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Development of Plant-Based Foliar Fertilizers from Tithonia diversifolia and Eichhornia crassipes to Enhance Growth of Irish Potato (Solanum tuberosum L.)

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Abstract

The aim of this study was to develop plant-based foliar fertilizers from *Tithonia diversifolia* and *Eichhornia crassipes* ashes and evaluate their effects on Irish potato (*Solanum tuberosum* L.) growth under Kenyan field conditions. Potato production is constrained by declining soil fertility, rising fertilizer costs, and impacts associated with synthetic inputs. Soil samples collected from Limuru Sub-County, Kiambu County, were analyzed for physicochemical properties, while plant ashes were characterized for potassium and phosphorus. Foliar fertilizer extracts were prepared from individual ashes and a 1:1 (w/w) mixture. A field experiment was conducted using a randomized complete block design comprising four treatments: untreated control, *T. diversifolia* fertilizer, *E. crassipes* fertilizer, and the combined formulation, each replicated three times. Plant height, leaf area, fresh weight, and dry biomass were measured 60 days after planting. The soil was slightly acidic and suitable for potato production, but exchangeable potassium was comparatively low. The combined ash contained the highest concentrations of potassium (3.62) and phosphorus (0.56), exceeding the values recorded for *T. diversifolia* (3.45 and 0.52) and *E. crassipes* (2.75 and 0.42), respectively. All fertilizer treatments significantly enhanced growth relative to the control ($p < 0.001$). The combined formulation produced the highest plant height (59.4 cm), leaf area (55.8 cm²), fresh weight (315.7 g plant⁻¹), and biomass (256.1 g plant⁻¹). These findings demonstrate that blended *T. diversifolia* and *E. crassipes* ash can serve as an effective, locally available, and environmentally sustainable foliar fertilizer for improving potato growth

Introduction

Irish potato (*Solanum tuberosum* L.) is one of the most important food crops worldwide and plays a vital role in improving household food security and income, particularly in developing countries [1]. In Kenya, it is the second most widely grown stable crop after maize and is mainly cultivated by smallholder farmers in the central and highland regions [2]. However, potato production continues to face challenges arising from declining soil fertility, especially deficiencies of essential nutrients such as potassium, nitrogen, and phosphorus [3]. Although inorganic fertilizers are commonly used to replenish these nutrients, their rising costs and long-term environmental impacts have limited their use among resource-constrained farmers [4]. As a result, there is growing interest in developing affordable and environmentally sustainable nutrient management strategies [5]. Foliar fertilization offers one such approach by supplying nutrients directly through the leaves, allowing rapid nutrient absorption and improving plant growth [6].

A major challenge in potato production in Kenya is the widespread depletion of soil nutrients caused by continuous cultivation and inadequate nutrient replenishment [7]. In Limuru Sub-County, where potato farming is an important economic activity, potassium deficiency has been identified as one of the major constraints to crop growth and productivity. At the same time, invasive plant species such as *Tithonia diversifolia* and *Eichhornia crassipes* are abundant in many parts of the country and are often regarded as environmental nuisances [8]. Despite their high nutrient content, these plants remain largely

underutilized. Converting this readily available biomass into nutrient-rich foliar fertilizers could provide a practical and low-cost solution to nutrient deficiencies while simultaneously addressing the environmental problems associated with invasive weeds [9].

This study introduces a different approach by formulating customized foliar fertilizers from the ashes of *Tithonia diversifolia* and *Eichhornia crassipes* and evaluating their effectiveness on Irish potato growth. While previous studies have mainly investigated these plants as green manure, compost materials, or organic soil amendments, limited attention has been given to their use as ash-based foliar fertilizers [10]. The study further examined both individual formulations and a combined formulation to determine whether blending the two nutrient sources could produce a more effective fertilizer. By transforming invasive plant biomass into a valuable agricultural input, this research demonstrates a practical strategy for nutrient recycling and sustainable crop production.

The findings of this study provide useful information for farmers, researchers, and agricultural policymakers seeking sustainable alternatives to conventional fertilizers. The customized foliar fertilizers developed from *Tithonia diversifolia* and *Eichhornia crassipes* have the potential to improve potato growth while reducing dependence on costly synthetic fertilizers [11]. In addition to lowering production costs, the utilization of invasive plant biomass contributes to environmental conservation by reducing weed proliferation and promoting resource recovery [12]. This study supports sustainable agricultural practices and offers a locally available solution that can contribute to improved crop productivity, enhanced soil nutrient management, and strengthened food security in Kenya and other regions facing similar agricultural challenges.

Materials and Methods

Study Area

The study was conducted in Limuru Sub-County, Kiambu County, Kenya, a major Irish potato-producing region located approximately 50 km northwest of Nairobi. The area lies at an altitude of 2,200–2,400 m above sea level and experiences a cool, humid climate with mean annual temperatures ranging from 12 to 20°C and average annual rainfall of approximately 1,200 mm distributed in two rainy seasons. The soils are predominantly deep, well-drained volcanic Andisols characterized by high organic matter content but are generally acidic and susceptible to nutrient leaching. The site was selected because of its importance in Irish potato production and the widespread soil fertility constraints affecting crop productivity.

Experimental Design

The study employed an experimental research design comprising laboratory analyses and a field experiment. Composite soil samples were collected from the study site and analyzed to determine their physicochemical properties before formulating customized foliar fertilizers. A field trial was established

using a randomized complete block design (RCBD) with four treatments replicated three times. The treatments consisted of: (i) untreated control, (ii) *Tithonia diversifolia* foliar fertilizer, (iii) *Eichhornia crassipes* foliar fertilizer, and (iv) a composite foliar fertilizer prepared by mixing the two plant ashes in a 1:1 (w/w) ratio.

Chemicals and Reagents

Analytical-grade chemicals were used throughout the study. These included concentrated nitric acid (HNO_3), sulfuric acid (H_2SO_4), hydrochloric acid (HCl), sodium hydroxide (NaOH), ammonium acetate, potassium chloride, ammonium molybdate, hydrazine sulfate, boric acid, urea, and distilled water. All reagents were obtained from reputable suppliers and used without further purification.

Soil Sampling and Analysis

Soil samples were collected from a depth of 0–30 cm using a grid sampling approach. Fifteen subsamples were combined to obtain a representative composite sample, which was air-dried, crushed, sieved through a 2-mm mesh, and stored prior to analysis. Soil pH and electrical conductivity were determined using calibrated pH and conductivity meters, respectively. Cation exchange capacity was measured using the ammonium acetate extraction method. Total nitrogen was determined by the Kjeldahl method [13], organic carbon by the Walkley–Black method [14], available phosphorus using the Mehlich extraction [15] followed by UV–Visible spectrophotometry, and exchangeable potassium using flame photometry. Calcium, magnesium, sodium, iron, manganese, copper, and zinc were quantified using atomic absorption spectrophotometry (AAS). All measurements were performed in triplicate following standard analytical procedures.

Collection and Preparation of Plant Materials

Fresh leaves of *Tithonia diversifolia* were collected from Kiambu County, while whole plants of *Eichhornia crassipes* were collected from Nairobi Dam. Plant materials were authenticated at the Kenyatta University Herbarium before being washed thoroughly, air-dried for seven days, oven-dried at 105°C for 24 h, and ground into fine powder. Approximately 100 g of each powdered sample was ashed in a muffle furnace at 550°C for 6 h. The ashes were cooled in a desiccator and stored in airtight containers until use. A composite ash sample was prepared by mixing equal weights (1:1, w/w) of the two plant ashes.

Nutrient Analysis and Foliar Fertilizer Formulation

Ash samples were digested with concentrated nitric acid, and the resulting solutions were analyzed for nitrogen, phosphorus, and potassium. Potassium concentration was determined using flame photometry, phosphorus by the molybdenum blue spectrophotometric method [16], and nitrogen using the Kjeldahl procedure [13]. Foliar fertilizers were prepared by extracting 100 g of ash with 50 mL of 0.25

M nitric acid. The suspension was stirred for 30 min, allowed to stand for 24 h, neutralized to pH 7.0 using 0.25 M sodium hydroxide, filtered, and diluted to 1 L with distilled water to obtain the stock solution. Nutrient concentrations of the formulated fertilizers were subsequently determined using the same analytical procedures.

Field Experiment and Foliar Fertilizer Application

The experimental field was plowed, harrowed, and divided into twelve plots measuring 2 × 2 m. Certified seed tubers of the Shangi variety were planted at a spacing of 50 cm between rows and 20 cm within rows at a depth of 8 cm. Each plot contained 20 plants, with the central rows designated for data collection. Foliar fertilizers were applied weekly using a hand-held sprayer, beginning 14 days after planting and continuing until 60 days after planting, resulting in seven applications. Each treated plot received 1 L of foliar fertilizer per application, while the control plots received no foliar fertilizer. Standard agronomic practices, including weeding and pest management, were applied uniformly across all treatments.

Measurement of Growth Parameters

Growth assessments were conducted 60 days after planting. Plant height was measured from the soil surface to the apex using a graduated ruler. Leaf area was estimated from leaf length and width using a correction factor of 0.75. Fresh weight of the above-ground biomass was determined immediately after harvesting using a digital balance. Dry biomass was obtained after oven-drying the plant material at 70°C until constant weight. Measurements were recorded from randomly selected plants within each plot, and the mean values were used for statistical analysis.

Statistical Analysis

Data were analyzed using one-way analysis of variance (ANOVA) to determine the effects of the different foliar fertilizer treatments on soil properties and Irish potato growth. Treatment means were separated using Tukey's Honestly Significant Difference (HSD) test at a significance level of $p < 0.05$. Statistical analyses were performed using IBM SPSS Statistics software.

Results and discussion

Soil Physicochemical Properties

The soil properties in Table 1 indicated that the experimental site provided generally suitable conditions for Irish potato cultivation. The soil was slightly acidic (pH 6.67 ± 0.17), contained appreciable amounts of organic carbon and nitrogen, and had adequate levels of phosphorus, calcium, magnesium, and micronutrients. In contrast, exchangeable potassium was comparatively low. This nutrient balance

suggests that while most essential nutrients were present in sufficient quantities, potassium was likely to be the nutrient most limiting crop performance. Such conditions provided a suitable basis for evaluating potassium-rich foliar fertilizers prepared from *Tithonia diversifolia* and *Eichhornia crassipes*.

The soil pH of 6.67 falls within the range considered favorable for Irish potato production because most nutrients remain readily available under these conditions [7]. The absence of measurable exchangeable acidity further suggests that soil acidity was unlikely to restrict root development or nutrient uptake during crop growth [17]. Similar soil conditions have been reported in the volcanic highlands of central Kenya, where slightly acidic soils support good potato yields [7]. A near-neutral pH also reduces the likelihood of aluminum toxicity and excessive phosphorus fixation, both of which commonly occur in strongly acidic soils [18]. Therefore, the observed pH created an environment where crop performance would be influenced more by nutrient availability than by soil acidity itself.

The soil contained 0.34% total nitrogen and 3.40% organic carbon, indicating relatively good organic matter status. Organic matter plays a central role in maintaining soil fertility by improving soil structure, increasing water retention, and gradually supplying nutrients through decomposition [19]. Although these values suggest that the soil has a reasonable capacity to support crop growth, potato is a nutrient-demanding crop that removes large amounts of nitrogen from the soil [20]. Continuous cultivation without adequate nutrient replacement can therefore reduce soil fertility over time. This means that even soils with moderate organic matter still require additional nutrient inputs to sustain high potato productivity.

Available phosphorus was relatively high, with a mean value of 77.2 ppm, although the large variation among samples indicates that phosphorus was not evenly distributed across the study site. Differences of this nature are common in smallholder farming systems where fertilizer application and previous land management practices vary from one field to another [21]. Phosphorus is particularly important during the early stages of potato growth because it promotes root development and supports tuber initiation [22]. Since phosphorus levels were generally adequate, it is unlikely that phosphorus deficiency limited crop growth during the experiment. The results point to the importance of maintaining a balanced supply of nutrients, particularly potassium, which works together with phosphorus in supporting plant growth and tuber development [23].

Table 1
Soil Physicochemical Properties in Limuru Sub-County, Kiambu County

Parameter	Unit	Value
Soil pH	–	6.67 ± 0.17
Exchangeable Acidity	meq%	0.00 ± 0.25
Total Nitrogen	%	0.34 ± 0.01
Total Organic Carbon	%	3.40 ± 0.15
Phosphorus (Mehlich)	Ppm	77.2 ± 54.7
Potassium	meq%	0.44 ± 0.01
Calcium	meq%	18.4 ± 3.4
Magnesium	meq%	4.26 ± 0.26
Manganese	meq%	0.69 ± 0.56
Copper	Ppm	1.80 ± 0.95
Iron	Ppm	93.75 ± 63.75
Zinc	Ppm	70.80 ± 65.3
Sodium	meq%	0.56 ± 0.06
Electrical Conductivity	mS/cm	0.61 ± 0.39

Among the macronutrients, potassium showed the lowest concentration (0.44 meq%), making it the most probable limiting nutrient in the study soil. Potatoes require large quantities of potassium because the nutrient regulates water movement within the plant, activates many enzymes, enhances photosynthesis, and facilitates the movement of carbohydrates to developing tubers [24]. Potassium is also one of the nutrients most readily depleted under continuous cultivation because it is removed in large amounts during harvest and can be lost through leaching, especially in well-drained volcanic soils [25]. Similar potassium deficiencies have been reported in potato-growing regions of Kenya, where farmers often apply fertilizers containing mainly nitrogen and phosphorus while giving less attention to potassium replenishment [7]. These findings support the rationale for developing foliar fertilizers from *Tithonia diversifolia* and *Eichhornia crassipes*, both of which are recognized as good natural sources of potassium.

Exchangeable calcium and magnesium were present in relatively high amounts, reflecting the mineral composition of the volcanic soils found in the study area [26]. Both nutrients contribute to healthy plant growth by supporting cell wall formation, enzyme activity, and photosynthesis [9]. Their adequate concentrations suggest that deficiencies of these nutrients were unlikely during the growing period. However, high concentrations of calcium do not eliminate the need for potassium because these

nutrients perform different physiological functions. In some situations, excessive calcium may even reduce potassium uptake by competing for absorption sites on plant roots, making an adequate external supply of potassium even more important [27].

The soil also contained sufficient concentrations of iron, zinc, copper, and manganese. These micronutrients are required in small amounts but are essential for several metabolic processes, including chlorophyll formation, enzyme activation, and protein synthesis [28]. The relatively high variability observed for iron and zinc suggests natural differences in soil composition across the sampling area, which is common in volcanic landscapes [29]. Nevertheless, the average concentrations indicate that micronutrient deficiencies were unlikely to have limited plant growth during the experiment.

Electrical conductivity was low (0.61 mS cm^{-1}), indicating that soluble salt levels were well below those known to affect potato growth. Likewise, the low sodium concentration suggests that the soil was free from sodicity problems that could interfere with soil structure or water infiltration [30]. These conditions provided a favorable environment for crop establishment and ensured that any differences observed among treatments were more likely to result from the foliar fertilizer applications rather than from salinity stress.

Taken together, the soil analysis shows that the study site had good fertility status for potato production, with the exception of exchangeable potassium. The combination of suitable soil pH, adequate organic matter, sufficient phosphorus, favorable secondary nutrients, and low salinity created conditions under which potassium became the most likely factor limiting crop performance [27]. This finding provides a clear justification for evaluating locally produced potassium-rich foliar fertilizers as a sustainable option for improving Irish potato growth in Limuru and other potato-growing areas with similar soil conditions.

Potassium and Phosphorus Concentrations in *Tithonia diversifolia* and *Eichhornia crassipes* Ashes

The nutrient composition of the plant ashes showed that both *Tithonia diversifolia* and *Eichhornia crassipes* are promising sources of potassium and phosphorus for foliar fertilizer production. However, *Tithonia diversifolia* consistently contained higher concentrations of both nutrients than *Eichhornia crassipes*. Potassium concentration reached 3.45 ± 0.12% in *Tithonia* ash compared with 2.75 ± 0.10% in *Eichhornia* ash, while phosphorus concentrations were 0.52 ± 0.04% and 0.42 ± 0.03%, respectively. The mixture of the two ashes recorded the highest values for both potassium (3.62 ± 0.15%) and phosphorus (0.56 ± 0.05%), indicating that combining the two plant materials produced a formulation with a richer nutrient composition than either ash alone. The relatively small variation among replicates also suggests that the nutrient concentrations were measured consistently, giving confidence in the reliability of the analytical results. These findings demonstrate that the two plant species can serve as valuable raw materials for producing nutrient-rich foliar fertilizers, particularly when used together.

Table 2

Potassium and Phosphorus Concentrations in Tithonia diversifolia and Eichhornia crassipes Ashes

Plant Species	Sample Type	Average Potassium (K) % (Mean ± SD)	Average Phosphorus (P) % (Mean ± SD)
Tithonia diversifolia	Individual Ash	3.45 ± 0.12	0.52 ± 0.04
Eichhornia crassipes	Individual Ash	2.75 ± 0.10	0.42 ± 0.03
Mixture of *Tithonia* and *Eichhornia* Ashes	Mixed Ash Sample	3.62 ± 0.15	0.56 ± 0.05

The higher nutrient content of *Tithonia diversifolia* agrees with earlier studies that describe the species as a highly nutrient-accumulating plant with considerable potential for improving soil fertility [31]. Its deep and extensive root system enables it to absorb nutrients from deeper soil layers and store them in its biomass, making it an effective source of recycled plant nutrients [32]. Although *Eichhornia crassipes* contained lower concentrations of potassium and phosphorus, its contribution should not be overlooked because the plant is known to accumulate substantial quantities of minerals from nutrient-rich aquatic environments. The superior nutrient content observed in the mixed ash suggests that combining different plant biomasses may improve the overall quality of the fertilizer by taking advantage of the strengths of each species [33]. This approach also creates an opportunity to convert two widely available invasive plants into useful agricultural inputs, reducing environmental problems associated with their uncontrolled growth while providing farmers with a low-cost alternative to conventional mineral fertilizers [34]. The results therefore highlight the potential of locally available biomass as a sustainable source of nutrients for crop production and support its use in the development of environmentally friendly fertilizer technologies.

Effect of Customized Foliar Fertilizers on the Growth Parameters of Irish Potato

The results in Table 3 showed that the application of customized foliar fertilizers substantially improved the growth of Irish potato compared with the untreated control. Plants sprayed with the combined *Tithonia diversifolia* and *Eichhornia crassipes* formulation recorded the highest plant height (59.4 ± 3.0 cm), leaf area (55.8 ± 2.6 cm^2), fresh weight (315.7 ± 13.8 g), and biomass (256.1 ± 12.4 g). In contrast, the control plants consistently produced the lowest values for all measured parameters. These results indicate that foliar nutrient application enhanced vegetative growth by supplying nutrients directly through the leaves, where they could be rapidly absorbed and utilized. The improved growth observed in the treated plants is likely associated with increased nutrient availability during periods of active growth, leading to enhanced photosynthesis, greater leaf development, and increased dry matter accumulation. Similar responses have been reported [35], who noted that foliar fertilization is an effective strategy for improving nutrient use efficiency, particularly when soil nutrient availability limits crop performance. Comparable increases in plant height and biomass following foliar nutrient application have also been

reported in potato by Shahzadi et al. [36] and Garcia et al. [37], who attributed these improvements to enhanced physiological activity and more efficient nutrient utilization.

Among the individual plant-based fertilizers, *Tithonia diversifolia* produced better growth responses than *Eichhornia crassipes*, although both treatments significantly outperformed the control. This trend is consistent with the nutrient analysis, which showed that *Tithonia* ash contained higher concentrations of potassium and phosphorus than *Eichhornia* ash. Potassium is essential for regulating stomatal opening, enzyme activation, carbohydrate transport, and water balance, while phosphorus plays a key role in energy transfer, root development, and cell division [27]. A greater supply of these nutrients would therefore be expected to stimulate vegetative growth, resulting in taller plants, larger leaves, and greater biomass production. These findings agree with those of Pazla et al. [38], who reported that *Tithonia diversifolia* is an excellent source of plant nutrients because of its high potassium content and rapid nutrient release. Similar observations were made by Agbede et al. [31], who found that biomass from *Tithonia* significantly improved crop growth and nutrient uptake compared with conventional organic materials. Although *Eichhornia crassipes* produced comparatively lower growth responses, its positive effect confirms earlier reports that water hyacinth contains appreciable amounts of essential nutrients that can be recovered and utilized as organic fertilizer [39].

Table 3
Effect of Customized Foliar Fertilizers on Growth Parameters of Irish Potato

Treatment	**Plant Height (cm) (Mean ± SD)**	**Leaf Size (cm^2) (Mean ± SD)**	**Fresh Weight (g/plant) (Mean ± SD)**	**Biomass (g/plant) (Mean ± SD)**
Control (No foliar fertilizer)	42.6 ± 2.1	38.4 ± 1.9	210.5 ± 10.3	165.2 ± 8.7
Tithonia diversifolia foliar fertilizer	56.8 ± 2.7	52.6 ± 2.4	298.4 ± 12.6	238.9 ± 11.2
Eichhornia crassipes foliar fertilizer	51.2 ± 2.3	47.1 ± 2.2	271.6 ± 11.4	214.3 ± 10.5
Combined (Tithonia + Eichhornia) foliar fertilizer	59.4 ± 3.0	55.8 ± 2.6	315.7 ± 13.8	256.1 ± 12.4

The superior performance of the combined foliar fertilizer suggests that blending the two plant materials produced a more balanced nutrient source than either biomass alone. Rather than reflecting the contribution of a single nutrient, the improved growth is likely the result of complementary interactions among macro- and micronutrients that collectively enhanced plant metabolism [40]. Balanced nutrient availability promotes chlorophyll formation, photosynthetic efficiency, protein synthesis, and the translocation of assimilates to actively growing tissues, all of which contribute to greater biomass accumulation [41]. Similar synergistic effects have been reported by Tripathi et al. [42], who emphasized that crop growth depends on balanced nutrient supply rather than on individual nutrients in isolation. From a practical perspective, the present findings demonstrate that invasive plant species such as

Tithonia diversifolia and *Eichhornia crassipes* can be converted into valuable agricultural inputs capable of improving crop growth while reducing dependence on expensive synthetic fertilizers. This approach supports sustainable nutrient management through the productive use of locally available biomass and offers a cost-effective option for smallholder potato farmers in Kenya and other regions with similar agroecological conditions.

Statistical Analysis of Growth Parameters

The results of the one-way analysis of variance (ANOVA) showed that the different foliar fertilizer treatments had a significant influence on the growth of Irish potato. All the measured growth parameters, namely plant height, leaf area, fresh weight, and biomass, differed significantly among the treatments ($p < 0.001$). This indicates that the observed improvements in plant growth were associated with the application of the customized foliar fertilizers rather than random variation [6]. The high R^2 values, which ranged from 0.918 to 0.944, show that more than 90% of the variation in the measured growth parameters was explained by the treatments applied. Similarly, the adjusted R^2 values remained high, confirming that the statistical models provided a good fit for the experimental data. Fresh weight and biomass recorded the highest F-values, suggesting that these parameters were the most responsive to foliar fertilizer application.

The statistical findings are consistent with the growth trends observed during the field experiment, where plants treated with the customized foliar fertilizers consistently outperformed those in the control plots. The direct application of nutrients to the leaves likely improved nutrient availability during critical stages of plant growth, leading to increased vegetative development and greater biomass accumulation [43]. The combined formulation of *Tithonia diversifolia* and *Eichhornia crassipes* produced the strongest growth response, indicating that the mixture provided a more balanced nutrient supply than either plant source used alone. Overall, the statistical analysis confirms that the customized foliar fertilizers had a positive effect on Irish potato growth and demonstrates their potential as an effective and sustainable alternative for improving crop productivity.

Table 4
Model Summary and One-Way ANOVA Results for Irish Potato Growth Parameters

Parameter	Model Summary	Sum of Squares	Mean Square	F	p-value
Plant Height (cm)	$R^2 = 0.927$, Adj. $R^2 = 0.913$	1478.9	492.97	37.8	< 0.001
Leaf Size (cm^2)	$R^2 = 0.918$, Adj. $R^2 = 0.902$	1786.3	595.43	34.5	< 0.001
Fresh Weight (g/plant)	$R^2 = 0.944$, Adj. $R^2 = 0.933$	38504.6	12834.9	52.3	< 0.001
Biomass (g/plant)	$R^2 = 0.939$, Adj. $R^2 = 0.927$	27212.8	9070.9	48.7	< 0.001

Comparisons for Potato Growth Parameter treatments

Tukey's HSD Post Hoc Comparisons for Irish Potato Growth Parameters

The Tukey's HSD post hoc analysis provided in Table 5 shows comparison of the performance of each foliar fertilizer treatment after the overall ANOVA indicated significant treatment effects. Unlike ANOVA, which only establishes that at least one treatment differs from the others, the Tukey test identifies the specific treatments responsible for these differences. The results revealed that every pairwise comparison was statistically significant ($p < 0.05$), demonstrating that each treatment produced a distinct response in plant height, leaf area, fresh weight, and biomass. The consistently low p-values indicate that the differences among treatments were not due to random variation but reflected genuine differences in the ability of the foliar fertilizers to promote Irish potato growth [44]. This confirms that nutrient source and formulation played a critical role in determining crop performance.

The comparisons between the untreated control and each of the foliar fertilizer treatments were all highly significant ($p < 0.001$), showing that the application of plant-based foliar fertilizers resulted in substantial improvements in all measured growth parameters. The untreated plants consistently recorded the lowest plant height, smallest leaf area, lowest fresh weight, and least biomass, suggesting that the nutrients naturally available in the soil were insufficient to support maximum vegetative growth [45]. Although the soil analysis indicated adequate levels of several nutrients, exchangeable potassium was comparatively low, making potassium the most likely limiting nutrient. The foliar fertilizers therefore supplied nutrients that complemented the existing soil fertility, allowing plants to overcome nutrient limitations during periods of rapid growth [46]. Because foliar-applied nutrients enter the plant directly through the leaf surface, they become available more rapidly than nutrients supplied through the soil, particularly under conditions where nutrient fixation or limited root uptake may reduce nutrient availability. The highly significant differences observed between the control and all treated plants therefore demonstrate the effectiveness of foliar fertilization as a means of improving nutrient availability and stimulating plant growth [47].

The comparison between *Eichhornia crassipes* and *Tithonia diversifolia* also revealed significant differences for all growth parameters, with p-values ranging from 0.024 to 0.033. Although both treatments enhanced plant growth relative to the control, *Tithonia diversifolia* consistently produced taller plants, larger leaves, greater fresh weight, and higher biomass. These differences are closely related to the nutrient composition of the two plant ashes. Earlier analysis showed that *Tithonia diversifolia* contained higher concentrations of potassium and phosphorus than *Eichhornia crassipes*, suggesting that plants receiving the *Tithonia*-based fertilizer had access to a greater supply of nutrients required for growth [31]. Potassium regulates stomatal function, enzyme activation, carbohydrate transport, and water balance, while phosphorus supports energy transfer, nucleic acid synthesis, and cell division [25, 27]. Together, these nutrients promote vigorous vegetative growth by increasing photosynthetic activity

and improving the movement of assimilates to developing tissues [48]. The superior performance of *Tithonia diversifolia* therefore reflects its greater nutrient contribution rather than differences in application rate or experimental conditions.

Table 5
Comparisons for Potato Growth Parameters (p-values)

Comparison	Plant Height	Leaf Size	Fresh Weight	Biomass
Control vs. Tithonia	< 0.001	< 0.001	< 0.001	< 0.001
Control vs. Eichhornia	< 0.001	< 0.001	< 0.001	< 0.001
Control vs. Combined	< 0.001	< 0.001	< 0.001	< 0.001
Eichhornia vs. Tithonia	0.024	0.031	0.028	0.033
Eichhornia vs. Combined	< 0.001	< 0.001	< 0.001	< 0.001
Tithonia vs. Combined	0.041	0.038	0.027	0.032

The largest differences were observed when the combined formulation was compared with *Eichhornia crassipes*, where all p-values were less than 0.001. These highly significant differences demonstrate that combining the two plant materials substantially enhanced fertilizer performance beyond that achieved with *Eichhornia* alone. More importantly, the combined formulation also differed significantly from *Tithonia diversifolia*, although the p-values (0.027–0.041) were closer to the significance threshold, indicating that the performance of these two treatments was more similar. Nevertheless, the statistical significance shows that even the relatively small increases in plant height, leaf area, fresh weight, and biomass produced by the combined fertilizer were consistent and reproducible across the experimental replicates. This finding suggests that blending the two ashes produced a more balanced nutrient composition than either ash individually [49]. In addition to supplying higher concentrations of potassium and phosphorus, the combined formulation may also have provided a broader range of secondary nutrients and micronutrients that worked together to support plant metabolism, resulting in greater overall growth [27].

From an agronomic perspective, these findings have important implications for sustainable potato production. The Tukey's HSD analysis establishes a clear ranking of treatment performance, with the combined *Tithonia diversifolia* and *Eichhornia crassipes* foliar fertilizer performing best, followed by *Tithonia diversifolia*, *Eichhornia crassipes*, and finally the untreated control. This ranking confirms that the response of Irish potato was influenced not only by the presence of additional nutrients but also by the quality and balance of those nutrients within each formulation [50]. The superior performance of the combined fertilizer highlights the potential benefits of integrating different nutrient-rich plant materials to develop customized foliar fertilizers tailored to crop requirements [51]. Such an approach offers a practical means of utilizing locally available invasive plant biomass while reducing reliance on expensive synthetic fertilizers. The statistical evidence therefore provides strong support for the use of mixed

plant-based foliar fertilizers as an effective strategy for improving Irish potato growth and promoting more sustainable nutrient management practices.

Conclusion

The results showed that the soil was slightly acidic and suitable for Irish potato production, although exchangeable potassium was comparatively low. *Tithonia diversifolia* ash recorded higher potassium and phosphorus concentrations than *Eichhornia crassipes* ash, while the combined ash formulation had the highest concentrations of both nutrients. All foliar fertilizer treatments significantly improved plant height, leaf area, fresh weight, and biomass compared with the untreated control ($p < 0.001$). The combined *T. diversifolia* and *E. crassipes* formulation produced the best results, recording a plant height of 59.4 cm, leaf area of 55.8 cm², fresh weight of 315.7 g plant⁻¹, and biomass of 256.1 g plant⁻¹. These findings confirm that the combined plant-based foliar fertilizer was more effective in promoting Irish potato vegetative growth than either individual formulation. Therefore, the combined fertilizer should be further evaluated for its effects on tuber yield, quality, nutrient uptake, and economic feasibility under different locations and growing seasons to establish suitable application recommendations for farmers

Declarations

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author contribution

Conceptualization, Methodology, Software, Validation, Formal Analysis, Investigation, Data Curation, Writing (Original Draft), and Supervision: Hilda ligami Adekha,Harun Mbuvi,Gerald Mbugua, John Wamumwe Mwangi, Ouma Fredick,

Data Availability Statement

All data generated or analysed during this study are included in this published article

Declaration of interest

The authors declare that there are no conflicts of interest.

Conflict of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

Consent to Publish

Not applicable

Plant guidelines

The collection and use of leaves of *Tithonia diversifolia* and *Eichhornia crassipes* complied with applicable local and national guidelines governing the collection and use of plant materials in Kenya.

Permissions to collect the plants/plant parts

Permission to collect *Tithonia diversifolia* and *Eichhornia crassipes* plant materials was obtained from the relevant local authorities.

Plant Ethics

Fresh leaves of *Tithonia diversifolia* and whole plants of *Eichhornia crassipes* were collected from naturally occurring populations in Limuru Sub-County, Kiambu County, Kenya, and Nairobi Dam, Nairobi, Kenya, respectively, with permission from local landowners. The plant materials were identified by Hilda Ligami Adekha, Kenyatta University, Nairobi, Kenya.

Voucher specimens: Voucher specimens representing *Tithonia diversifolia* (H. Adekha 3055) and *Eichhornia crassipes* (H. Adekha 3056) were deposited in the Kenyatta University Herbarium, Nairobi, Kenya, where they are stored and available for reference. The study was conducted in Limuru Sub-County, Kiambu County, Kenya. Collection and use of the plant materials complied with applicable Kenyan national and local guidelines.

Ethics and Consent to Participate declarations

We all agree with Ethics and Consent to Participate declarations

Ethical approval

Not applicable

Consent to participate

Not applicable

Funding declaration

No funding

Clinical trial test

Not applicable

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