brown)

The highest mean GY was recorded from the plots treated with TLE 10 = 488.65 ± 23.66 kg/ha. However, this was not significant different from the mean GY (p = 0.12) recorded the plots treated TLE 7.5 = 485.34 ± 23.20 kg/ha (Table 14). This was followed by the mean GY recorded from the hand weeding plots HW = 457.65 ± 16.01 kg/ha. The lowest mean GY was observed from the weed check plots WC = 293.58 ± 45.30 kg/ha. This was significantly different (p = 0.02) from the mean GY observed from each of the other entire experimental plots. The mean GY observed from the herbicide-treated plots GLY = 426.49 ± 1.68 kg/ha was not significantly different (p = 0.52) from the mean GY recorded from the plots treated TSE 10 = 424.24 ± 1.70 kg/ha; TSE 7.5 = 423.56 ± 1.68 kg/ha and SE 10 = 425.22 ± 1.24 kg/ha (Table 14). The highest percentage increase in yield 66.45% was recorded from the plots treated with TLE 10. This was closely followed by the GY recorded from the plots treated with TLE 7.5 which had 65.32% increase in GY. The hand weeding plots had 59.12% while the herbicide treated plots had 45.27% increase in GY. However, the plots treated with SE 10 also had 44.84% increase in GY (Table 14).

CHAPTER FIVE

5 .0 DISCUSSION

The result of this study has revealed the allelopathic potentials of the aqueous extracts of *T. diversifolia* in biological control of weeds in cowpea cropping system. The predominant weed species in the experimental sites were *Tridax procumbens*, *Talinum triangulare*, *Chromolaena odorata*, *Amaranthus viridis*, and *Ageratum conyzoides*. This confirmed the findings of several authors that have reported *T. procumbens*, A. spp, *T. triangulare*, *P. minor*, *C. odorata* and *A. conyzoides* as some of the weeds associated with the cowpea on the field (Madukwe *et al*., 2012; Sunday and Udensi, 2013). Also, Adigun *et al*. (2014) identified *Euphorbia heterophyla, T. tringulare, C. odorata, T. procumbens, A. viridis* and *Imperata cylindrica* as some of the weeds associated with cowpea cropping system.

The weed suppressive effects aqueous extracts of *T.diversifolia* on weeds infestation of cowpea cropping system revealed that 10% and 7.5% (w/v) concentrations of the extracts of the stem and leaf had significant effect on weed density both at 30 and 65 DAP. Maximum weed reduction was observed in the plots treated with herbicide (glyphosate) but it was statistically at par with the hand weeding plots. However, 7.5 % and 10 % (w/v) TLE were found to be effective in reducing weed density at 30 and 65 DAP in the cropping systems of the two accessions of cowpea in Field Experiment I and II.

The lower concentration of the extracts and TRE in particular did not have significant effect on weed infestation as they did not exhibit significant reduction on weed density at 30 and 65 DAP. The results of the present study were in line with the findings of Khan *et al*. (2012) who reported 70 – 75% reduction in weed density and weed dry weight when aqueous extract of *Sorghum* was used in combination with half and 1/3rd dose of atrazine. The results of this study also corroborated the findings of Ahmad *et al*. (2000), who

reported that foliar spraying of *Sorghum* water extract reduced the total weed density by 34 – 57% and total weed bio-masses by 13 – 54%. The results of this study were also in line with the findings of Bhatti *et al*. (2000) who reported that hand weeding gave maximum reduction 78% in total weed density, followed by application of sorgaab which reduced weed density by 63%. However, the result contradicted their findings that hand weeding decreases dry weight by 45%. The results of this study revealed that the decrease in weed dry weight by herbicide and hand weeding were significantly higher than that of the aqueous extract of *T. diversifolia*. The results were also contradictory to Cheema *et al*. (2000) who reported that sorgaab gave weed control equalled to the labeled dose of pendimethalin (herbicide). This inconsistency might be due to environmental factors such as soil properties and the types of soil microbes as reported by Farooq *et al*. (2013). Also it had been reported that some microbes secrete allelochemicals that neutralize or reduce the effects of allelochemicals in natural conditions (Ilori, 2013). Naseem *et al*. (2010) found similar reduction in weed dry weight by 70% with the three sprays of aqueous extract of sunflower extract in wheat cropping system. Arif *et al*. (2015) also observed significant reduction in WD by 55 – 59% at 25 and 40 DAP with application of two sprays of *Sorghum* + sunflower + *Brassica* each at 18 l/ha. They also observed that maximum reduction was obtained by herbicidal treatment which reduced weed density by 78 – 90% and dry weight by 76 – 89%. Higher weed control efficiency by chemical herbicidal than allelochemical as observed in the present study may be attributed to inhibition of biosynthesis of essential amino acids in weeds by the herbicide (Mason-sedun *et al*., 1986). Rehman *et al*. (2010) also recorded maximum weed control efficiency (76 – 82%) in rice by application of chemical herbicide.

It was observed that *Tithonia* leaf extracts at 10% (w/v) had significant effect on weed infestation than the the extracts from the root and stem. This might be due to the fact that

allelochemicals are highly concentrated in leaf than other parts of plants especially in *T. diversifolia*. Previous work has identified a number of phenolic compounds which are more concentrated in the leaves of *T. rotundifolia* (Braca *et al*., 2003). Effectiveness of *T. diversifolia* leaf extract might be due to inference of the allelochemicals with the cell division, hormone-biosynthesis and mineral-uptake of the weeds (Rizvi *et al*., 1992). It might also be that the allelochemicals at higher concentrations interferred with membrane permeability, photosynthesis, respiration protein metabolism and plant/water relation which caused substantial growth reduction in weeds (Kruse *et al*., 2000; Farooq *et al*., 2013).

It was observed that the allelopathic effect of *T. diversifolia* is species selective as the extract did not affect the crop growth negatively. This is in line with the findings of Oyerinde *et al*. (2009) who reported that allelopathic function of *T.diversifolia* is species-selective and also has selectivity on the developmental stages of *Zea mays*. This might be due to the facts that larger-sized seeds are less adversely affected by the allelochemicals (Usuah *et al*., 2013). The size of cowpea seeds is relatively larger than the sizes of most of the seeds of the weeds in the experimental sites.

Also, the result obtained in this study has revealed the allelopathic effects of aqueous extracts of from the root, stem and leaves of *T. diversifolia* on the germination and seedlings growth of cowpea. *T. diversifolia* extracts did not have significant inhibitory nor stimulatory effect on the germination ($p > 0.05$) of cowpea seeds (IT 84E-124 and Ife Brown) but the seedlings growth was significantly enhanced ($p < 0.05$). This result is consistent with that of Oyerinde *et al*. (2009) who discovered that the shoot extract of *T. diversifolia* did not have inhibitory effect on germination of maize.

However, Musyimi *et al*. (2012) found that aqueous extract of *T.diversifolia* shoot stimulated the germination of *Cleome gynandra* seeds. Otusanya *et al*. (2007) demonstrated the inhibitory effect of shoot extract of *T. diversifolia* on germination of *Amaranthus cruentus*. The disparity in the findings might be due to environmental factors such as soil characteristics of the studied location and the climate. It may as well be due to the sizes of the seeds or human induced factors such as wrong planting methods. Usuah *et al*. (2013) revealed that larger-sized seeds are less adversely affected by the allelochemicals; this is because a reduced amount of allelochemicals could get to the embryo due to the relative distance of the embryo from the seed surfaces compared to those in small seeds. This agrees with the findings of Mohler (2001) and Aliota *et al*. (2006) who reported that the effectiveness of allelochemicals has to do with the size of the seed.

The result of this study also indicated that the extracts at 10% (w/v) concentration enhanced the growth of the shoot and root of cowpea as it was evident in the seedling growth parameters. The allelochemicals in the aqueous extracts of *T. diversifolia* stimulated seedling growth in terms of shoot length, root length, number of leaves per plant, shoot dry and root dry weight at four WAP in the two accessions of cowpea, however the effect was more pronounced in the regimes of plants treated with 10% (w/v) concentration of aqueous *Tithonia* leaf extract which exhibited significant percentage increase in dry weight in comparisons with the weedy check and the herbicides treated plants. For instance, in comparison the weedy check, the shoot length was increased by 36.75% and 25.71% in the two accessions of cowpea (IT 84E-124 and Ife Brown) respectively. In comparison with the herbicides treated plots, the shoot length was increased by 23.53% and 14% in the two accessions respectively. The same trend was observed in the other seedling growth parameters (Table 10). This is at variance with

observation made by Ilori *et al*. (2007) who reported that the shoot extract of *T.diversifolia* inhibited seedling growth of *Oryza sativa*. However, the result is consistent with the findings of Oyerinde *et al*. (2009) who reported that fresh shoot aqueous extract of *T.diversifolia* stimulated the seedling growth of maize plants.

It was further revealed that the extract stimulated significant increase in average number of leaves per plants in the two accessions studied. This is in line with the findings of Nasir *et al*. (2005b) who reported stimulatory effect of *Stevia rebaudiana* extract on lettuce and cucumber. Taiwo and Makinde (2005) have equally reported similar effects in *Vigna unguiculata* treated with *T. diversifolia* shoot extract.

In this study, the aqueous extracts of *T.diversifolia* also enhanced shoot and root dry weights of the two accessions (IT 84E-124 and Ife Brown) of cowpea. In the same vein, the effect was more pronounced in the regimes of plants in the plots treated with 10% (w/v) concentration of TLE which exhibited 43% and 21% increases in SDW in comparison with the weedy check (control) in the two accessions respectively. However, in comparisons with the herbicide-treated plots, there were 30% and 18% increases in the two accessions correspondingly. The increase in SDW observed in this study probably was as a result of increase in the numbers of leaves per plants which might have led to increase in the rate of photosynthesis and consequently an increase in the accumulation of biomass and shoot growth. These findings were in agreement with the observation of Bano *et al*. (2012) who reported that neem (*Azadirachta indica*) leaf extract had significant stimulatory effect on shoot growth of oat seedlings. Also, these findings corroborate the findings of Alam (1990) who reported that *Azadirachta indica* leaf extract significantly increased shoot growth of wheat. Kanayo *et al*. (2014) also reported similar effects of decaying leaf litter on growth of maize.

Similarly, it was discovered that the root growth was significantly enhanced by the 10% (w/v) concentrations of aqueous extracts of TLE exhibited 83% and 72% increases in the root dry weights in relation to the weedy check in the two accessions respectively. While in relation to the herbicide treated plant, TLE at 10% (w/v) concentration exhibited 34% and 29% increases in root dry weight. This finding supports the discoveries of Oyerinde *et al*. (2009) who reported that aqueous extract of *T. diversifolia* significantly enhanced shoot and root dry weight of *Zea mays*. However, this result indicated higher stimulatory effects on the root length and dry weight than the shoot length and dry weight. This may be due to the fact that, roots have direct contact with the allelochemicals applied on the soil. This also corroborates the earlier findings of several researchers such as Chou and Waller (1980); Swami-Rao and Reddy (1984); Chou and Kuo (1986); Alam (1990) and Zackrisson and Nilsson (1992) who all asserted that root growth was more sensitive to plant extracts in comparison to the shoot growth. Munir and Tawaha (2002) also reported that the root length was more sensitive to allelochemicals than the shoot length. Ilori *et al*. (2007) also found that the root growth was more affected than the growth of stem and leaves of plants because the roots were in continuous contact with the extract.

The result of the evaluation of the allelopathic effects of aqueous extracts from the different parts of *T. diversifolia* on yield of cowpea showed that the extracts at 7.5% and 10% (w/v) concentrations significantly enhanced yield parameters in the two accessions of cowpea studied. The plant height was significantly influenced by 7.5% and 10% (w/v) concentrations of the aqueous extracts of *T. diversifolia* in the two accessions of cowpea in the two field experiments. There was considerable increase in plant height in relation to the control at six WAP. The increased yield parameters were due to decrease in weed interference with the cowpea plants at the critical period of weed control. It had been

reported that weed competition is most critical during the first 20-40 days of cowpea growth (Olorunmaye, 2010). This was in line with the findings of Oyerinde *et al*. (2009) who reported that fresh shoot extract of *T. diversifolia* significantly influenced shoot length, shoot fresh and shoot dry weight of *Zea mays*. It has been reported that green biomass of *T. diversifolia* can serve as an effective source of nutrients for *Zea mays* (Jama *et al*., 2000; Nziguheba *et al*., 2002). The result was consistent with the findings of Quassem (1995) who reported that incorporation of *Andersonia gracilis* residues increased plant height and wheat yield significantly.

The results of this study showed that *Tithonia root* extract did not have significant effect ($p > 0.05$) both at 10% and 5% (w/v) concentrations on yield parameters of cowpea. This may be due to the fact that plants especially crops respond in diverse ways to aqueous plant extracts depending on type of extract (dry or fresh), concentration of the extract and the part from which the extract was prepared (Taiwo and Makinde, 2005). It had been reported that the type and concentration of allelochemicals vary in different parts of the plant (Otusanya and Ilori, 2014).

Similarly, the number of pods per plant was significantly influenced by 10% and 7.5% (w/v) concentrations of TSE and TLE. It was discovered that the number of pods per plant in the regimes of plants in the plots treated with 10% and 7.5% (w/v) concentrations of TLE were significantly higher than the number pods observed in the plots treated with herbicides and hand weeding at $p < 0.05$. This finding supports the observation of Arif *et al*. (2015), who reported increase in number of productive tillers wheat. Cheema *et al*. (2000) and Anwar *et al*. (2003) also reported similar findings of increased tillers by allelopathic aqueous extract. The increase in pods per plant may be due to better weed control which helped the cowpea plants to utilize the available resources maximally

coupled with the nutrients content of the aqueous extract resulting in increased number of pods. It might also be due to the reaction between the microorganisms in the soil and the allelochemicals in the plant extracts thus, converting it to nutrients which enhanced better production of pods per plants. In addition to weed suppression, allelochemicals enhance mineralization of nutrients and improve their uptake which resulted in better nutrient and subsequent increase in the PPP (Barber, 1984; Harms and Oplinger, 1993).

It was observed that the grain yield of cowpea was significantly enhanced ($p < 0.05$). The cowpea in the plots treated with 10% and 7.5% (w/v) concentrations of the aqueous *Tithonia leaf* extract has better yield in relation to the weedy check (control) and the conventional methods of weed control considered in the study. The effectiveness of the extracts in enhancing grain yield as observed in this study was in line with the findings of Arif *et al*. (2015) who reported higher wheat grain yield by two foliar sprays of *Sorghum*, sunflower and *Brassica* at 18 l/ha. However, grain yield of wheat was reported to be lesser than that of herbicidal treatment. The disparity might be due to the species of plant and the part of plants from where the extract was prepared or the differences in the critical period of weed interference. It had been reported that *T. diversifolia* is a potential green manure and organic fertilizer for vegetable crops (Sangakkara, 2002). A similar observation has been reported by Ilori *et al*. (2007) that *T. diversifolia* can enhance the growth parameters of older plants after seedling establishment of *Oryza sativa.*

The effectiveness of the extract at 10% and 7.5% (w/v) concentrations is probably due to the fact that the concentration and potency of the allelochemicals were concentration dependent. This finding was consistent with Daniel (1990) who observed that allelopathy is a concentration-dependent phenomenon. The use of allelopathic aqueous extract of *T. diversifolia* as demonstrated in this study was effective as the weeds were controlled at the

critical period of weeds interference such that subsequent weeds have no effect on the yield of cowpea. Though, the aqueous extract did not attain maximum weed reduction as the conventional methods (herbicide and hand weeding), the extracts enhanced greater yield which is the ultimate reason for weed control in cropping system. The weeds were controlled at the critical period of weed interference. Thus, considering the labour intensiveness of hand weeding and the deleterious effects of synthetic herbicides on the environment and human health concerns, aqueous extract of *T. diversifolia* leaf could be an organic option in weed control of cowpea cropping system.

Common allelochemicals from plants are generally secondary metabolites which include phenolics, tannins, alkalods, saponin, flavonoids, steroids and quinines (Einhellig 1986). The result of the phytochemical screening of aqueous extracts of *T. diversifolia* indicated the presence of phenols, flavonoids, tannin, saponin and alkaloids. The concentrations of the allelochemicals were according to the following trends: phenol > saponin > tannin > alkaloids > flavonoids in TLE. In TRE the concentrations were tannin > phenols > saponin > flavonoid > alkaloid. However in TSE, the concentration was phenols > tannin > saponin > flavonoid > alkaloids. This was contrary to the findings of Ilori (2013) who discovered that the concentration of allelochemicals in methanolic extract of *T. rotundifolia* was according this trend: phenol > alkaloid > tannin. The disparity might be due to the solvent used in extraction; probably alkaloid is more soluble in methanol than water. TLE had the highest concentrations of all the allelochemicals quantified. This is in line with the findings of Braca *et al.* (2003), who identified high concentration of phenolic compounds in the plant leaves.

The higher concentration of total phenols in TLE corroborated the work of (Vijay and Jain, 2010) that identified and isolated 17 components; out of which ten were phenolic

compounds. Phenolic acids occupied a large proportion of the potential allelochemical that were detected in litter aqueous extract of *Eucalyptus* (Zhao *et al*., 2010). Many investigators have suggested phenolics as the cause of inhibition of metabolic processes during germination and seedling growth. It is also possible that phenolic compounds might have interfered in oxido-reduction reaction, nucleoticle biosynthesis, controlling and prevention of gibberellins biosynthesis and accumulation of growth regulators in the cells causing inhibitory effect on the vegetative growth which ultimately led to weed suppression and ultimately low weed density in the plots treated with the aqueous extract of *T diversifolia* (Gantayet *et al*., 2011). It had also been reported by Vijay and Jain (2010) that maximum allelochemicals are present in leaves. Khan *et al*. (2012) also demonstrated that aqueous extract of *Rhazya stricta* leaf has higher concentration of allelochemicals than stem. Tefera (2002) also reported that leaves of *Parthenium hysterophorus* have been more phytotoxic in nature. Many phenolic compounds are able to bring about alterations in the hormonal balance of the receiving plant which in certain cases lead to inhibition of growth of weeds and ultimately low weed density and biomass in the plots treated with the aqueous extract as it was discovered in this study (Ilori, 2013).

HPLC analysis identified several components as detected by the various peaks; however, four phenolic compounds were identified and quantified in the extracts. These are resourcinol, vanillic acid, p-hydrobenzoic and benzoquinone. The concentrations of these phenolic compounds followed the trend: p-hydroxybenzoic acid > benzoquinone > vanillic acid > resorcinol. However, in TLE, resourcinol was higher than vanillic acid, while resorcinol was not detected in TRE and TSE. The HPLC quantification showed that the quantity of phenolic compounds in TRE and TSE were very low. This might be the reason for their insignificant effect on weed infestation and yield of cowpea as observed in the

study. Resorcinol had been reported to be a potent phytotoxin produced by *Sorghum* root hairs and is likely to be responsible for weed suppression (Dayan *et al*., 2007).

Won *et al*. (2013) identified p-hydroxybenzoic acid, p-coumaric acid and trans-cinnamic in the extract of sorghum leaves. It was also reported in their study that p-hydroxybenzoic acid was the highest among the phenolics acid quantified. Alsaadawi *et al*. (2009) also identified and quantified six phenolic acids from *Sorghum* residue. These are vanillic acid, p-hydroxybenzoic acid, p-coumaric, gallic acid, syringe acid and ferulic acid. In their study p-hydroxybenzoic acid had the highest concentration as it was observed in the present study. It has been reported that resorcinol had the strongest herbicidal activity on small seeded weeds and that large seeded-weeds tend to be less sensitive to resorcinol possibly because they may avoid the herbicidal effect by rapidly growing beyond the zone of the *Sorghum* rhizosphere where the lipophilie exudates accumulate (Einhelig and Leather, 1998).

Past studies have attributed significant allelopathic potency of plant extracts in weed suppression to the presence of phenolic compounds which include p-hydroxybenzoic acid, vanillic acid, cinnamic acid, resorcinol and benzoquinone (Chon *et al*. 2003, Chon and Kim, 2004). The direct relationship between weed control efficiency and the concentrations of the allelochemicals may be as a result of water-uptake inhibition by the weeds and the disturbance in the synthesis and the activity of gibberellic acid (Olofsdotter *et al*., 2002). Phenolic acids have been reported to inhibit the synthesis of gibberellic acid (Chandler *et al*., 1984). Consequently, phenolic compounds are water soluble allelochemical (Rice, 1984).

The results of the HPLC (the quantification of total phenolic compounds) in the aqueous extract of *T. diversifolia* had positive correlation with the weed control efficiency of the

extracts in this study. This result is consistent with the findings of Heidarzade (2010) who reported that there was positive correlation with the phenolic acid content of rice and the inhibition percentage of all parameters. This implies that weed suppression was higher with an increase in total phenolic contents as observed in this study. This result is in agreement with the result of Mattice *et al*. (1998) who suggested that allelelopathy of rice against weed is correlated with the amounts of phenolic acids released by living rice roots

CHAPTER SIX

6.0 SUMMARY OF FINDINGS

The summary of findings of this study is presented below:

OBJECTIVES	SUMMARY OF FINDINGS
(1) Determination of the allelochemical constituents of the aqueous extracts from the different parts of *T. diversifolia*.	Tannins, phenols, alkaloids, flavonoids and saponins were found to be concentrated in *Tithonia* leaf extract than the extracts from the stem and the root. The concentration of the allelochemicals was according to the following trends: in TLE: phenols (2.42 mg/g) > saponins (1.82 mg/g) > tannins (1.75 mg/g) > alkaloids (1.50 mg/g) > flavonoids (0.60 mg/g); in TRE: Tannins (0.90 mg/g) > phenols (0.79 mg/g) > saponins (0.42 mg/g) > flavonoids (0.34 mg/g) > alkaloids (0.19 mg/g) and in TSE: phenols (0.84 mg/g) > tannins (0.82 mg/g) > saponins (0.37 mg/g) > flavonoids (0.29 mg/g) > alkaloids (0.17 mg/g).
(2) Identification and quantification of some of the phenolic compounds in *Tithonia diversifolia*	HPLC identified p-hydroxybenzoic acid, vanillic acid, resorcinol and p-benzoquinone in TLE while resorcinol was not detected in TSE and TRE. The phenolic compounds were more concentrated in TLE than TSE and TRE.
(3) Investigation of the allelopathic effects of aqueous extracts from different parts of *T. diversifolia* on	Aqueous extracts of *T. diversifolia* did not have significant ($p > 0.05$) stimulatory or inhibitory effect on germination of cowpea seeds but significantly enhanced seedling

the germination and seedling growth of cowpea.	growth ($p < 0.05$).
(4) Assessment of the weed suppressive effect of aqueous extract from different parts of *T. diversifolia* on weeds of cowpea cropping system.	10% and 7.5% (w/v) concentrations of aqueous extract of *T. diversifolia* leaf reduced weed infestation to a considerable level when compared to glyphosate herbicide and hand weeding.
(5) Evaluation of the allelopathic effects of the application of aqueous extracts from the different parts of *T. diversifolia* on yield of cowpea	10% and 7.5% (w/v) concentrations of aqueous extract of *T. diversifolia* significantly enhanced yield parameters ($p < 0.05$) of cowpea resulting in 27-71% yield increase.

CHAPTER SEVEN

7.0 CONTRIBUTIONS TO KNOWLEDGE

(1) The study elucidated the presence and the trend of phenols, tannins, saponins, flavonoids and alkaloids in the aqueous extracts from the different parts of *T. diversifolia*.

(2) The study asserted that aqueous leaf extract of *T. diversifolia* leaf controls weeds effectively beyond the critical period of weed interference in cowpea cropping system because of the presence of higher concentrations of p-hydroxybenzoic acid, vanillic acid, resorcinol and p-benzoquinone.

(3) The study established the effectiveness of aqueous extracts of *T. diversifolia* as bioherbicide in the control of weeds in cowpea cropping system.

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APPENDICES

Result of the Analysis of Variance (ANOVA) to show the allelopathic effect of aqueous extracts of *T. diversifolia* on germination of cowpea seeds (IT 84E -124)

Tests of Between-Subjects Effects

Dependent Variable:

Germination %

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	16.769[a]	9	1.397	.956	.511
Intercept	373968.231	1	373968.231	2.559E5	.000
Trmt germination	16.769	9	1.397	.956	.511
Error	38.000	17	1.462		
Total	374023.000	30			
Corrected Total	54.769	29			

a. R Squared = .306 (Adjusted R Squared = -.014)

Result of the Analysis of Variance (ANOVA) to show the allelopathic effect of aqueous extracts of *T. diversifolia* on germination of cowpea (Ife brown)

Tests of Between-Subjects Effects

Dependent Variable
:Germination %

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	10.564[a]	9	.880	.660	.772
Intercept	377501.769	1	377501.769	2.831E5	.000
Trtmt germination %	10.564	9	.880	.660	.772
Error	34.667	17	1.333		
Total	377547.000	30			
Corrected Total	45.231	29			

a. R Squared = .234 (Adjusted R Squared = -.120)

Result of the Analysis of Variance (ANOVA) to show the weed suppressive effects of aqueous extracts of *T. diversifolia* on weed density at 30 DAP of cowpea (IT 84E-124)

Tests of Between-Subjects Effects

Dependent Variable:Density@30

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	22329.282[a]	9	1860.774	94.718	.000
Intercept	32773.251	1	32773.251	1.668E3	.000
Trmtdenat30days	22329.282	9	1860.774	94.718	.000
Error	3575.467	182	19.645		
Total	58678.000	195			
Corrected Total	25904.749	194			

a. R Squared = .862 (Adjusted R Squared = .853)

Result of the Analysis of Variance (ANOVA) to show the weed suppressive effect of aqueous extracts of *T. diversifolia* on weed density at 30 DAP of cowpea (Ife Brown)

Tests of Between-Subjects Effects

Dependent Variable: Density at 30^{th} DAP

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	23571.354[a]	9	1964.279	83.736	.000
Intercept	32205.313	1	32205.313	1.373E3	.000
Trmtden@30days	23571.354	9	1964.279	83.736	.000
Error	4269.333	182	23.458		
Total	60046.000	195			
Corrected Total	27840.687	194			

a. R Squared = .847 (Adjusted R Squared = .837)

Result of the Analysis of Variance (ANOVA) to show the weed suppressive effect of aqueous extracts of *T. diversifolia* on weed density at 65 DAP of cowpea (IT 84E-124)

Tests of Between-Subjects Effects

Dependent Variable: Density at 65th DAP

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	64021.051[a]	9	5335.088	68.954	.000
Intercept	135666.782	1	135666.782	1.753E3	.000
Trmtden@65days	64021.051	9	5335.088	68.954	.000
Error	5029.167	65	77.372		
Total	204717.000	78			
Corrected Total	69050.218	77			

a. R Squared = .927 (Adjusted R Squared = .914)

Result of the Analysis of Variance (ANOVA) to show the weed suppressive effect of aqueous extracts of *T. diversifolia* on weed density at 65 DAP of cowpea (Ife brown)

Tests of Between-Subjects Effects

Dependent Variable: WD at 65 DAP

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	62821.385[a]	9	5235.115	67.452	.000
Intercept	146726.782	1	146726.782	1.890E3	.000
Trmt WD at 65 DAP	62821.385	9	5235.115	67.452	.000
Error	5044.833	65	77.613		
Total	214593.000	78			
Corrected Total	67866.218	77			

a. R Squared = .926 (Adjusted R Squared = .912)

Result of the Analysis of Variance (ANOVA) to show the weed suppressive effect of aqueous extracts of *T. diversifolia* on weed dry weight at 65 DAP in cowpea cropping system (IT 84E-124)

Tests of Between-Subjects Effects

Dependent Variable: Weed dry weight

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	34633.897[a]	9	2886.158	231.724	.000
Intercept	62040.519	1	62040.519	4.981E3	.000
Trmt dry weight	34633.897	9	2886.158	231.724	.000
Error	323.833	17	12.455		
Total	96998.250	30			
Corrected Total	34957.731	29			

a. R Squared = .991 (Adjusted R Squared = .986)

Result of the Analysis of Variance (ANOVA) to show the weed suppressive effects of aqueous extracts of *T. diversifolia* on weeds dry weight at 65 DAP of cowpea cropping system (Ife Brown)

Tests of Between-Subjects Effects

Dependent Variable: Weed dry weight at 65 DAP

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	37305.356[a]	9	3108.780	260.350	.000
Intercept	68980.924	1	68980.924	5.777E3	.000
Trmt WDW at 65 DAP	37305.356	9	3108.780	260.350	.000
Error	310.460	17	11.941		
Total	106596.740	30			
Corrected Total	37615.816	29			

a. R Squared = .992 (Adjusted R Squared = .988)

Result of the Analysis of Variance (ANOVA) to show the allelopathic effect of aqueous extracts of *T. diversifolia* plant height at six WAP of cowpea (IT 84E-124)

Tests of Between-Subjects Effects

Dependent Variable: Height

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	13557.877[a]	9	1129.823	56.298	.000
Intercept	688800.256	1	688800.256	3.432E4	.000
Trmtheight	13557.877	9	1129.823	56.298	.000
Error	7565.867	287	20.069		
Total	709924.000	300			
Corrected Total	21123.744	299			

a. R Squared = .642 (Adjusted R Squared = .630)

Result of the Analysis of Variance (ANOVA) to show the allelopathic effect of aqueous extracts of *T. diversifolia* on plant height (Ife Brown)

Tests of Between-Subjects Effects

Dependent Variable: Plant Height

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	13725.563[a]	9	1143.797	65.308	.000
Intercept	708855.808	1	708855.808	4.047E4	.000
Trmt PH at 6 WAP	13725.563	9	1143.797	65.308	.000
Error	6602.735	287	17.514		
Total	729278.000	300			
Corrected Total	20328.297	299			

a. R Squared = .675 (Adjusted R Squared = .665)

Result of the Analysis of Variance (ANOVA) to show the allelopathic effects of aqueous extracts of *T. diversifolia* on pods per plant in cowpea (IT 84E-124)

Tests of Between-Subjects Effects

Dependent Variable: Pods per plant

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	244.544[a]	9	20.379	89.024	.000
Intercept	2930.156	1	2930.156	1.280E4	.000
Trmtblock	244.544	9	20.379	89.024	.000
Error	86.300	287	.229		
Total	3261.000	300			
Corrected Total	330.844	299			

a. R Squared = .739 (Adjusted R Squared = .731)

Result of the Analysis of Variance (ANOVA) to show the allelopathic effect of aqueous extracts of *T. diversifolia* on pods per plant of cowpea (Ife Brown)

Tests of Between-Subjects Effects

Dependent Variable: Pods/ plant

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	354.144[a]	9	29.512	95.148	.000
Intercept	2826.923	1	2826.923	9.114E3	.000
Trmtblock	354.144	9	29.512	95.148	.000
Error	116.933	287	.310		
Total	3298.000	300			
Corrected Total	471.077	299			

a. R Squared = .752 (Adjusted R Squared = .744)

Result of the Analysis of Variance (ANOVA) to show the allelopathic effect of aqueous extracts of *T. diversifolia* on seeds per pod of cowpea (IT 84E-124)

Tests of Between-Subjects Effects

Dependent Variable:
Seeds/pod

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2006.256[a]	9	167.188	152.824	.000
Intercept	65624.310	1	65624.310	5.999E4	.000
Trmtseeds/pod	2006.256	9	167.188	152.824	.000
Error	412.433	287	1.094		
Total	68043.000	300			
Corrected Total	2418.690	299			

a. R Squared = .829 (Adjusted R Squared = .824)

Result of the Analysis of Variance (ANOVA) to show the allelopathic effect of aqueous extracts of *T. diversifolia* on seeds per pod of cowpea (Ife Brown)

Tests of Between-Subjects Effects

Dependent Variable: Seeds/ pod

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2162.841[a]	9	180.237	147.374	.000
Intercept	66066.092	1	66066.092	5.402E4	.000
Trmtseed	2162.841	9	180.237	147.374	.000
Error	461.067	287	1.223		
Total	68690.000	300			
Corrected Total	2623.908	299			

a. R Squared = .824 (Adjusted R Squared = .819)

Result of the Analysis of Variance (ANOVA) to show the allelopathic effect of aqueous extracts of *T. diversifolia* on grain yield of cowpea (IT 84E-124)

Dependent Variable: grain yield

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2.800E7[a]	9	2332971.190	3.743	.000
Intercept	1.801E8	1	1.801E8	288.998	.000
Trmtyield	2.800E7	9	2332971.190	3.743	.000
Error	4.051E7	65	623278.303		
Total	2.486E8	78			
Corrected Total	6.851E7	77			

a. R Squared = .409 (Adjusted R Squared = .299)

Result of the Analysis of Variance (ANOVA) to show the allelopathic effect of aqueous extracts of *T. diversifolia* on grain yield of cowpea (Ife Brown)

Tests of Between-Subjects Effects

Dependent Variable: grain yield

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2.625E7[a]	9	2187474.927	3.521	.000
Intercept	1.699E8	1	1.699E8	273.404	.000
Trmtyield	2.625E7	9	2187474.927	3.521	.000
Error	4.039E7	65	621348.064		
Total	2.365E8	78			
Corrected Total	6.664E7	77			

a. R Squared = .394 (Adjusted R Squared = .282)

Result of the Analysis of Variance (ANOVA) to show the allelopathic effect of aqueous extracts of *T. diversifolia* on 1000 seeds weight of cowpea (IT 84E-124)

Tests of Between-Subjects Effects

Dependent Variable: 1000
Seeds weight

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	7213.744[a]	9	601.145	9.205	.000
Intercept	1588529.256	1	1588529.256	2.432E4	.000
Trmtseedweight	7213.744	9	601.145	9.205	.000
Error	1698.000	17	65.308		
Total	1597441.000	30			
Corrected Total	8911.744	29			

a. R Squared = .809 (Adjusted R Squared = .722)

Result of the Analysis of Variance (ANOVA) to show the allelopathic effect of aqueous extracts of *T. diversifolia* on 1000 seeds-weight of cowpea (Ife brown)

Tests of Between-Subjects Effects

Dependent Variable: 1000
Seeds- weight

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	7557.077[a]	9	629.756	12.886	.000
Intercept	1547226.256	1	1547226.256	3.166E4	.000
Trmtseedweight	7557.077	9	629.756	12.886	.000
Error	1270.667	17	48.872		
Total	1556054.000	30			
Corrected Total	8827.744	29			

a. R Squared = .856 (Adjusted R Squared = .790)

FIELD EXPERIMENT 11

Result of the Analysis of Variance (ANOVA) to show the allelopathic effect of aqueous extracts of *T. diversifolia* on plant height of cowpea

Tests of Between-Subjects Effects

Dependent Variable: Plant Height

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	14086.089[a]	7	1280.554	138.115	.000
Intercept	702603.378	1	702603.378	7.578E4	.000
Trtment	14086.089	7	1280.554	138.115	.000
Error	3226.533	228	9.272		
Total	719916.000	240			
Corrected Total	17312.622	239			

a. R Squared = .814 (Adjusted R Squared = .808)

Result of the Analysis of Variance (ANOVA) to show the allelopathic effect of aqueous extracts of *T. diversifolia* on pods per plant in cowpea (Ife Brown)

Tests of Between-Subjects Effects

Dependent Variable: Number of pods per plant (Ife Brown)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	172.808[a]	7	15.710	53.827	.000
Intercept	2640.625	1	2640.625	9.048E3	.000
TrtmtpodIT	172.808	7	15.710	53.827	.000
Error	101.567	228	.292		
Total	2915.000	240			
Corrected Total	274.375	239			

a. R Squared = .630 (Adjusted R Squared = .618)

Result of the Analysis of Variance (ANOVA) to show the allelopathic effect of aqueous extracts of *T. diversifolia* on seeds per pod in cowpea (Ife Brown)

Tests of Between-Subjects Effects

Dependent Variable: Number of Seeds per pod (Ife brown)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	946.964[a]	7	86.088	81.328	.000
Intercept	55031.669	1	55031.669	5.199E4	.000
TrtmtIT	946.964	7	86.088	81.328	.000
Error	368.367	228	1.059		
Total	56347.000	240			
Corrected Total	1315.331	239			

a. R Squared = .720 (Adjusted R Squared = .711)

Result of the Analysis of Variance (ANOVA) to show the allelopathic effect of the aqueous extracts of *T. diversifolia* on grain yield of cowpea (Ife Brown)

Tests of Between-Subjects Effects

Dependent Variable: Grain Yield

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.000[a]	0	.	.	.
Intercept	631.567	1	631.567	368.323	.000
TrtYit	.000	0	.	.	.
Error	60.015	25	1.715		
Total	691.582	24			
Corrected Total	60.015	23			

a. R Squared = .000 (Adjusted R Squared = .000)

Result of the Analysis of Variance (ANOVA) to show the weed suppressive effect of aqueous extracts of *T. diversifolia* on weed density at 30 DAP in cowpea cropping system (Ife Brown)

Tests of Between-Subjects Effects

Dependent Variable: Weed density at 30 DAP (Ife Brown)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	7727.153[a]	7	702.468	91.593	.000
Intercept	11883.681	1	11883.681	1.549E3	.000
TrtmtwIT	7727.153	7	702.468	91.593	.000
Error	460.167	40	7.669		
Total	20071.000	48			
Corrected Total	8187.319	47			

a. R Squared = .944 (Adjusted R Squared = .933)

Result of the Analysis of Variance (ANOVA) to show the weed suppressive effect of aqueous extracts of *T. diversifolia* on weed density at 65 DAP in cowpea cropping system (Ife Brown)

Tests of Between-Subjects Effects

Dependent Variable: Weed Density at 65 DAP (Ife Brown)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	55140.500[a]	7	5012.773	104.614	.000
Intercept	73344.500	1	73344.500	1.531E3	.000
Trtmt65	55140.500	7	5012.773	104.614	.000
Error	2875.000	40	47.917		
Total	131360.000	48			
Corrected Total	58015.500	47			

a. R Squared = .950 (Adjusted R Squared = .941)

Result of the Analysis of Variance (ANOVA) to show the weed suppressive effect of aqueous extracts of *T. diversifolia* on weed dry weight at 65 DAP in cowpea cropping system (Ife brown)

Tests of Between-Subjects Effects

Dependent Variable: Weed Dry Weight
Ife Brown

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	25402.080[a]	7	2309.280	17.280	.000
Intercept	52572.376	1	52572.376	393.398	.000
Trtm weed dry wt	25402.080	7	2309.280	17.280	.000
Error	3207.279	14	133.637		
Total	81181.735	24			
Corrected Total	28609.359	23			

a. R Squared = .888 (Adjusted R Squared = .837)