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Stimulatory Effect of *Tithonya diversifolia*-by Products on Plantain Banana Vivoplants in Nursery (A Review)

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Abstract

Plantain banana is an important cash crop that serves as stable food for millions of people around the world and contributes to income generation. Indeed, they provide a major staple food crop for millions of people and play an important role in the social fabric of many rural communities. Plantain banana cultivation encounters major problem of seedlings unavailability that are essential for the creation of new plantations, as well as parasitic constraints. *Mycosphaerella fijiensis* is the main pathogen attack constraints of banana plant responsible of black Sigatoka disease, and viruses, which can severely reduce the photosynthetic leaf area, leading to banana production losses of more than 80% in plantations with soil fertility problems. The repeated use of synthetic input is the origin of contamination to the environment, different pollution sources of plants and human health, as well as resistance to some strains of pathogens and plant fertilization problems over time. Recent works carried out in nursery have shown that vivoplants of plantains treated with biostimulants based on natural products notably *Tithonia diversifolia* biopromote good growth and less susceptibility to *M. fijiensis*. Indeed, an increase in agromorphological characteristics, good accumulation of growth and defense biomarkers was also observed. In this context, *Tithonia diversifolia* is shown to be involved in the stimulatory effect mechanism of growth promotion and defensive reaction of plantain vivoplants against various pathogens and it is suggested to be acting as a vital stimulator. This article reviews the current state of knowledge on plantain banana cultivation constraints and on the potential of *Tithonia diversifolia* in relation with its different stimulatory effects on plantain vivoplants.

Keywords

Tithonia diversifolia, Plantain Banana, Black Sigatoka Disease, Growth Biopromotion, Bioprotection, Induced Resistance, Biofungicidal Effect

1. Introduction

Bananas (*Musa* spp.) belong to the *Musaceae* family. They are perennial monocotyledonous plants that grow in the tropics where there is a wide seasonal variation in rainfall and temperature. In Central and West Africa, bananas play a vital role in contributing to food security as well as income generation for millions of populations. Moreover, they are particularly important because they produce good quality food all year-round and are adapted to a wide range of cultivation systems. The two most important varieties of bananas are the dessert banana and the cooking banana. Cameroon is ranked 4th in the world (4.66 million tons in 2022) in terms of plantain production and the first in Central Africa [1]. Banana production in the world and Cameroon in particular still encounters a number of problems. The major issues include pest-related constraints and unavailability of seedlings in quantity and quality, which have caused the lack of establishment of new plantations, thus leading to high demand and consequently very high prices for the commodity [2].

An innovative vegetative multiplication technique (macropropagation) for mass production of banana seedlings has been developed as an alternative method for seedlings production [3]. The banana seedlings produced by this innovative multiplication technique are called in French "Plants Issus de Fragments de tiges" (PIF) *i.e.* "Plants from stem fragments" or vivoplants as opposed to vitroplants. This technique allows the massive production of seedlings in quantity in a very short period of time (2 to 3 months) and at a low cost. Indeed, one banana sucker can produce between 20 to 100 seedlings depending on the variety and the farmer's experience. Nevertheless, despite these advantages, seedlings produced by PIF technique face the problem of acclimatization and contamination on farmlands resulting in plants mortality of about 60% when establishing new plantations and are now rejected by some farmers [2]. Even when banana seedlings are generated from PIF, they are disseminated on farmlands in soils that often contain pathogenic microorganisms like nematodes, weevils, bacteria and fungi that cause various diseases. Among these diseases of banana plant, black Sigatoka disease (BSD) is a leaf disease caused by the fungus *Mycosphaerella fijiensis* whose infection, when severe, can lead to a substantial reduction in leaf area and is the most economically destructive disease of the banana tree, responsible for production losses estimated at about 50% [4] [5]. Additionally, banana streak badnavirus (BSV) was reported in Cameroon and Nigeria farms in late 1997 with no severe impact on the crop yield [6].

The fundamental and major concerns of the Food and Agriculture Organization of the United Nations are to feed and subsidize substantially, an estimated world population of around 9.6 billion in 2050 without corruptible and unpolluted nutrients. Therefore, global food production must increase by 70% to feed the need of this massive population [7]. However, in agriculture pathogen attacks and poor-quality seeds/plants are some of the factors that lead to yield reduction of around 80%. Pathogens constantly compete with crops for water, light and nutrient resources, sometimes coupled with soil fertility, resulting in huge economic losses [8]. Therefore, crops cultivation uses an important number of synthetic inputs such as fertilizers, fungicides and herbicides for yield improvement. Indeed, among physical or mechanic control methods including stripping or cutting, chemical inputs such as herbicides, fungicide and fertilizer are repeatedly used in farms to mitigate these factors. The use of these inputs in developing countries increased drastically from 2.7 to 121.6 million tones, between 1960 and 2020 [9]. However, usage of chemicals such as the application of different pesticides, fertilizers, herbicides and insecticides is not safe and has resulted in noticeable damage to both the environment and human health [10].

Indeed, the intensive use of these synthetic inputs has led to negative impacts on human health, the environment and increased resistance of some strains of pathogens to pesticides, in particular fungicides or insecticides.

Furthermore, the accumulation of toxic farm inputs residues causes the degradation of soil fertility and underground water pollution through toxic runoff, affecting the balance of the ecosystem [11]. However, the use of phytopharmaceuticals is more rigorous, with more than 90% of the cost of the study allocated to approval expenses against a part for the agronomic efficiency of analysis process. Indeed, the implementation of the new regulations has led to the withdrawal of more than 750 actives substances out of thousands of molecules present on the market by European Food Safety Authority and Phyteis, new name of the Crop Protection Industry Association [12]. The decrease in the number of active products has implied the development of alternative methods. Nowadays to overcome these problems, numerous countries have been promoting the use of agricultural biological inputs that are good for ecoresponsible agriculture.

Plant promotion and protection strategies could double food production while dramatically reducing the environmental impacts of bad agricultural practices. One of these strategies relies on the optimization of the natural defense mechanisms of plants implemented during the plant-parasite interaction [13]. In this context, the natural product based on plant extracts containing several compounds could be a real solution to promote plant growth, to fight against the attacks of phytopathogens such as fungi, bacteria or insect, as well as to fertilize the soil [2] [14]-[16].

Tithonia diversifolia is 2 - 3 meters tall woody herb native to eastern Mexican and Central America. The species is spreading rapidly and has become naturalized in more than 70 countries in the tropics, where it is invasive [17] (Chagas-Paula *et al.*, 2012). It is rich in elements such as nitrogen (N), phosphorus (P) and potassium (K) and its application to the soil results in rapid decomposition thereby enriching the soil with N, P and K which help promote the growth [18] [19]. *Tithonia diversifolia* extract is rich in secondary metabolites (flavonoids, tannins, alkaloids, pathogenesis related proteins and terpenoids), which appear to stimulate the accumulation of defense biomarkers in plants. These secondary metabolites are known to be a good source of bioactive compounds and to have therapeutic potential as antifungal, antimicrobial, insecticidal and organic fertilizer, or green manure, which makes it interesting for the development of potential future biostimulators [20]-[22].

Recent studies conducted in Cameroon on the use of *Tithonia diversifolia* alone or associated with clam shells and other plants on plantain vivoplants and plants have shown the stimulation of growth promotion and protection against biotic and abiotic stresses [2] [16] [23]-[27]. Updated information will be presented below both on the issues of daily plantain banana cultivation and on *Tithonia diversifolia* content in relation with its various stimulating effects on banana plants.

2. Banana

2.1. Origin and Distribution

Banana (*Musa* spp.) is a plant native to the hot, humid tropical jungles of Southeast Asia, a geographical area that includes India, Papua New Guinea and the Pacific Islands. Malaysia or Indonesia is being said to be the centre of diversity of these cultures. However, these crops are grown in more than 120 countries in the tropical and subtropical regions of the world. These crops would have been transported from Indonesia to Madagascar then to East Africa, to Zaire and then to West Africa [28].

Humans migration and the exchange of plant material have allowed the introduction of banana into different ecological zones [29]. In Africa, banana production was introduced by the Arabs and the Portuguese along the east coast of Africa from where they passed through Central Africa countries to West Africa. Desert bananas grown in the highland East Africa are classified as AAA, while cooking bananas (plantain) are AAA, AAB and ABB. These cultivars are widely distributed around the world, particularly in Latin and Central America, the Caribbean, South East Asia and Africa [28].

2.2. Biology and Agroecology

Bananas belong to the family of Musaceae, class Liliopsida, and the order Zingiberales. There are perennial plants that reach the height of about 3 meters. Cultivated edible bananas and plantains have evolved from intra- or interspecific crosses between two diploid progenitor species, *Musa accuminata* (“AA”), and

Musa balbisiana ("BB"). However, various important combinations such as AB, AAB, AABB and ABBB also occur as a result of hybridization. *M. balbisiana* genes are said to induce stronger disease resistance, higher nutritional value with increased starch content. Moreover, they provide hybrids suitable for cooking compared to the pure *M. accuminata* cultivars mainly suitable for desert use [30].

Banana and plantain plants are mostly grown in the tropical and subtropical regions, which means they need hot, and humid conditions to thrive well. The growing areas are geographically located at the equator between 20° N latitude and 20° S latitude. However, in subtropics, they are located between 20° and 30° North or South of the equator [31]. The average air temperature required by these crops should be around 30˚C [28]. Moreover, an essential climatic condition that determines where banana and plantain could grow apart temperature is rainfall. Areas that cannot have a well-distributed average annual rainfall of 2000 - 2500 mm require an external source of water supply through irrigation. Banana and plantain need deep, well-drained soils that are very fertile and high in organic matter [30]. Furthermore, they need soils without compaction and excess clay and with a pH between of 4.5 to 8.5. The mineral elements indispensable for the development of banana and plantain are nitrogen, phosphorus, potassium, calcium and magnesium [28].

2.3. Production of Banana Seedlings

The production of banana seedlings in Africa faces the main constraint of unavailability of seedlings in quantity and quality essential to promote the creation of new plantations [2]. Moreover, traditionally a banana plant is obtained from a sucker of another banana plant, and is usually disseminated with the soil of farmland which often contains pathogenic microorganisms. In order to improve the production of banana seedlings, many propagation techniques have been implemented. Currently, propagation of edible plantains and bananas are carried out by micropropagation and macropropagation techniques.

2.3.1. Micropropagation

Banana seedlings production can be done by many *in vitro* techniques, but the most suitable are tissue culture and cell culture leading to the production of vitroplants. Tissue culture is a laboratory multiplication technique. It offers the dual benefit of high propagation rates and elimination of pest and diseases [32]. The technique as applied to banana is also called short tip cultivation or micropropagation due to the small size of the starting material (2 - 20 mm). This technique involves isolating a growing tip from a sucker or male bud and disinfecting it to kill surface organisms. The cleaned tissue is planted in a container with sterile nutrient culture medium. Growth regulators are then added to induce bud proliferation and root development [33]. Growth is achieved under control light, temperature and humidity conditions. Additionally, meticulously clean environment is maintained to keep away microbes that can outgrow and kill propagated plants. The periodic subdivisions and the transfer of the culture to fresh medium lead to exponential multiplication of the tissues. A record of up to 10,000 seedlings from a single sucker in eight months has been reported. Tissue-grown seedlings flower earlier than suckers, give a uniform harvest and have a 20% - 50% advantage in fruit yield [34]. Furthermore, the system has a higher propensity to produce types due to the strong auxins used to induce callus.

2.3.2. Macropopagation

Different techniques are employed with regards to the macropropagation method. Prominent among them are split corm and decorticated techniques. The techniques for splitting and decorticating the bulbs are confronted with the problem of contamination by weevils and nematodes. In an attempt to solve this problem and revive banana production, an improved method of macropropagation (PIF technique) was discovered by the African Centre for Research on Banana and plantain, namely CARBAP located in the locality of Njombé in Cameroon, gradually adopted by the farmers and used for the dissemination of new banana and plantain cultivars [35] [36]. The PIF technique is a horticultural propagation method that allows mass production of banana vivoplants in just two to three months in sanitized environment [2] [23]-[26]. Using the PIF technique for vivoplants production in opposition to vitroplants, the following summary steps can be identified (**Figure 1**).

Figure 1. Successive steps in vivoplants production from PIF method.

Step 1: Selection of suckers.
Step 2: Preparation (cleaning) of suckers.
Step 3: Trimming of discard to white.
Step 4: Shelling of suckers.
Step 5: Disinfection of the explants.
Step 6: Drying of the explants in the shade.

Step 7: Incision. If the incision is not well made to destroy all the buds, a single bud will have preference and this action will prevent germination.

Step 8: Introduction and management of the propagator. At the age of two (02) open leaves and three (03) to four rootlets, the seedlings are weaned.

Step 9: Weaning and monitoring under shade. They are further transferred to the shade house for acclimatization and growth.

2.3.3. Integrated Benefits of All Banana Propagation Techniques

Banana production can be improved by timely access and use of clean planting material of desirable varieties in adequate quantities. The propagation method has applications at different levels of production. Traditional field grown suckers have the lowest multiplication rates and pre-planting treatment is inadequate to eliminate some pests and diseases. Among improved propagation methods, tissue culture remains superior to others as it enables the elimination of systemic pathogens and allows for faster subsequent multiplication of clean material [37]. Tissue culture plants, however, are still tender and require more care for the first two months after planting. Once established the tissue-cultured plants have a greater ability to produce suckers.

2.4. Socio-Economic and Nutritional Importance of Bananas

Bananas play a key role in the economies of many developing countries where there are produced. In terms of gross value of production, bananas are the fourth most important food crop in the world after rice, wheat and maize [1]. Bananas are the third tropical fruit crop, with over 145 million tons produced globally in more than 150 countries [3]. As staple food, bananas contribute to the food security of millions of people in much of the developing world and, when traded in local markets, they provide income and employment for the rural population. As an export commodity, they are key contributors to the economy of many low-income food deficit countries, including Cameroon. Most people in the urban communities are notably known for making banana fibre. These fibres are being processed into mats, baskets, ropes, etc., which constitutes a great economic activity. The average world production in tons from 1998 to 2000 was estimated at around 99 million in 2001 [38]. Report indicates that almost 85% of the approximately 145 million tons of world annual harvest of banana and plantain comes from plots and backyard gardens which are mainly situated in the developing world [39]. Plantain banana contains a good amount of daily vitamin C recommended for humans. This vitamin acts as an antioxidant that can boost the immune system. Moreover, it also protects the body against free radical damage associated with ageing, heart diseases, and even certain types of cancer. A high amount of potassium present in plantain bananas is essential for maintaining cellular and body fluids that control the heart rate and blood pressure.

2.5. Diseases of Bananas

Banana and plantain production are affected by various pests and diseases, including nematodes, weevils, fusarium wilt and Sigatoka diseases [40]. Additionally, we have banana bunchy top virus, steak virus and cucumber mosaic virus [41]. Amongst these diseases (**Table 1**), the most prominent in bananas is the Sigatoka disease, a fungal disease caused by fungi of the class Ascomycetes and of the genus *Mycosphaerella*. This disease causes 11% - 80% yield lost in banana plants by reducing the photosynthetic tissues through necrotic leaf lesions [42]. There are two types of banana Sigatoka diseases: yellow Sigatoka and black Sigatoka. Yellow sigatoka disease caused by *Mycosphaerella musicola* while black Sigatoka disease caused by *Mycosphaerella fijiensis* is considered one of the most economically important phytosanitary problems [4].

Table 1. Major diseases affecting banana plants.

Diseases and casual organisms	Organs attacked	Symptoms	Impact	Prevention/ Control	References
Black Sigatoka (black leaf) **disease:** the fungus *Mycosphaerella fijiensis*	Leaves	Reddish-brown to black streaks on the underleaf surface	Fruit losses of 20-80% occur due to the reduction in leaf surface area resulting to the loss of photosynthetic capabilities	Deleafting	Churchill (2011)
Banana viral disease: the virus Banana Streak Virus (BSV)	Corms	Yellow and necrotic leaf streak	Symptoms ultimately lead to the production of small bunches with short fruits and yield losses of 7-90 %	Planting of banana streak virus free material	Agindotan *et al.* (2006)
Panama disease: the fungus *Fusarium oxysporum*	Leaves and Pseudo stem	Systemic foliage and disruption of translocation	Spreading of infection in the plant resulting to collapse of the pseudo stem	Weed control within the banana plantation and strict quarantine practices	Ploetz (2006)
Banana bunchy top disease: the virus Banana Bunchy Top Virus (BBTV)	Leaves	Yellowing of the leaf leading to subsequent withering and plant dead.	Failure of fruits development	There is no treatment for the disease, and affected plants must be destroyed	Su *et al.* (2003)
Banana bacterial disease: the bacterial *Xanthomonas wilt*	Pseudo stem and leaves	Yellowing and wilting of leaves, premature and uneven fruits ripening	damage of male buds and flowers	Early removal of the male buds, proper sanitation practices, and the use of clean planting material	Biruma *et al.* (2007)

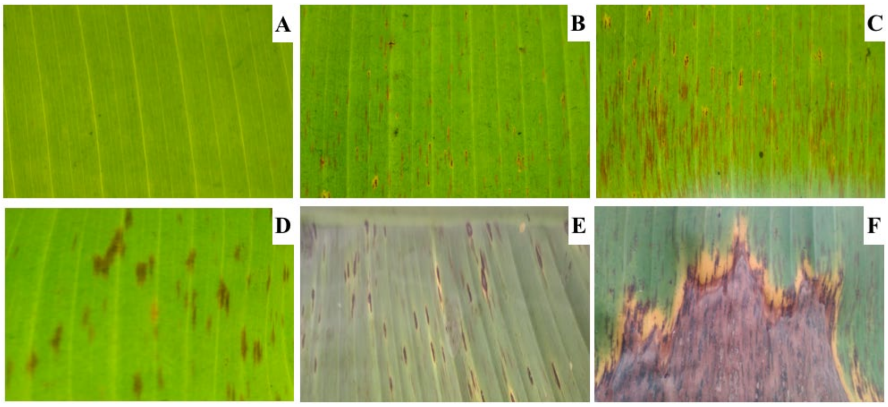
Black Sigatoka Disease

1) Origin and distribution

Black Sigatoka disease (BSD) originated from Southeast Asia around Malaysia, the Philippines, Indonesia and Papua New Guinea. It is the main banana disease in banana producing countries, caused by the fungus *Mycosphaerella fijiensis*. BSD is economically the most destructive leaf disease of banana and plantain worldwide. It induces leaf streaks which significantly reduces the photosynthetically active leaf area. Estimates of losses to black Sigatoka disease for dessert banana and plantains are in the range of 20% - 80% in the absence of fungicides [43].

2) Symptoms

A first symptom of the disease typically occurs between 7 and 14 days after contamination depending on the local environmental conditions. Following fungal penetration of leaf stomata, colonization of intercellular spaces and the resulting necrotic damage decrease the photosynthetic capacity of the plant, reducing quantity and quality of fruits [44]. Black Sigatoka disease symptoms are recognized in six distinct stages (**Figure 2**). These stages include:



(A: stage 1, B: stage 2, C: stage 3, D: stage 4, E: stage 5, F: stage 6)

Figure 2. Evolution of black Sigatoka disease stages on banana leaf.

Stage 1: Faint, minute, reddish-brown specks on the lower surface of the leaf.

Stage 2: Specks elongate, becoming slightly wider to form narrow reddish-brown streaks.

Stage 3: Streaks change color from reddish brown to dark brown or black, sometimes with a purplish tint tinge, clearly visible at the upper surface of the leaf.

Stage 4: The streaks broaden and become more or less fusiform or elliptical in outline, and a water-soaked border appears around each lesion.

Stage 5: The dark brown or black center of each lesion becomes slightly depressed and the water-soaked border becomes more pronounced.

Stage 6: The centers of the lesions dry out turning light grey, with a bright yellow band forming between them and the normal green color of the leaf. Lesions remain visible after leaf necrosis due to their light-colored center and dark border.

3) Control strategies of black Sigatoka disease

The control of black Sigatoka disease is a major challenge for world banana production. Different methods such as cultural control, chemical control, genetic control and biological control have been adopted by farmers to control this disease.

Cultural control generally aims to reduce the level of inoculum and relative humidity in the plantations. To reduce the rate of inoculum, necrotic areas of the leaves or the completely necrotic leaves are excised and then placed on the ground to accelerate their decomposition. The reduction in relative humidity is achieved through an efficient drainage system aimed at preventing water from infiltrating the plots. The higher the fertility, the lower the severity of black Sigatoka. This suggests that good management of organic matter is essential for the sustainable banana production, helping to minimize the severity of black Sigatoka disease [8]. It was confirmed in Cameroon with morphological differences that were observed among fruits of different groups of BSD severity levels. Indeed, fruits with a lower disease severity index (DSI) at flowering had bigger grades than those with high DSI [4].

Chemical control consists of using pesticides to control and delay the development of *M. fijiensis*. A pesticide (fungicide, bactericide and nematicide) refers to any synthetic chemical substance used in agriculture to control, destroy, repel or reduce the effect of any living organism harmful to plants. Fungus-specific fungicides can be systemic (benzimidazoles, triazoles, morpholines and strobilurins) or contact (mancozeb or chlorothalonil). The massive and quasi-systemic spraying of fungicides alone or in combination causes epidemics of persistent diseases. However, this method has many disadvantages such as the need for frequent application, the high cost of fungicides, pollution, toxicity and the accumulation of these products [45].

Generally, the term biological control has been applied to the use of microorganisms and/or natural products extracted or fermented from various sources, and relies to plant bioprotection through some potential bioinsecticidal, biofungicidal, biobactericidal and bionematicidal effects. These natural products are called biopesticides and have been used recently to control black Sigatoka disease caused by *Mycosphaerella fijiensis* with a significant biofungicidal effect on the resistance of the Big-Ebanga banana-plantain variety in the nursery [2], as well as with the liquid extract in the field [26].

3. Tithonia Diversifolia

3.1. Origin and Distribution

Tithonia diversifolia also known as Mexican sunflower is a plant native to Mexico and Central America, but is naturalized in Africa, Australia, Brazil and Asia, where it is considered as an invasive plant or aggressive invader [17] [47] [48]. It grows spontaneously around houses and roads and is considered an annual, biannual or even perennial plant.

Tithonia diversifolia is widely distributed in countries such as India, Cameroon, Kenya, Tanzania, Uganda and Zambia where it was introduced as an ornamental plant. Indeed, *Tithonia diversifolia* is cultivated and planted in many countries for its beautiful, large flowers (often used for decorations). It is now widely distributed in the tropics, particularly in Africa (West Africa) and Asia where it was speeded on the basis of its multiple uses (therapeutics, fodder plant, green manure, natural insecticide). It is considered today as an invasive plant with a high reproductive capacity, partly thanks to its great capacity to adapt to different ecological zones [49].

T. diversifolia is a plant found along roadsides and in disturbed areas (**Figure 3**).

Figure 3. *Tithonia diversifolia* plant with flowers.

It easily propagated by cuttings or seed, and seed dispersal is by vectors such as humans, livestock and water currents. The seeds of *T. diversifolia* allow this species to quickly invade disturbed habitats by forming dense stands that prevent the growth of young native plants due to their allelopathic effect [48]. It tolerates heat and drought well and can quickly form large herbaceous bushes.

3.2. Taxonomy and Biology

Tithonia diversifolia is a perennial plant belonging to the kingdom Plantae, the class of Dicotyledonae, the order of Asterales and the family of Asteraceae (**Table 2**). The genus *Tithonia* is made up of 11 species with the specific name "*diversifolia*" means "separated leaves" from the Latin "diversus" [47].

Table 2. Taxonomy of *Tithonia diversifolia* (Hemsl.) A. Gray.

Kingdom	Plantae
Phylum	Spermatophyta
Subphylum	Angiospermae
Class	Dicotyledonae
Order	Asterales
Family	*Asteraceae*
Tribe	*Heliantheae*
Genus	*Tithonia*
Species	*Tithonia diversifolia*

Tithonia diversifolia is a woody herb or succulent shrub that grows to a height of two to three meters tall in regions of 550 - 1950 meters altitude with mean annual temperature of 15˚C~31˚C and mean annual rainfall of 100 - 200 mm. This plant flowering varies depending on the period, but usually flowers in October and produces about 80,000 to 160,000 seeds annually, with germination rates ranging from 18 to 56% at 25˚C. Its reproduction can be carried out by seeds or more simply by cuttings and layering [47].

It is having alternate leaves with ten to fifteen centimeters long, blade with three to five lobes. *T. diversifolia* flower are yellow to orange-yellow and the number of petals variable from eight to fourteen, while the diameters is up to fifteen centimeters. The flowers of the outer ring are sterile, their function being to attract pollinating insects, like the petals of an individual flower. The flowers of the inner disc are hermaphroditic, numerous (one hundred to two hundred), with a tubular corolla of approximately eight millimeters long with five teeth [47]. Its seeds are achenes with four angles, having five millimeters long, topped with a pappus of one hundred to two hundred seeds per flower head. The germination capacity of *Tithonia diversifolia* is three to five years.

3.3. Composition and Use

Tithonia diversifolia is full of numerous exploitable virtues, thanks to its composition in a wide range of compounds such as nitrogen (N), potassium (K), phosphorus (P), calcium (Ca), magnesium (Mg), terpenoids, diterpenoids, sesquiterpenoids, flavonoids, phenols, saponins, tannins which gives it biofertilizing and biofungal properties [47] [50] [51]. It has a large quantity of leaves rich in essential nutrients with the particularity of easily decomposing to release them (N, K, P, Ca, Mg) at concentrations that can be higher than those in other agroforestry species (**Table 3**) and, which not only improves the quality of the soil and at the same time crops production [50]. The decomposition of its leaves constitutes a natural fertilizer for other plants and also a natural amendment for the soil. Furthermore, some studies have highlighted their presence in leaves and stems but also in roots [51].

In addition, the aqueous and ethanoic extracts of the parts of *T. diversifolia* are rich in phytochemicals such as alkaloids, flavonoids, phenols, saponins, tannins and terpenoids [52] [53]. However, these phytochemical compounds (**Table 4**) are more predominant in the leaves followed by the roots and stem; except the phenols which are predominant and distributed in the roots.

Table 3. Comparison of the chemical composition of *Tithonia diversifolia* leaves to that of some agroforestry species (Kaho *et al*., 2011).

Espèces	Concentration (%)				
	N	P	K	Ca	Mg
Tithonia diversifolia	3,53	0,42	4,70	3,52	0,45
Desmodium intortum	1,79	0,30	0,58	1,70	0,28
Pueraria phaseoloides	2,17	0,37	0,59	2,75	0,32
Caliandra calothyrsus	3,40	0,15	1,10	Nd	Nd
Lantana camara	2,80	0,25	2,10	Nd	Nd
Tephroria vogelli	3,00	0,19	1,00	Nd	Nd

Table 4. Screening of phytochemical quantities of *T. diversifolia* (in mg) by organs (Olayinka *et al*., 2015).

Composition (mg/100 g)	Leaves	Stems	Roots	Global Mean
Alkaloids	1535,00	361,67	863,33	853,33
Tannins	540,00	125,00	481,67	382,22
Flavonoids	851,67	33, 33	131,67	338,89
Saponins	761,70	38, 33	183,33	327,78
Terpenoids	126,67	18,33	50,00	65,00
Phenols	64,58	9,77	71,03	48,46

In addition, its composition of secondary metabolites such as terpenoids which have antimalarial, antibacterial, antiviral and antifungal pharmacological activities have made *T. diversifolia* a plant with great exploitable pharmacological potential [54] [55]. Recently, the use of its extracts in fighting cancer disease was efficiently reported [56]. *Tithonia diversifolia* is a plant that has beneficial effects in various areas, notably in medicine and agriculture. Indeed, since time immemorial, it has been traditionally used to relieve many ailments.

3.4. Importance of *Tithonia diversifolia* in Agriculture

The importance of *Tithonia diversifolia* in agriculture has been demonstrated in many scientific reports. Indeed, numerous studies have highlighted the application of *Tithonia diversifolia* during crops cultivation and have proven its effectiveness in organic farming. Due to the ability of its biomass to decompose rapidly and release nitrogen (N), phosphorous (P) and potassium (K) into the soil, it has been extensively used to improve soil [57]. Indeed, fresh biomass of *T. diversifolia* improves soil fertility and significantly increases soybean yields [57]. Moreover, the shoot biomass of *T. diversifolia* has been peddled as a potential source of nutrients for lowland rice in Asia and more importantly for maize and vegetables in eastern, southern and central Africa [47]. Its fresh biomass, whether or not combined with inorganic fertilizers, significantly improves the development and yield of cassava [58]. The various uses of *T. diversifolia* have been shown to be effective in improving the growth and yield of several crops in Africa such as maize [21] [59], cassava [58] and diverse other crops through its nutrients source potential. Moreover, it has been reported that non-nitrogen-fixing species such as *T. diversifolia* and *Chromolaena odorata* can be used for improving soil fertility, furthermore, significantly increasing crop yields from one growing season to the next other [16].

Similarly, farmers use *Tithonia diversifolia* as a biopesticide plant in several ways, either to fight against certain pests that attack their crops, or to conserve their crops after harvest.

Tithonia diversifolia is used for bioprotection as a pesticide thanks to its composition of sesquiterpenes, lactones and diterpenoids, which have biological activity against insects and is used as a biocontrol agent notably as biofungicide for crops [60] [61]. *Tithonia diversifolia* in addition to being a biofertilizer and rich in secondary metabolites (flavonoids, tannins, alkaloids, phenols, and others), has the capacity to induce biostimulating mechanism in the plant though the synthesis of growth promoting macromolecules, as well as defense metabolites such as pathogenesis related (PR) proteins in plants to cope with biotic and abiotic stresses [16] [23]-[27].

3.5. *Tithonia diversifolia* Effect on Plantain Vivoplants Growth Promotion and Protection

Recent studies carried out in Cameroon on *Tithonia diversifolia*-based products have shown a stimulating mechanism in banana plant notably their beneficial effects on promoting plantain vivoplants (PIF) growth as well as their biofungicidal effects *in vitro* and *in vivo*, especially on *M. fijiensis*, the fungus responsible for black Sigatoka disease of bananas [2] [16] [23]-[27]. These products obtained from *T. diversifolia* dried leaves and stems were used alone or combined in the form of flakes, powder and liquid, applied as substrate amendment, mulches or foliar spray. *T. diversifolia* effect as biofertilizer and biocontrol agent was well highlighted as well as the induction of resistance in vivoplants of plantains treated. Indeed, it was demonstrated that *Tithonia diversifolia* act through a mechanism of biostimulation of the plantain vivoplants in the nursery and induces a less susceptibility to *Mycosphaerella fijiensis* through the accumulation before and after inoculation of constitutive and the *novo* synthesis biomarkers such as proteins, phenols, chitinase, glucanase, peroxidases, polyphenol oxidase compared to the control vivoplants [16] [23]-[27].

In one hand, the *Tithonia diversifolia* stimulatory effect has permitted the growth biopromotion and thus to obtain vigorous vivoplants through the improvement of germination rate (pre-emergence and emergence stages) and agro-morphological parameters of the vegetative stages such as the length, diameter of the pseudo stems, number of leaves and photosynthetic leaf area. Moreover, the accumulation in treated vivoplants of growth biomarkers such as chlorophylls, amino acids, proteins, phenols and sugars was significantly important [2] [16] [23]-[27].

In the other hand, the *Tithonia diversifolia* stimulatory effect has permitted the vivoplants bioprotection through induction of resistance well demonstrated by the less development of necrosis after *M. fijiensis* inoculation compare to the control ones, as well as the *in vitro* inhibition of phytopathogens growth in the presence of *Tithonia diversifolia*-based products. In addition, the accumulation in treated vivoplants of defense biomarkers such as *de novo* proteins, phenols and defense-related enzymes (phenylalanine ammonia lyase, peroxidase, polyphenol oxidase, chitinase and glucanase) was significantly important. Indeed, the treated vivoplants showed maximum bioprotection against black Sigatoka disease of up to 87% in the nursery compared to controls [16]. However, in the field stage with the mature plantain tree, *T. diversifolia* liquid extract has shown its bioefficacy with biopesticide potential to reduce the severity of BSD over time, and confirmed by the very low diluted concentration of 25% [26]. *T. diversifolia*-based products have good growth biopromoting effects, directly on the physiology of plantain vivoplants and indirect on substrate in nursery [27]. Indeed, this organic amendment has modified soil physical properties such as stability of aggregates and porosity that can improve the roots growth, rhizosphere and stimulate plant growth. It shows the potential stimulatory role of *T. diversifolia*-based products to increases the assimilates availability during growth.

Tithonia diversifolia was also associated with clam shells in the cultivation of banana vivoplants in nurseries and allowed a significant increase of performance in the growth of these plants as well as the induction of less resistance to black Sigatoka disease [2]. Indeed, clam shells are aquatic mollusks of the gastropod class, which consist of calcium carbonate (more than 60%), proteins (5%) and minerals (phosphorus, manganese, zinc, potassium, aluminum, silicon) as well as polysaccharides like chitin [62]. Chitin is a polysaccharide of high molecular weight but low solubility, formed of a chain of N-acetylglucosamines linked together by a glycosidic bond (1 - 4) [64]. Shells in general have shown a biostimulating effect by promoting plant growth and reducing sensitivity to pathogens by highlighting their antifungal properties, growth stimulators and plant defense systems [2] [63].

4. Conclusion

In summary, this study presents the state of art of the current evidence on the stimulatory effect of the *T. diversifolia*-based products on plantain vivoplants such as biofertilizing, biostimulating, and bioprotecting through the induction of plant defense (biofungicidal effect) against abiotic and biotic stress. As shown, *T. diversifolia* is an excellent biostimulation tool on the growth biopromotion and bioprotection of plantain vivoplants. The strengthening of the plant cell wall which is the first mechanism triggered during the plants attack, could quickly be observed with the plantain vivoplants treatment with *T. diversifolia*-based products [26]. Indeed, precise information on the mechanism of action of this *T. diversifolia*-based products on banana plants in farms needs to be urgently accessed for correlation with the main results obtained in the nurseries. It was demonstrated that most of these products are composed of a metabolic fraction and a microbial faction, leading to hybrid products. Phytochemical knowledge of the composition of this *T. diversifolia*-based products is still lacking and should be urgently identified.

Conflicts of Interest

The authors declare no conflict of interest.

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