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Comparative effects of potassium humate, feldspar, and chemical potassium fertilizers on the yield of yam (*Dioscorea abyssinica*) under Egyptian conditions

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Abstract

Yams (*Dioscorea* spp.) are major tropical tuber crops used as staple or secondary food for more than 500 million people worldwide. Large amounts of potassium-related fertilizer are used in agriculture to improve crop yield and soil K content, but the high cost and overuse have caused soil and environmental concerns. Therefore, the aim of this work was to study the use of natural sources of potassium (K-humate and feldspar) as an alternative to chemical potassium fertilizers and to increase the productivity of yam (*Dioscorea abyssinica*) under Egyptian conditions. Two field experiments were established at Kaha Vegetable Research Farm, Qalyubia Governorate, Egypt, during two successive seasons of 2021/2022 and 2022/2023. The experiment was arranged in a randomized complete block design with three replicates. The plot area was $10m^2$ (10 m in length and 1 m in width). The drip irrigation was used. The experiment consisted of eight potassium treatments, control treatment (144 units K_2O) as potassium sulphate (48% K_2O), and three levels of feldspar (100, 80, and 60% of recommended fertilizer) and three levels of potassium humates (100, 80, and 60% of recommended fertilizer) and a mixed treatment (40% potassium humate + 60% feldspar). Our results indicated that using natural sources of potassium, *i.e*., feldspar and humate, can serve as alternative sources of potassium (potassium sulphate). The treatment 60% K-feldspar + 40% K-humate+KSB increased all the vegetative growth parameters, total yield of yam tubers, quality and chemical composition, while the treatment of 60% K-humate increased total saponin content of tubers in both seasons.

Key words: *Dioscorea abyssinica*, potassium natural sources, vegetative growth, yield, chemical composition**.**

Introduction

Yams (*Dioscorea spp.*) recognized as tropical tuber crops, are a crucial staple or supplementary food source for approximately 500 million people worldwide. These tuberous vegetables are not only high in energy but also offer a pleasant taste and medicinal benefits. In tropical regions, particularly in West Africa, Southeast Asia, the Pacific Islands, Papua New Guinea, and the Caribbean, yams are vital for ensuring food security (Suja *et al.,* 2012). West Africa is the leading region for yam cultivation globally, accounting for approximately 96% of global production. Nigeria leads yam production, accounting for 74% of global output, followed by Ghana, Côte d'Ivoire, Benin, and Togo (FAO, 2022).

Potassium is a crucial nutrient necessary for plant growth. It plays a significant role in various physiological functions, such as photosynthesis, the movement of photosynthetic products, the maintenance of ionic balance, the regulation of stomatal function and transpiration, and the activation of plant enzymes. Potassium sulfate is suitable for all types of crops, adaptable to diverse soil conditions, improves plant resilience, is water-soluble, and releases K^+ ions that are easily absorbed by the soil (Pahalvi *et al*., 2021). In Egypt, farmers apply substantial quantities of potassium-based chemical fertilizers, such as potassium sulfate or chloride, to enhance crop yields per unit area and replenish soil potassium levels depleted by plant uptake. Their high cost increases production expenses and leads to environmental pollution. Alternatively, natural potassium fertilizers and biofertilizers offer a cost-effective means of supplying potassium to plants, potentially replacing costly chemical fertilizers (Labib *et al.,* 2012). K-feldspar, in particular, can serve as a valuable slow-release fertilizer and a more affordable potassium source (Labib *et al.,* 2012).

The use of potassium-solubilizing bacteria as a biofertilizer was suggested as a sustainable solution to improve plant growth, nutrition, root growth, plant competitiveness, and responses to external stress factors. Moreover, potassium-solubilizing bacteria play an important role in the formation of humus in soil and in the cycling of other minerals tied up in organic matter (Merwad, 2016).

Substances are divided into three categories: humin, humic acids, and fulvic acids, based on their solubility in water. Humic acid is the portion that dissolves at neutral and alkaline pH and is a key agent in the movement of pollutants in the environment. According to previous studies (Chianese *et al.,* 2020), Humic acid can attach to cations through electrostatic forces and to non-ionic organic compounds via hydrogen bonds, dipole-dipole interactions, and hydrophobic interactions. Owing to these characteristics, Humic acid has been suggested as an adsorbent for use in wastewater treatment facilities (Chianese *et al.,* 2020). Potassium humate is a commercial product that contains numerous elements essential for plant growth (El-Sharkawy and Abdel-Razzak, 2010). Additionally, potassium feldspar is a natural and cost-effective source of K^+. Abou-el-Seoud and Abdel-Mageed (2012) noted that alternative chemical forms of K^+ provide plants with a slow-release K^+ supplement that enhances plant development. Carbohydrates, as part of saponins, influence their solubility, bioavailability, and ability to bind to biological targets. For example, the sugar moiety in saponins determines their foaming ability and their interactions with proteins and other cellular structures. Saponins play a role in plant defence against pathogens by disrupting cell membranes. They also have pharmacological properties, such as anti-inflammatory, antimicrobial, and immune-boosting effects, where carbohydrates are integral to the structure and function of saponins across various biological and chemical contexts. (Guo *et al.,* 2020). Therefore, the aim of this work was to study the effects of different natural potassium fertilizer sources and rates on the growth, yield, and quality of yam plants under Egyptian conditions.

Materials and methods

Fertilizer sources: Feldspar (10.6% K_2O) was purchased by Al-Ahram mining and natural fertilizers company, Egypt. Potassium-facilitating bacteria (*Bacillus circulans*) provided by Central Lab of Organic Agriculture, Agricultural Research Centre, Egypt. *B. circulans* was prepared as a liquid culture by inoculation of a loopful of *B. circulans* in to 1000 ml Nutrient Broth (NB) as a growth medium and incubated at 30ºC for 48 hours. The bacterial suspension was adjusted to contain 10^7 CFU mL^{-1} using spectrophotometer (OD600) (Abdelrahman *et al.,* 2021). Potassium humates (10% K_2O) and compost were purchased from Agrochemicales and El-Faranaa companies. The chemical analysis of feldspar is presented in Table 1.

Table 1. Feldspar chemical compositions

Item	Percentage (%)
SiO_2	68.23
TiO_2	0.04
Al_2O_3	16.25
Fe_2O_3	0.40
MnO	0.02
MgO	0.03
CaO	0.47
Na_2O	3.25
K_2O	10.12
P_2O_5	0.02
L.O.I	0.7

Preparation of yam tubers (seeds): Due to dormancy, yam tubers do not sprout readily after harvest; tuber dormancy is a temporary suspension of sprouting from the eyes of the buds containing meristem. Therefore, tubers soaked in BA (1 mg L^{-1}) for 15 min., and cut into pieces of 100-150 g, after that yam tuber pieces (seeds) were soaked in mixed solution of fungal disinfectant containing Rhizolex T + Topsin M70 + Ridomil plus by concentrations of 3:2:1.5 for 15 min according to Farag *et al.* (2019) Each tuber piece was sown in plastic pot containing peat moss and vermiculite (1:1) on 1st of April 2021 and 2022. The seedlings were transplanted in the open field after 2 months of sprouting, spaced 1m apart, and inserted into the soil for about 10 cm, then covered with soil.

Experimental layout and agricultural practices: Two field experiments were established at the Kaha Vegetable Research Farm, Qalyubia Governorate, Egypt, during the 2021/2022 and 2022/2023 seasons. The soil of the experiment was clay with pH 7.8, 1.41 dsm^{-1} EC and 4.26 $CaCO_3$ in the first season and pH 8.3, 4.78 dsm^{-1} EC and 5.02 $CaCO_3$ in the second season. The soil soluble cations (mequiv/l) were Ca^{++} (8.0 and 21.0), Mg^{++}(4.28 and 11.46), Na^+ (3.74 and 17.12) and K^+ (0.3 and 0.76), O.M% (2.74 and 2.43) in the first and second seasons. The soil was deeply ploughed and divided into beds 1 m wide and 60 m long. Seedlings of yam (*Dioscorea abyssinica*) were planted on 1st of June 2021 and 2022. The average temperature and total precipitation weather data in Qalyubia Governorate during the growing seasons are presented in Table 2. Spacing was 1 m between rows and 1 m between plants. During the preparation, soil organic fertilizer (compost) was applied at 48 m3/ha, plus 240 units of phosphorus as calcium super phosphate (15.5% P_2O_5) and 480 kg/ha of sulfur. Nitrogen fertilizer (240 units) was divided equally into three portions and applied to the plants after 30 days of seedling transplantation, and after 60 and 90 days as urea (46%N). The experiment was arranged in a randomized complete block design with three replicates. The plot area was $10m^2$ (10 m in length and 1 m in width). The drip irrigation system was used in the experiment.

Table 2. The average temperature and total precipitation weather data of Qalyubiya Governator, Egypt, during yam growth period

Month	2021/2022		2022/2023	
	Average Temperature (°C)	Total Precipitation (mm)	Average Temperature (°C)	Total Precipitation (mm)
June	28.6	0.0	29.63	1.0
July	31.1	0.1	30.4	1.5
August	32.05	1.4	27.9	1.1
September	29.5	0.8	29.6	0.8
October	25.7	3.7	25.3	2..8
November	22.9	19.8	23.7	0.8
December	21.4	8.9	22.3	10.7
January	11.1	32.2	14.1	42.8
February	12.9	10.5	12.3	15.1

Source: Egyptian Ministry of Agriculture & Land Reclamation Agricultural Research Centre, Central Lab. for Agricultural Climate (CLAC).

Potassium treatments: The experiment consists of eight potassium treatments, control treatment (345.6 units K_2O/ ha) as potassium sulphate (48% K_2O), and three levels of feldspar (100, 80, and 60% of recommended fertilizer) and three levels of potassium humates (100, 80, and 60% of recommended fertilizer). Moreover,mixed treatment (40% potassium humate + 60% feldspar). Feldspar was added to the plots for feldspar treatments during soil preparation, while a potassium-facilitating bacterium for feldspar treatments was added 2 months after planting, applied 3 times via irrigation at a rate of 24 l/ha. Potassium humate was applied equally at 60 and 90 days after transplanting as a soil application, while potassium sulphate was applied at 90, 120, and 150 days after transplanting as a soil application.

Vegetative growth and yield measurements: Three plants were chosen randomly from each plot after five months of transplanting date to measure vine lengths from ground level up to the highest petiole. Number of lateral branches/ plant (developed directly from the main stem, including secondary and tertiary branching levels of the plant during vegetative growth), number of leaves/ plant and leaf area of the fifth top fully expanded leaf. It was determined by cutting 10 leaf discs from each plant using a cork borer and weighing them. The leaf area was calculated according to the following formula:

Relative chlorophyll content (SPAD reading) was measured in the fresh fifth top fully expanded leaf, by using SPAD-502. Dry matter (%) / plant was estimated according to the following formula:

$$\text{Plant dry matter (\%)} = \frac{\text{Plant dry weight}}{\text{Plant fresh weight}} \times 100$$

After 10 months of transplanting (harvesting time), the entire whole-plot area was harvested to determine yield/plant and the total yield/ha. Tubers length and diameter were also determined as physical characters. Moreover, tuber dry matter % was determined as previously mentioned in plant dry matter.

Leaves pigments content: Chlorophyll a, b, total, and carotenoid content were determined using 80% acetone according to the method described by Saric *et al.* (1967).

Leaves and tubers chemical compositions: Yam tubers were harvested in February 2022 and 2023, in the first and second seasons. Three tubers from each of three plants per plot in all experiments were taken, and 100g fresh weight from each tuber was dried at 65 C for 72 h until constant weight, then used for chemical analyses of minerals. All chemical analyses of tubers and leaves were performed in three replications. N, P, K and Ca were determined in the digested dry matter of each plant foliage and tubers. Total nitrogen was determined according to the method described by Jones *et al.* (1991) using the microkjeldahl apparatus. Phosphorus was determined calorimetrically according to John (1970). Potassium was evaluated by using flame photometric ally as mentioned by Brown and Lillel (1946). Calcium was estimated through flame photometer device according to the method described by Chapman and Pratt (1961). Total hydrolyzable carbohydrate content was determined according to Dubois *et al.* (1956). Total phenolic compounds were determined according to the method of Singleton and Rossi (1965). Total antioxidant activity %was determined according to Brand-Williams *et al.* (1995). Total saponin content was extracted with ethanol and determined using vanillin 4% according to Le *et al.* (2018).

Statistical analysis: The data were exposed to proper statistical analysis of variance by M-statc (version 2.1 Michigan State University, East Lansing, MI, USA) statistical software. The experiment was arranged in a randomized complete block design with three replicates. Means were separated by Duncan's multiple range test at 5% level. Pearson correlation was done by SPSS program (Inc., Chicago, IL, USA, version, 14).

Results and discussion

Plant vegetative growth parameters: The results in Figs. 1a and 1b present the effect of potassium humate and feldspar levels on vine length (m) and the number of lateral branches/plants. The results showed that plants treated with 80% K-feldspar, 100% K-humate, and 60% K-feldspar + 40% K-humate recorded the highest vine length, with no significant difference from the control treatment in both seasons. According to number of lateral branches/ plants, treating the plants with 60% K-humate and all the tested levels of K-feldspar (100%, 80% and60%) obtained the highest number of lateral branches/plant, while the lowest number of lateral branches/plant was observed by 60% K-feldspar + 40% K-humate in the first season (Fig. 1b). In the second season, there was no significant difference between all the tested treatments and control treatment on number of lateral branches/plant.

Data presented in Figs. 1c and 2a showed that both the number of leaves/plant and leaf area (mm^2) were significantly affected by potassium sources and levels. The maximum number of leaves per plant and leaf area in both seasons were achieved by the combination treatment of 60% K-feldspar + 40% K-humate (Figs. 1c and 2a). On the other hand, 60% K-humate had the lowest number of leaves /plant in both seasons. Additionally, 100% K-feldspar obtained the lowest leaf area in both seasons (Fig. 2a).

Relative chlorophyll content (SPAD reading) was affected significantly by potassium treatments. Data presented in Figs. 2b and 2c showed that K-feldspar with 80%, and 60 % and K-humate with 100%, and 60 % obtained the highest relative chlorophyll content in both seasons, while the lowest relative chlorophyll content was recorded in plants treated with 100% K-feldspar in both seasons. The mixed treatment (60% K-feldspar + 40% K-humate) achieved the highest dry matter of the plant in both seasons compared to all other treatments. In both seasons, the dry matter percentage of plants decreased by 100% or 60% in the K-feldspar treatments.

Potassium humate and feldspar+ biofertilizer treatment illustrated the maximum vegetative growth due to the presence of a sufficient

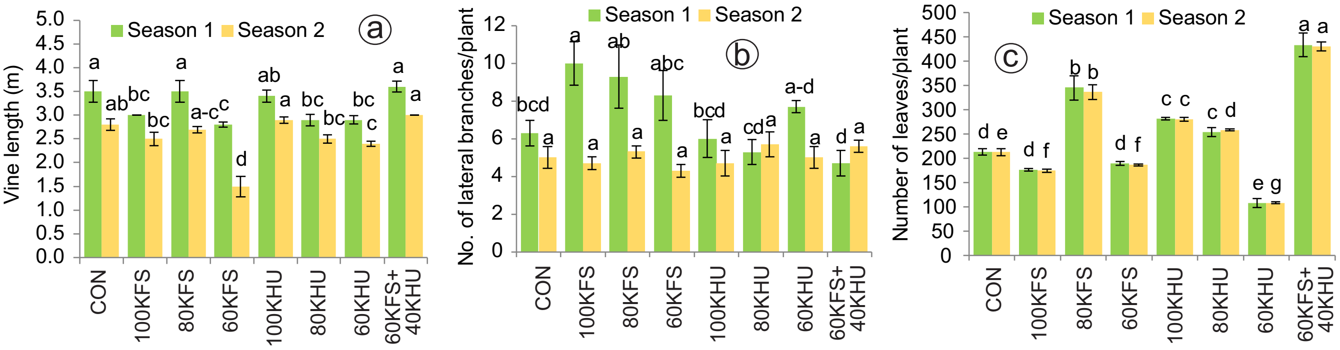

Fig. 1. Influence of potassium humate and feldspar levels on (a) vine length, (b) number of lateral branches per plant and (c) number of leaves per plant during 2021/2022 and 2022/2023 growing seasons. Where CON:100%K-feldspar; 100KFS:80% K-feldspar; 80KFS:60% K-feldspar; 60KFS:100% K-humate; 100KHU:80% K-humate; 80KHU:60% K-humate; 60KHU:60% K- feldspar + 40% K-humate; 60KFS+40KHU: Results are shown ± SE. Means and different letters indicate significant difference between treated and control treatments (Duncan's of 95%).

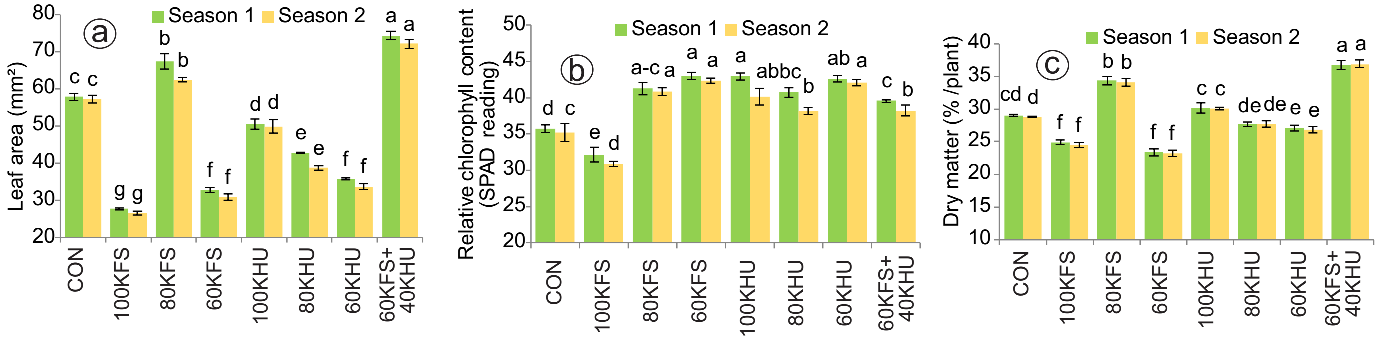

Fig. 2. Influence of potassium humate and feldspar levels on (a) Leaf area (mm^2), (b) Relative chlorophyll content (SPAD reading) and (c) Dry matter (%) during 2021/2022 and 2022/2023 growing seasons. For treatment abbreviations and statistical notation, see Fig. 1 caption.

amount of available K for growth of both soil microorganisms and plant. Humic acid improved soil chemical properties by increasing soil microorganisms, enhancing nutrient uptake, and reducing soil pH (Hemida *et al.,* 2017). Thus increasing the absorption of the following nutrients: N, P, and K.. The positive effects of potassium humate on plant growth could be attributed to its acting as source of plant growth regulators. Moreover, K soluble bacteria play a vital role in the formation of soil humus and the recycling of other minerals tied up in the soil organic matter (Sattar *et al.,* 2019). Potassium-solubilizing bacteria (KSB), particularly species such as Bacillus and Pseudomonas, play a vital role in transforming the potassium locked within feldspar (a naturally abundant but insoluble mineral) into forms accessible to plants. These bacteria achieve this by secreting organic acids (*e.g.*, citric, oxalic, and lactic acids) that lower soil pH and help dissolve silicate bonds in feldspar, thereby releasing potassium ions into the soil. Recent studies have shown that KSB can increase potassium solubilization from minerals by up to 45%. KSB also enhances plant growth and yield, improving physiological functions such as root development, water regulation, and carbohydrate metabolism when used with feldspar. This bio-based strategy can reduce dependence on chemical potassium fertilisers by 30-50% while maintaining crop productivity (Meena *et al.,* 2023). Furthermore, they can enable solubilization of rock-K minerals, such as feldspar, by producing and excreting organic acids or chelating silicon ions that transfer K into solution. On the other hand, inoculation with potassium-solubilising bacteria combined with potassium humate or K-feldspar can provide a faster, continuous supply of K, enhancing plant growth, yield, and final product quality (Abdel-Salam and Shams, 2012). Ali *et al.* (2021) reported a positive effect on the growth of potato plants treated with feldspar-K and potassium-solubilizing bacteria.

Yield and tuber quality: The tuber length (cm) of yam plants as influenced by potassium treatments is presented in Fig. 3a obtained results indicated that the highest tuber length was obtained in control treatment and 60% K-feldspar + 40% K-humate treatment as compared to the other treatments in the first season, while in the second season, the highest tuber length was found in the control, K-feldspar (100% and 80%), K-humate (100% and 80%) and 60% K-feldspar + 40% K-humate without significant difference between them as compared to 60% K-feldspar and 60% K-humate. This study showed that the tuber diameter (cm) responded significantly and positively to 60% K-feldspar + 40% K-humate compared to the other tested treatments in both seasons (Fig. 3b).

As presented in Figs. 3c and 4a, the potassium treatment of 60% K-feldspar + 40% K-humate had the highest values of total tuber yield/plant (g) and total tuber yield/ha (ton) compared to all other potassium treatments in both seasons. Total yield was increased by 143.8% and 114.9% in 60% K-feldspar + 40% K-humate treatment in the first and second seasons, respectively, compared to the control treatment (Table 3).

Table 3. Influence of potassium humate and feldspar levels on total yield increase (%) during 2021/2022 and 2022/2023

Treatments	First season	Second season
	Total yield increase (%)	Total yield increase (%)
100%K-feldspar	-33.2^b ± 1.11	-11.9^c ± 6.67
80% K- feldspar	1.9^b ± 13.89	29.0^b ±21.71
60% K- feldspar	-66.2^b ± 2.33	-48.6^d ± 6.75
100% K-humate	-8.8^b ± 11.47	21.0^b ± 10.32
80% K-humate	-47.9^b ± 9.23	-40.6^d ± 7.66
60% K-humate	-49.4^b ± 8.14	-21.3^{cd} ± 7.46
60% K- feldspar + 40% K-humate	143.8^a ± 65.02	114.9a ± 3.55

Means within a column followed by different letters are significantly different by Duncan's testing (95%). (n= 3).

The findings of our study indicate that adding most of the

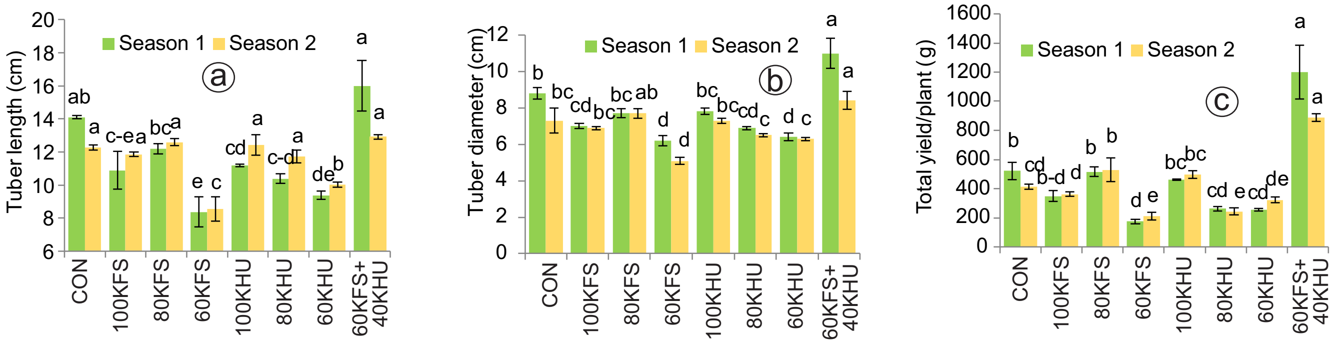

Fig. 3. Influence of potassium humate and feldspar levels on (a) Tuber length (cm), (b) Tuber diameter (cm) and (c) total yield (g)/plant during 2021/2022 and 2022/2023 growing seasons. For treatment abbreviations and statistical notation, see Fig. 1 caption.

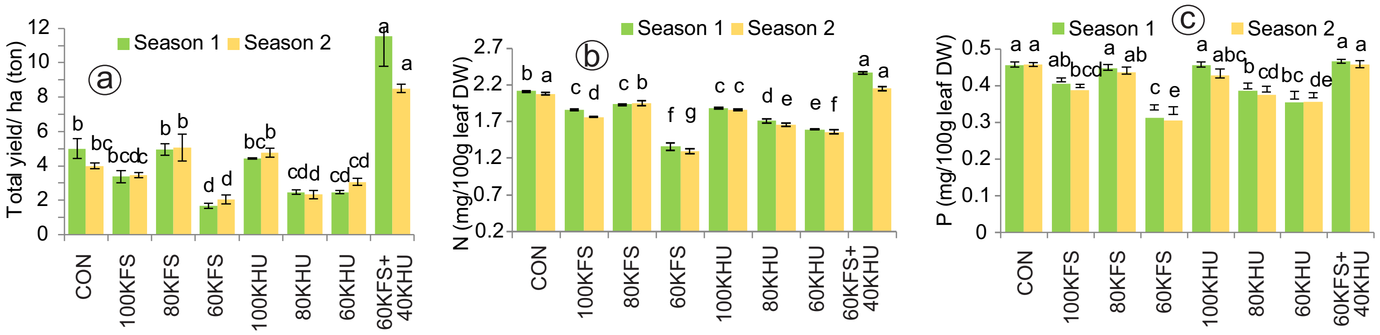

Fig. 4. Influence of potassium humate and feldspar levels on (a) Total yield (ton) / ha, (b) Leaf N content (mg/100g D.W) and (c) P content (mg/100g D.W) during 2021/2022 and 2022/2023 growing seasons. For treatment abbreviations and statistical notation, see Fig. 1 caption.

plant potassium requirements with organic fertilizers (60% K-feldspar + 40% K-humate) as well as biofertilizers (potassium-degrading bacteria) may increase K uptake by plants due to better availability and consequently improve biosynthetic processes and carbohydrate accumulation, which led to an increase of tuber size and tuber yield. (Lallawmkima *et al.*, 2018) reported that increasing foliar application of humic acid up to a particular concentration accompanied by a progressive increase in green pods yield of snap bean. Similar results were reported by Ali *et al.* (2021) on potato, who found that the beneficial effects of potassium fertilisation on potato yield parameters are associated with numerous physiological processes, such as osmotic regulation, ionic balance, stomatal and enzymatic activity, which directly affect plant growth and, consequently, tuber formation and yield. In addition, the combined application of mineral fertilizers with biofertilizers containing Azotobacter and potassium-solubilizing bacteria may also increase plant growth and tuber yield (Lallawmkima *et al.,* 2018). The fact that in our study the high rates of K fertilizer (K-humate and feldspar) resulted in the highest tuber yield could be explained by the realization of yam K requirements through the soil-added rates, which exceeded the control (345.6kg K_2Oha). However, the additional application of K-humate or feldspar individually resulted in significantly decreased the yield than the other tested treatments, indicating that the improved potassium availability during the growing period is critical for achieving high tuber yields. According to the literature, potassium application rates are effective in regulating potato tuber quality, especially when considering the high requirements of the crop fort his specific macronutrient (Farheen *et al.,* 2018).

Leaves pigments content: It is evident from data in Table 4 that chlorophyll a, b, total chlorophyll and carotenoid in leaves of yam plant were significantly affected by different potassium treatments. In this regard, our data reveal that the application of 60% K-feldspar + 40% K-humate during the two growing seasons resulted in the highest values of chlorophyll a, b, total chlorophyll, and carotenoid. On the other hand, chlorophyll b content was not significantly affected by the tested treatments in the first season. In the second season, 60% K-feldspar + 40% K-humate, 80% feldspar, 100% humate and 80% humate recorded the highest chlorophyll b content with no significant difference from the control treatment. The positive effect of combination treatment (potassium humate, feldspar and biofertilizer) on leaf total chlorophylls and carotenoid content. Similar results were reported by Abbas (2013) on faba bean.

Leaves chemical compositions: The highest content of nitrogen (mg/100g D.W) was achieved by 60% K-feldspar + 40% K-humate treatment in both seasons with no significant difference from control treatment in second season (Fig. 4b). It was evident from presented data in Fig. 4c that potassium treatments (Control, 80% K-feldspar, 100% K-humate and 60% K-feldspar + 40% K-humate) significantly increased P content (mg/100g D.W) of yam leaves. Potassium content (mg/100g D.W) was achieved with the 60% K-feldspar + 40% K-humate treatment in both seasons, followed by the control treatment (Fig. 5a).

Tubers chemical compositions: Data in Figs. 5b and 5c showed that tuber dry matter (%) and carbohydrates (%) were significantly affected by potassium treatments. The lowest value of tuber dry matter (%) was obtained with the 80% K-humate application, while all other tested treatments had the same significant tuber dry matter % in the first season. On the other hand, plants treated with 60% K-humate treatment and 60% K-feldspar + 40% K-humate had the highest values of tuber dry matter (%) in the second season compared to all other treatments. With respect to the prevailing potassium treatment, the treatment of 60% K-feldspar + 40%

Table 4. Influence of potassium humate and feldspar levels on chlorophyll leaves content and carotenoid during seasons 2021/2022 and 2022/2023

Treatments	First season				Second season			
	Chl. A	Chl. B	Total. Chl	Carotenoid	Chl. A	Chl. B	Total. Chl	Carotenoid
Control	0.30^{c}	0.10^{a}	0.41^{c}	0.25^{bcd}	0.28^{c}	0.16^{ab}	0.44^{c}	0.22^{b}
100%K-feldspar	0.18^{ef}	0.11^{a}	0.29^{d}	0.19^{d}	0.17^{e}	0.13^{bc}	0.31^{d}	0.22^{b}
80% K- feldspar	0.36^{b}	0.16^{a}	0.49^{b}	0.30^{b}	0.36^{b}	0.19^{a}	0.55^{b}	0.34^{a}
60% K- feldspar	0.14^{f}	0.11^{a}	0.25^{d}	0.14^{e}	0.11^{f}	0.08^{c}	0.19e	0.11^{c}
100% K-humate	0.28^{ed}	0.11^{a}	0.38^{e}	0.22^{ed}	0.27^{ed}	0.17^{ab}	0.44^{e}	0.24^{b}
80% K-humate	0.26^{cd}	0.15^{a}	0.41^{c}	0.26^{bc}	0.25^{cd}	0.14^{abc}	0.39^{c}	0.23^{b}
60% K-humate	0.22^{de}	0.16^{a}	0.38^{c}	0.21^{cd}	0.22^{de}	0.10^{c}	0.31^{d}	0.21^{b}
60% K-f + 40% K-humate	0.47^{a}	0.16^{a}	0.64^{a}	0.40^{a}	0.45^{a}	0.19^{a}	0.64^{a}	0.39^{a}

Means within a column followed by different letters are significantly different by Duncan’s testing (95%). (n= 3).

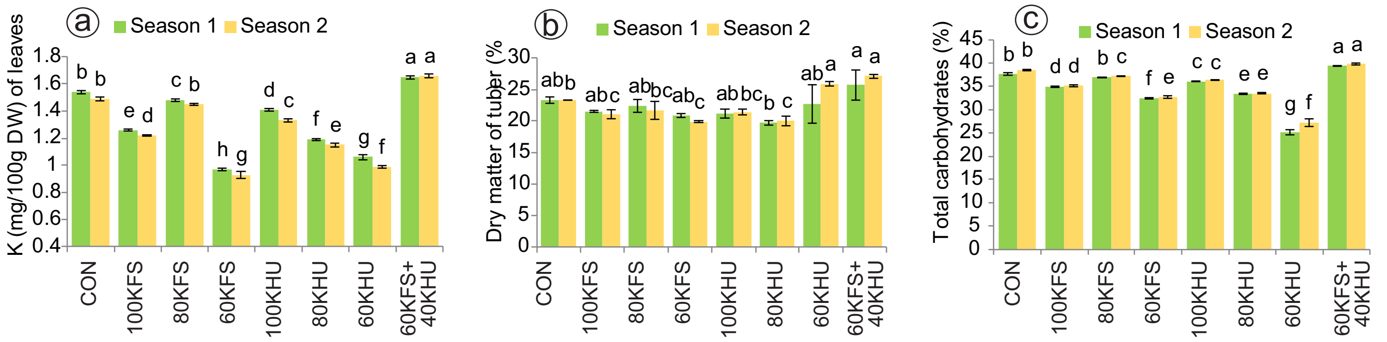

Fig. 5. Influence of potassium humate and feldspar levels on (a) Leaf K content (mg/100g D.W), (b) Dry matter (%) of tubers and (c) Carbohydrates (%), during 2021/2022 and 2022/2023 growing seasons. For treatment abbreviations and statistical notation, see Fig. 1 caption.

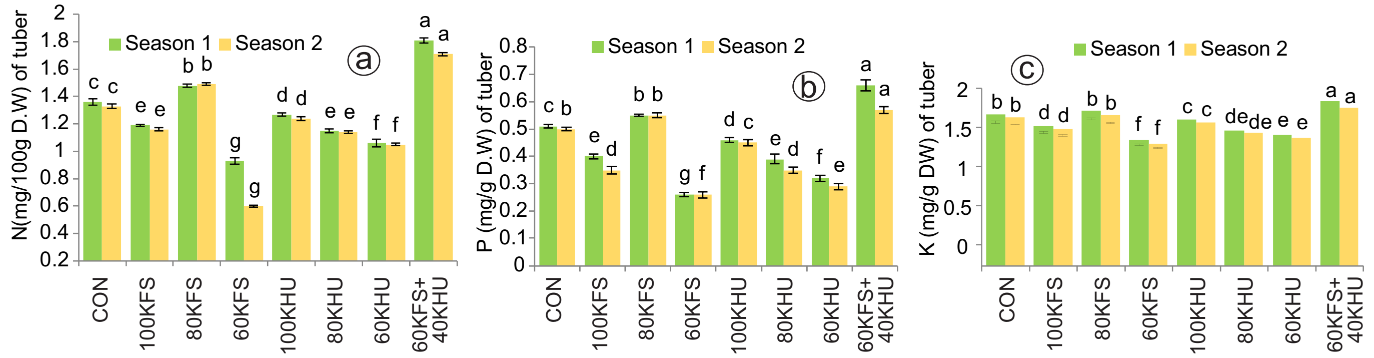

Fig. 6. Influence of potassium humate and feldspar levels on (a) Tubers N content (mg/100g D.W), (b) Tubers P content (mg/100g D.W) and (c) Tubers Kcontent (mg/100g D.W) during 2021/2022 and 2022/2023 growing seasons. For treatment abbreviations and statistical notation, see Fig. 1

K-humate recorded the highest carbohydrate (%) in yam tuber in both seasons, followed by the control treatments (Figs. 5b and 5c).

Potassium treatments had a significant effect on tuber chemical compositions, as presented in (Figs. 6a, 6b and 6c). The highest levels of nitrogen, phosphorus, and potassium in yam tubers were found in the combination treatment (60% K-feldspar + 40% K-humate) in both seasons. The highest calcium content in yam tubers was obtained with the 60% K-feldspar + 40% K-humate treatment, with no significant difference from the control, 60 K-feldspar, or 100% K-humate treatments in the first season. Plant treated with 60% K-feldspar+ 40% K-humate achieved the highest significant calcium content in the second season compared to all other tested treatments (Fig. 7a and 7b).

Data presented in Figs. 7b and 7c indicated that total phenolic compounds content (mg/g) and total antioxidant capacity (inhibition %) were significantly affected by potassium treatments. Results shown in Fig. 8 indicated that total saponin content (mg/g) of yam tubers was achieved by 60% K-feldspar treatment compared to all other treatments and control treatment.

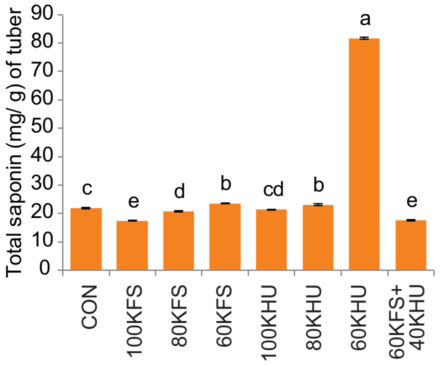

Fig. 8. Influence of potassium humate and feldspar levels on total saponin content (mg/g). For treatment abbreviations and statistical notation, see Fig. 1

The combination of potassium humate and K-feldspar may improve carbohydrate content and macronutrient uptake (N, P, and K) in tubers and shoots, and increase potato yield (Abdel-Salam and Shams, 2012). The positive effect of the combination of K-feldspar + K-humate+ KSB could be attributed to its effects

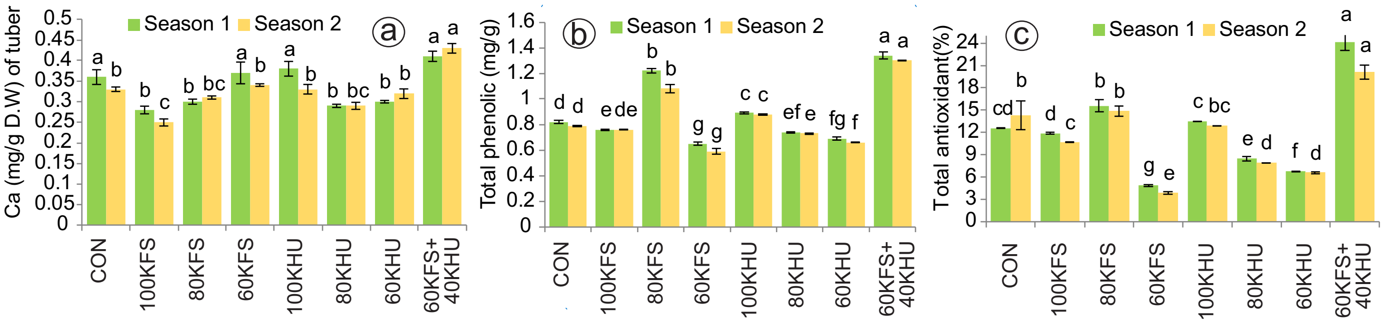

Fig. 7. Influence of potassium humate and feldspar levels on (a) Ca content (mg/100g D.W), (b) Total phenolic compounds (mg/g) and (c) Total antioxidant activity (inhibition %) during 2021/2022 and 2022/2023 growing seasons. For treatment details and DMRT significance, refer to the footnotes in Table 1.

on supplying plants with their requirements of potassium as well as its effect on lowering soil pH by K-humat; which could facilitate the availability of potassium, and their effects on the plant physiological processes such as photosynthetic activity as well as the utilization of carbohydrates. However, the substitution of 50% potassium sulfate with K-feldspar yielded the best results in the study by Labib *et al*. (2012).

Moreover, KSB plays a vital role in the formation of soil humus and the recycling of other minerals bound in soil organic matter (Sattar *et al.,* 2019). On the other hand, inoculation with potassium-solubilising bacteria combined with either potassium sulfate or K-feldspar can provide a faster, continuous supply of K, thereby enhancing plant growth, yield, and final product quality (Abdel-Salam and Shams, 2012). potassium enhances nitrogen uptake from soil (Naumann *et al.,* 2020). Our results demonstrated an inverse relationship among yam yield, total carbohydrate content and saponin concentration in yam tubers. Treatment with 60% K-feldspar + 40% K-humate exhibited the highest carbohydrate levels, which were associated with a marked reduction in saponin content. This trend may be attributed to the fact that elevated carbohydrate availability serves as a signal of energy sufficiency, prompting the plant to allocate metabolic resources to primary growth processes rather than to the synthesis of secondary defence compounds such as saponins. Similar findings have been reported in medicinal plants such as *Panax ginseng*, where increased sugar supply has been linked to reduced saponin accumulation, likely due to a shift in metabolic prioritization. These results underscore the importance of nutrient balance and metabolic regulation in optimizing the biosynthesis of secondary metabolites in functionally valuable crops (Guo *et al.,* 2020). The results indicate that the 60% humate treatment produced a higher saponin content, suggesting that the plant may have been under moderate nutritional stress due to reduced potassium fertilisation. This stress likely triggered the activation of secondary metabolic pathways, including saponin biosynthesis. This finding aligns with the concept of stress-induced secondary metabolism, in which plants redirect metabolic resources from growth to defence in response to environmental constraints. Several studies have shown that under abiotic stress conditions—such as limited nitrogen, phosphorus, or other essential nutrients—plants tend to accumulate secondary metabolites as part of their defense and adaptation strategy (Selmar and Kleinwächter, 2013). In this study, lower humate concentrations might not provide sufficient nutrients to optimise growth but could stimulate the plant's defence machinery, leading to increased saponin accumulation as a protective response. Stress can affect plant growth and secondary metabolite production; saponin content in Panax notoginseng decreased with increased water deficit or organic fertiliser (Li *et al*., 2021).

Table 5. Correlation coefficients among vine length, leaf area, dry matter/plant, total yield per hectar, dry matter of tuber, carbohydrate, total phenolic compounds, antioxidant and total saponin content

	Vin	LA	DMP	Y/ha	DMT	Carb	Phe	Anti
LA	0.744**							
DMP	0. 728**	0.925**						
Y/ha	0.651**	0.786**	0.788**					
DMT	0.335	0.452*	0.337	0.632**				
Carb	0.644**	0.680**	0.580**	0.637**	0.252			
Phen	0.677**	0.898**	0.942**	0.818**	0.428*	0.674**		
Anti	0.725**	0.819**	0.883**	0.889**	0.426*	0.794**	0.919**	
Sapon	-0.314	-0.326	-0.223	-0.312	0.047	-0.879**	-0.367	-0.428*

Vin= vine length, LA= leaf area, N/l= N. leaves, DM*P*= dry matter/plant, Y/ha= yield per hectar, DMT= dry matter of tuber, Carb= carbohydrat, T.Phen= total phenolics, Anti= antioxidant and Sapon= total saponin content. *= significant at 0.05, **= significant at 0.01, ***= significant at 0.001.

Correlation: This part of the study was conducted to explain the relationships between the different measurements. The results in Table 5 showed a positive, significant relationship between vegetative growth measurements (vine length and leaf area) and dry matter (0.728** and 0.925**). Yield/hectare was positively correlated with vegetative growth parameters. Yield was affected by vine length (0.651**), leaf area (0.786**), dry matter % (0.788**) and carbohydrate content (0.637**). Tubers carbohydrate, total phenolic compounds and antioxidant % correlated positively with vine length (0.644**, 0.677** and 0.725**), leaf area (0.680**, 0.898** and 0.819**), and with dry matter% (0.580**, 0.442** and 0.883**). The saponin content was correlated negatively with carbohydrate content (-0.879**) and antioxidant content (-0.428*)

There were a few studies on the effects of natural potassium sources on the growth, yield, and quality of yams. Our results indicated that using natural sources of potassium, *i.e* ., feldspar and humate, can serve as alternative sources of potassium (potassium sulphate). Using 60% K-feldspar + 40% K-humate + KSB increased all vegetative growth parameters, total yield of yam tubers, quality, and chemical composition.

References

Abbas, S.M. 2013. The influence of biostimulants on the growth and on the biochemical composition of *Vicia faba* cv. Giza 3 beans. *Rom. Biotechnol. Lett.*, 18: 8061-8068.

Abdelrahman, H., R. Zaghloul, H. Abou-Aly, A.A. Ragab and M.M.K. Elmaghraby, 2021. Application of some organic farming methods to enhancement the growth and production of green onion. *J. Agric. Chem. Biotechnol.*, 12(4): 79-89.

Abdel-Salam, M. and A. Shams, 2012. Feldspar-K fertilization of potato (*Solanum tuberosum* L.) augmented by biofertilizer. *J. Agric. Environ. Sci.*, 12: 694-699.

Abou-el-Seoud, I.I. and A. Abdel-Megeed, 2012. Impact of rock materials and biofertilizations on P and K availability for maize (*Zea mays)* under calcareous soil conditions. *Saudi J. Biol. Sci.*, 19: 55-63.

Ali, A.M., M.Y.M. Awad, S.A. Hegab, A.M.A. El Gawad and M.A. Eissa, 2021. Effect of potassium solubilizing bacteria (Bacillus cereus) on growth and yield of potato. *J. Plant Nutr.*, 44: 411-420.

Brand-Williams, W., M.E. Cuvelier and C. Berset, 1995. Use of free radical method to evaluate antioxidant activity. *LWT Food Sci. Technol.*, 28: 25-30.

Brown, J.D. and O. Lilleland, 1946. Rapid determination of potassium and sodium in plant material and soil extracts by flame photometry. *Proc. Amer. Soc. Hortic. Sci.*, 48: 341-344.

Chapman, H.D. and P.F. Pratt, 1961. *Methods of Analysis for Soils, Plants and Waters*. Division of Agric. Sci., Univ. of California, Berkeley.Priced Publication 4034.

Chianese, S., A. Fenti, P. Iovino, D. Musmarra and S. Salvestrini, 2020. Sorption of organic pollutants by humic acids: A review. *Molecules*, 25: 918.

Dubois, M., K.A. Gilles, J.K. Hamilton, P.A. Rebers and F. Smith, 1956. Colorimetric method for determination of sugars and related substances. *Anal. Chem.*, 28: 350-356.

El-Sharkawy, G.A. and H.S. Abdel-Razzak, 2010. Response of cabbage plants (*Brassica oleracea* var. capitata L.) to fertilization with chicken manure, mineral nitrogen fertilizer and humic acid. *Alex. Sci. Exch. J.*, 31: 416-432.

FAO, 2022. *Food and Agriculture Organisation Yearbook.*

Farag, M.A., S.S. Taha, Z.A. El-Shrkawy, M.E. Abdelaziz and E. Boraeiy, 2019. Optimizing yam planting date and potassium fertilizer levels under Egyptian conditions. *Plant Arch.*, 19(2): 3087-3092.

Farheen, N., M.M. Iqbal, B. Fatima, M.R. Kashif and A. Maqshoof, 2018. Modeling the potassium requirements of potato crop for yield and quality optimization. *Asian J. Agric. Biol.*, 6: 169-180.

Guo, Q., D. Meng, X. Gao, X. Zhang and S. Wang, 2020. Appropriate nitrogen application enhances saponin synthesis and growth mediated by optimizing root nutrient uptake ability in *Panax notoginseng*. *Frontiers Plant Science*, 11: 595095.

Hemida, Kh.A., A.Z.A. Eloufey, M.A. Seif El-Yazal and M.M. Rady, 2017. Integrated effect of potassium humate and α-tocopherol applications on soil characteristics and performance of *Phaseolus vulgaris* plants grown on a saline soil. *Arch. Agron. Soil Sci.*, 63: 1556-1571.

John, M.K. 1970. Colorimetric determination of phosphorus in soil and plant materials with ascorbic acid. *Soil Sci.*, 109: 214-220.

Jones, J.R., B.J. Wolf and H.A. Mills, 1991. *Plant Analysis Handbook: A Practical Sampling, Preparation, Analysis and Interpretative Guide*. Micro Macro.

Labib, B.F., T.K. Ghadour, I.S. Rahim and M.M. Wahba, 2012. Effect of potassium bearing rock on the growth and quality of potato crop (*Solanum tuberosum*). *Int. J. Res. Manag.*, 108-119.

Lallawmkima, I., S. Singh and M. Sharma, 2018. Application of azotobacter, vesicular arbuscular mycorrhiza and phosphate solubilizing bacteria for potato cultivation in Central Plain Zone (Pb-3) of Punjab. *J. Environ. Biol.*, 39: 985-989.

Le, A.V., E.P. Sophie, H.N. Minh and D.R. Paul, 2018. Improving the vanillin-sulphuric acid method for quantifying total saponins. *Technologies*, 6: 84.

Li, J., Q. Yang, Z. Shi, Z. Zang and X. Liu, 2021. Effects of deficit irrigation and organic fertilizer on yield, saponin and disease incidence in *Panax notoginseng* under shaded conditions. *Agr. Water Manage.*, 256.

Meena, R.K., B.R. Maurya, J.P. Verma and V.S. Meena, 2023. Potassium solubilizing microorganisms: mechanism and their role in potassium solubilization. *Frontiers in Microbiology*, 14: 1123456.

Merwad, A.M.A., 2016. Efficiency of K-sulphate and K-feldspar combined with silicate dissolving bacteria on yield and nutrient uptake by maize plants. *Egypt. J. Soil Sci.*, 56: 249-259.

Naumann, M., M. Koch, H. Thiel, A. Gransee and E. Pawelzik, 2020. The importance of nutrient management for potato production Part II: plant nutrition and tuber quality. *Potato Res.*, 63: 121-137.

Pahalvi, H.N., L. Rafiya, S. Rashid, B. Nisar and A.N. Kamili, 2021. Chemical fertilizers and their impact on soil health. In: *Microbiota and Biofertilizers. Ecofriendly Tools for Reclamation of Degraded Soil Environs*. p. 1-20.

Saric, M., R. Kastroi, R. Curic, T. Cupina and I. Geric, 1967. *Chlorophyll determination*. Univ. Unoven Sadu Parktikum is Fizio logize Biljaka, Beagard, Hauncna, Anjiga.

Sattar, A., M. Naveed, M. Ali, Z.A. Zahir, S.M. Nadeem, M. Yaseen, V.S. Meena, M. Farooq, R. Singh and M. Rahman, 2019. Perspectives of potassium solubilizing microbes in sustainable food production systems. A review. *Appl. Soil Ecol.*, 133: 146-159.

Singleton, V.L. and J.A. Rossi, 1965. Colorimetry of total phenolics with phosphomolybdic - phosphtungstic acid reagents. *Amer. J. Enol. Vitic.*, 16: 144-158.

Suja, G., S. Sundaresan, K.S. John, J. Sreekumar and R.S. Misra, 2012. Higher yield, profit and soil quality from organic farming of elephant foot yam. *Agron. Sustain. Dev.*, 32: 755-764.

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