PROXIMATE ANALYSIS AND MINERAL PROFILE OF TARO (*Colocasia esculenta*) IN EMBU, KENYA †

[ANÁLISIS PROXIMAL Y PERFIL MINERAL DEL TARO (*Colocasia esculenta*) EN EMBU, KENIA]

Anne N. Karuma[1], Joyce Wambui Njuguna[1*], Patrick Gicheru[2] and Fabian Kaburu[3]

[1]Department of Land Resource Management and Agricultural Technology, University of Nairobi. P.O BOX 29053 - 00625, Nairobi, Kenya.
[2]Kenya Agricultural and Livestock Research Organization - Embu Research Centre, P.O BOX 27 - 60100, Embu, Kenya.
*[3]Kenya Agricultural and Livestock Research Organization - Kabete, P.O BOX 14733 – 00800, Nairobi, Kenya. Email: *joycenjuguna20@gmail.com*
**Corresponding author*

SUMMARY

Background. Taro (*Colocasia esculenta*) is one of the underutilized crops in Kenya, grown under a wide range of environmental and edaphic conditions. This crop has exceptional dietary value and numerous culinary applications due to its edible leaves and corms. However, the mineral nutrient composition of taro in Kenya is still not well known due to a lack of scientific information concerning production. **Objective.** To determine the proximate composition and mineral profile of taro under different watering regimes and planting densities in Embu, Kenya. **Methodology.** A study was conducted at the Kenya Agricultural and Livestock Research Organization (KALRO) – Embu Research Centre, during the long rains (LR) 2021, and short rains (SR) 2021/2022. A factorial experiment with a split-plot layout arranged in a completely randomized block design was adopted. The watering regimes (100 %, 60 %, and 30 % based on the field capacity (FC)) were the main factor while the sub-factor was the planting density, with three replications. The planting densities used were 0.5 m × 0.5 m (40,000 plants ha^{-1}), 1 m × 0.5 m (20,000 plants ha^{-1}), and 1 m × 1 m (10,000 plants ha^{-1}), representative of high, medium, and low planting densities respectively. Proximate analysis and mineral content were determined. **Results.** Significant differences ($P < 0.05$) in seasons were noted for protein, fibre, potassium, calcium, sodium, and zinc in the taro corms. The high carbohydrate content observed in this study (35 – 39 %) indicates that taro tubers are a good source of nutritional energy. Potassium (> 5000 mg kg^{-1}) and magnesium (> 1000 mg kg^{-1}) were the most prevalent mineral elements in taro corms and leaves, with copper (< 25 mg kg^{-1}) being the least prevalent. **Implications.** Consumption of nutrient-rich foods such as taro helps the body to utilize the necessary nutrients to combat malnutrition and promote food security in rural communities. **Conclusion.** Taro leaves can be recommended as leafy vegetables as they are good sources of potassium, magnesium, calcium, manganese, iron, copper, and zinc; and the corms have low fat and protein content, high calorific energy, and high carbohydrate content. Taro represents one of the main sources of energy in many parts of the tropics and its production can be recommended in sub-humid areas in Kenya.

Key words: Taro; nutrition; mineral composition; proximate analysis.

RESUMEN

Antecedentes. El taro (*Colocasia esculenta*) es uno de los cultivos infrautilizados en Kenia y se cultiva en una amplia gama de condiciones ambientales y edáficas. Este cultivo tiene un valor dietético excepcional y numerosas aplicaciones culinarias debido a sus hojas y bulbos comestibles. Sin embargo, la composición de nutrientes minerales del taro en Kenia aún no se conoce bien debido a la falta de información científica sobre su producción. **Objetivo**. Determinar la composición proximal y el perfil mineral del taro bajo diferentes regímenes de riego y densidades de siembra en Embu, Kenia. **Metodología.** Se realizó un estudio en la Organización de Investigación Agrícola y Ganadera de Kenia (KALRO) - Centro de Investigación de Embu, durante las lluvias largas (LR) de 2021 y las lluvias cortas (SR) de

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ORCID = Anne N. Karuma: http://orcid.org/0000-0002-4497-2173**; Joyce Wambui Njuguna:** http://orcid.org/0000-0002-6583-6058**; Patrick Gicheru:** http://orcid.org/0000-0002-6115-0155

2021/2022. Se adoptó un experimento factorial con un diseño de parcelas divididas dispuestas en un diseño de bloques completamente al azar. Los regímenes de riego (100 %, 60 % y 30 % en base a la capacidad de campo (FC)) fueron el factor principal mientras que el subfactor fue la densidad de siembra, con tres repeticiones. Las densidades de siembra utilizadas fueron 0.5 m × 0.5 m (40.000 plantas ha^{-1}), 1 m × 0.5 m (20.000 plantas ha^{-1}) y 1 m × 1 m (10.000 plantas ha^{-1}), representativas de condiciones altas, medias y altas. y bajas densidades de siembra respectivamente. Se realizó análisis proximal y análisis de contenido mineral. **Resultados.** Se observaron diferencias (P <0.05) según las estaciones para la proteína, fibra, potasio, calcio, sodio y zinc en los cormos de taro. El alto contenido de carbohidratos observado en este estudio (35 – 39 %) indica que los tubérculos de taro son una buena fuente de energía nutricional. El potasio (> 5000 mg kg^{-1}) y el magnesio (> 1000 mg kg^{-1}) fueron los elementos minerales más prevalentes en los cormos y las hojas de taro, siendo el cobre (< 25 mg kg^{-1}) el menos prevalente. **Implicaciones**. El consumo de alimentos ricos en nutrientes como el taro ayuda al cuerpo a utilizar los nutrientes necesarios para combatir la desnutrición y promover la seguridad alimentaria en las comunidades rurales. **Conclusión**. Las hojas de taro se pueden recomendar como verdura de hoja, ya que son buenas fuentes de potasio, magnesio, calcio, manganeso, hierro, cobre y zinc; y los bulbos tienen bajo contenido de grasas y proteínas, alto contenido de energía calórica y alto contenido de carbohidratos. El taro representa una de las principales fuentes de energía en muchas partes de los trópicos y su producción puede recomendarse en zonas subhúmedas de Kenia.

Palabras clave: Taro; nutrición; composición mineral; Análisis proximal.

INTRODUCTION

One of Kenya's underutilized root crops is taro (*Colocasia esculenta*), which subsistence farmers, largely women, grow for its nutritious leaves and fleshy corms (Ngetich *et al.*, 2015). The leaves and corms are rich sources of carbohydrates. They aid in digestion, are gluten-free, fat-free, and low in calories. Thiamin, riboflavin, iron, phosphorus, zinc, vitamin B6, vitamin C, niacin, potassium, copper, and manganese are just a few of the vitamins and minerals that the leaves are rich in (Enwelu *et al.*, 2014; Palapala and Akwee, 2016). On a dry-weight basis, the young leaves have a high protein content of roughly 23 % (Tumuhimbise *et al.*, 2009). Additionally, the leaves are dried and ground into a powder that can be used with wheat flour or as a food flavour. Since the leaves and corms contain high calcium oxalate content, they cannot be consumed directly, therefore, properly cooking them eliminates calcium oxalate, the acridity-causing component (Verma *et al.*, 2023). In East Africa, the corms have traditionally been steamed and eaten as a snack alongside tea or a beverage (Akwee *et al.*, 2015; Chivenge *et al.*, 2015; Palapala and Akwee, 2016). Most root crops are regarded as excellent energy providers due to their high starch content, but they are marginal to poor protein suppliers (Huang *et al.*, 2007). The taro root contains many complex carbohydrates and is a good source of starch. Taro starch is also good for patients with peptic ulcer, pancreatic cancer, chronic liver problems, inflammatory bowel disease, and gall bladder disease (Enwelu *et al.*, 2014; Buke and Gidago, 2016).

Taro also serves as a buffer crop when other staple foods are in low supply (Ngetich *et al.*, 2015). In Kenya, it is mainly grown in riverbeds and is commonly referred to as *nduma*. However, riverbeds are already a scarce resource in the face of climate change, particularly during periods of water scarcity (AECOM, 2021). Taro can be cultivated on moisture beds that are lined with a polyethylene sheet in upland farming to prevent water loss through its percolation into the soil (Oxfarm, 2021). Water must be available constantly throughout the growing season to avoid water stress, which can result in the formation of malformed and poor-quality corms (Sibiya, 2015; Ansah, 2016). Taro's role in ensuring food security, earning money as a cash crop, promoting rural development, and improving livelihoods cannot be underscored (Temesgen and Retta, 2015). However, little attention has been given to its production in Kenya. In addition to taro corms, taro leaves can also be promoted as leafy vegetable alternatives in Kenyan communities. There has been an increase in nutritional studies of leafy vegetables in Africa, emphasizing indigenous species and neglected species (Azubuike *et al.*, 2018) to increase food security and improve livelihoods. However, taro leaves consumption in Kenya is not common compared to the corms, and therefore offers the potential to contribute to human nutrition. In addition to human consumption, taro leaves, petioles (stems), and corms have been used as by-product feeds for pigs in some Asia nations (Toan and Preston, 2010), further stressing the importance of the taro crop as whole.

When considering a crop as a food source, the nutritional content is paramount. Consumers place a high value on the nutritional value of food, hence there is a tremendous need for information on the nutritional contents of root crops (Temesgen and Retta, 2015). Nutritionally, the proximate composition of taro is rich in carbohydrates and minerals. However, its composition varies depending on the variety, growing condition, country of origin, soil type, moisture, fertilizer application, maturity at harvest, post-harvest handling, and storage (Huang *et al.*, 2007; Alcantara, 2013; Alam *et al.,* 2019). Taro contains thiamin, riboflavin, iron, phosphorus, zinc, potassium, copper, manganese, and vitamins, which aid the immune system and the human body in resisting illnesses (Huang *et al*., 2007; Soudy *et al*., 2016). Taro is higher in calcium, magnesium, and potassium than other tuber crops. Its leaves also have high levels of zinc, copper, manganese, and iron (USDA, 2018). Despite its importance and potential for addressing nutrient deficiencies, most taro evaluation studies have focused on agronomic factors such as growth, development, and yield (Gerrano *et al.,* 2021). Taro's chemical composition in Kenya still suffers from a lack of scientific information concerning water regimes, planting densities, and their influence on the mineral composition. Agronomic knowledge of taro is mostly derived from outside Kenya with limited studies done locally. The objective of this study is to analyse the approximate composition and mineral profile of taro under different irrigation regimes and planting densities in Embu, Kenya.

MATERIALS AND METHODS

Study Site Description

The research was carried out at the Kenya Agricultural and Livestock Research Organization (KALRO) – Embu Research Centre for two growing seasons: long rains (LR) 2021 (March 2021 - August 2021), and short rains (SR) 2021/2022 (September 2021 – February 2022). Embu County is situated between latitudes 0° 8’ and 0° 50’ South and longitudes 37° 3’ and 37° 9’ East (Kangai *et al.,* 2021) (Figure 1). The Research Centre receives 1250 mm of annual rainfall in two rainy seasons, as shown in Figure 2, namely, March to May (long rainy season) and October to December (short rainy season). The temperature ranges from 12 °C in July to 30 °C in March and September, with a mean temperature of 21 °C. The soils are mostly clay, deep, well-drained, and have a strong structure (Kisaka *et al.,* 2015; Embu County Government, 2019).

Table 1 displays the chemical characteristics of the soil. According to the IUSS Working Group WRB (2015) classification, the soils are classified as Eutric Nitisols. The composite soil samples were analyzed using standard methods as described in Okalebo *et al.* (2002). Soil samples were collected at the beginning of the experiment, long rains (LR) 2021 (baseline) and after the final harvest (SR 2021/2022). Several disturbed subsamples were taken using a soil auger at various positions in a zig-zag pattern to ensure homogeneity throughout the experimental plot area. The sub-samples were then thoroughly mixed in a bucket to form a composite sample, which was then sealed in a zip-lock bag. After drying, the samples were packed in a container and sent to the laboratory for determination of soil texture and chemical analysis. Undisturbed soil samples were collected using core rings and sent to the laboratory for saturated hydraulic conductivity testing.

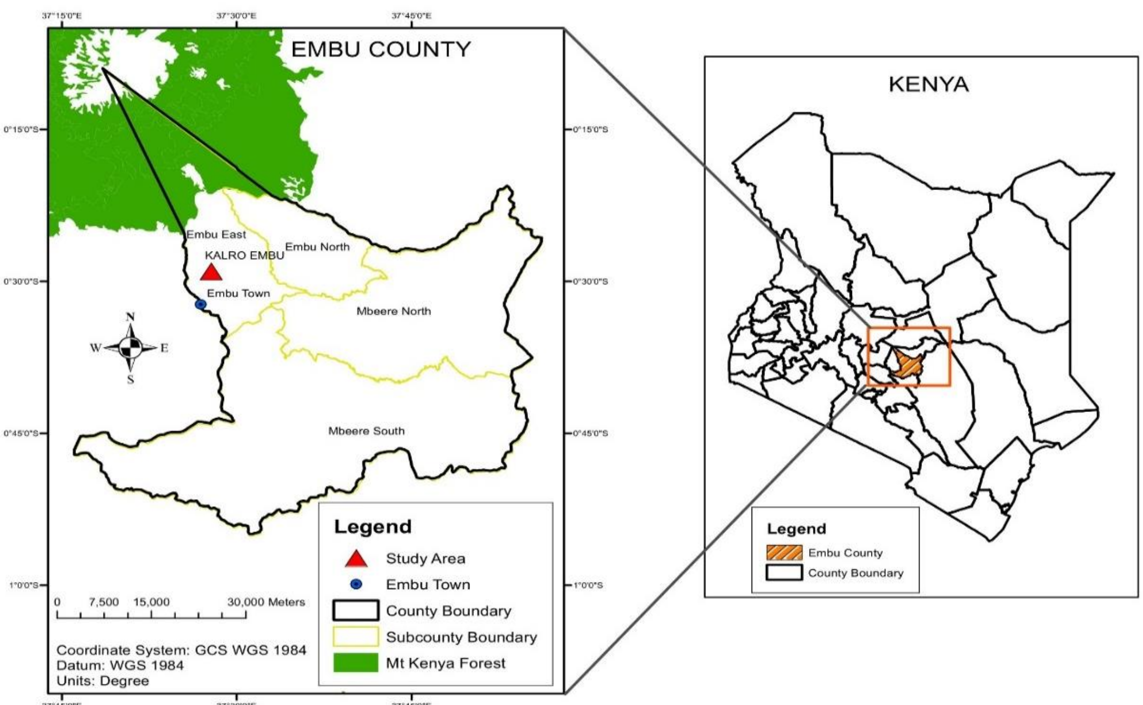

Figure 1. Location of the Study Site, KALRO – Embu, Kenya (Generated from ArcGIS).

The soil textural class is clay; the saturated hydraulic conductivity (Ksat) is 13.36 cm hr^{-1}; bulk density is 1.06 g/cm^{-3}, permanent wilting point is 16 %; and the field capacity is 37.8 %. Potassium is high (624 mg kg $^{-1}$), phosphorous is moderate (50.75 mg kg $^{-1}$) and total nitrogen is very low (0.09 %), all of which are important for crop growth (Msanya *et al.*, 2001). The soil has a pH of 5.12, slightly acidic, which is ideal for the growth of taro (Onwueme, 1999) (Table 2). Using the Soil Water Characteristics Hydraulic Properties Calculator (https://hrsl.ba.ars.usda.gov/soilwater/Index.htm), the soil texture analysis was used to calculate the field capacity (FC), and permanent wilting point (PWP). The irrigation water used for watering taro was analyzed to establish its quality for growth (Table 2). It was analyzed for electrical conductivity (EC), fluorides, pH, sulphates, magnesium (Mg^{2+}), calcium (Ca^{2+}), sodium (Na^{+}), alkalinity, potassium (K^{+}), and chlorides (Katerji *et al.,* 2003). The quality of the irrigation water meets the standards for irrigation water (Ayers and Westcot, 1994; Republic of Kenya, 2006).

Experimental Design

A factorial experiment with a split-plot layout arranged in a completely randomized block design was used. The main factor was the watering regimes while the sub-factor was the planting density, with three replications. The three irrigation levels were at 100 %, 60 %, and 30 % based on the field capacity (FC). The planting densities used were 0.5 m × 0.5 m (40,000 plants ha $^{-1}$), 1 m × 0.5 m (20,000 plants ha $^{-1}$), and 1 m × 1 m (10,000 plants ha $^{-1}$), representative of high, medium, and low planting densities respectively. The growing season was considered an experimental factor to test the changes within and across the growing seasons.

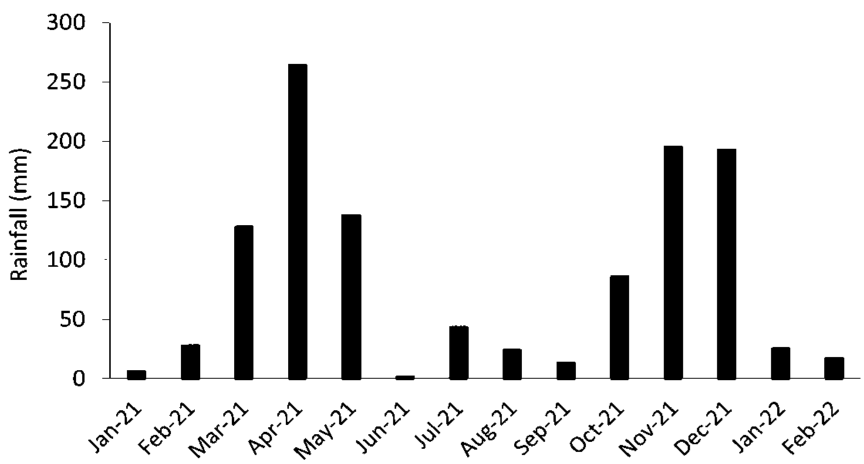

Figure 2. Monthly rainfall averages during the two growing seasons (LR 2021 and SR 2021/2022) of taro (*Colocasia esculenta*) at KALRO, Embu.

Table 1. Soil chemical properties of the experimental site (0 - 30 cm) at KALRO Embu, Kenya.

Chemical Properties	K	Mg	Mn	Ca	Zn	Na	P	pH	Org. C	Total N
	(mg kg $^{-1}$)								(%)	
Baseline	624.0	154.8	143.50	700.0	51.70	26.45	50.75	5.12	2.10	0.09
Post- Harvest	207.65	70.95	130.10	443.6	48.65	22.0	30.5	5.71	2.84	0.35

Table 2. Irrigation water chemical analysis in the experimental site at KALRO Embu, Kenya.

Parameter	Value	Parameter	Value
pH	6.8	Alkalinity (mg L^{-1})	13
EC (uS cm $^{-1}$)	400	Calcium (mg L^{-1})	0.89
Sodium (mg L^{-1})	14.7	Chlorides (mg L^{-1})	30.96
Magnesium (mg L^{-1})	2.3	Sulphates (mg L^{-1})	6.15
Potassium (mg L^{-1})	4.52	Flouride (mg L^{-1})	0.40

Planting Material

Taro basal stems were sourced from farmers' fields in Kirinyaga County. The planting materials were collected as apical 1-2 cm of the corm with basal 15-20 cm of the petioles attached. The common landrace and commercially preferred and available was the *Dasheen* variety, characterized by one large cylindrical main corm and preferred by the farmers in the region.

Moisture bed preparation and Irrigation

Each plot was 4 m × 4 m separated by 2 m wide spacing, dug to a 0.5 m depth, and lined with a 1000-gauge double-folded black polythene sheet to create a moisture bed. The polythene sheet prevented lateral water movement between plots and seepage. Manure was added to the dug-out soil from each plot in a 2:1 ratio before being added back to each plot (the moisture bed) leaving a depression of about 10 cm (Njuguna *et al.,* 2023a). The drip system consisted of a 5000 litres tank, a water filter, a water metre, a ball valve, nine valves, nine T-joins, button drippers, start connectors, PVC pipes, L-bows, drips lines, end lines, and end caps. The tank was raised to 1.5 metres and supplied water to the crop. The system also consisted of a one-inch diameter disk filter. This filter is effective for water-laden with debris, and it does not allow any particles or debris to pass through. Water was then supplied to the crop through a one-inch diameter mainline, which was connected to a sub-main line, which was further connected to the drip lines within the plots. Button drippers/emitters on the drip lines supplied water to the individual plants. The end caps were fixed to terminate the water flow. The drip line spacing was dependent on the different plant spacings in each plot. The emitter discharge was 5.6 L/hr.

Irrigation Scheduling

Irrigation scheduling was determined using the soil moisture depletion technique (AgriInfo, 2018; Dong, 2023). This technique is more site-specific than the climatic parameter technique, which is generalized and widely variable. For the first two months of the trial, all treatments were irrigated to field capacity to ensure good crop establishment. Thereafter, the watering regime treatments were applied. To ensure water availability during the day's peak demand periods, irrigation was carried out three times every week, in the mornings. The irrigation schedule for the 100 % FC, 60 % FC, and 30 % FC watering regimes were 22 minutes, 13 minutes, and 6 minutes respectively. After 24 hours, skipping a day, the irrigation water was applied. The average total amount of water used for each irrigation regime was 2000 litres (30 % FC), 4000 litres (60 % FC), and 8000 litres (100 % FC), and this was determined using a water metre (Njuguna *et al.,* 2023b).

Determination of proximate analysis and mineral nutrient profile

A subsample of about 1 kg was taken from each plot yield and analyzed for the proximate and mineral nutrient analysis. The recommended methods of the Association of Official Analytical Chemists (AOAC, 2006) were used for the determination of moisture, ash, fat, fibre, and nitrogen contents in the taro corm samples. Protein was obtained by determining the organic nitrogen content using the micro Kjeldahl method (AOAC, 2006) and multiplying the nitrogen by a protein conversion factor of 6.25. The carbohydrate was determined using estimation by difference. The taro leaves, stems, and corms mineral nutrients (calcium, magnesium, copper, manganese, iron, sodium, potassium, and zinc) in homogenized samples were determined using an atomic absorption spectrophotometer (AA-6200 Shimadzu Corp.). Each leaf, stem, and corm sample were analyzed in triplicate.

Statistical Analysis

The proximate analysis of taro corm data collected was subjected to a split-plot analysis of variance (ANOVA) using the GenStat statistical software. Mean separation was done using Fisher's LSD at a 5 % level of probability where significant *F*-values were significant.

RESULTS AND DISCUSSION

The mineral nutritional profile of taro leaves under varying watering regimes

The mineral element potassium (K) was the most prevalent in the taro leaves, and its predominance was seen under the 100 % FC watering regime (Figure 3). This shows that saturated conditions favoured the abundance of potassium, and similar trends were observed for zinc and iron. Taro leaves have been reported to be abundant sources of K (Temesgen and Retta, 2015; Azubuike *et al.,* 2018; Beato *et al.,* 2024). Low K consumption has been linked to several clinical and experimental studies, and the development of several chronic disorders, including hypertension or high blood pressure, an increased risk of cardiovascular disease, renal disease, and bone demineralization. To increase K intake and decrease the incidence of disorders connected with malnutrition relative to K intake, the consumption of vegetables rich in K is advised (Cruz *et al.,* 2018). According to Özenç *et al.* (2014), people need 4700 mg of potassium per day; hence potassium in taro leaves used in this study (16,099 mg kg $^{-1}$) meets this requirement.

Magnesium (Mg) values ranged around 1799 mg kg $^{-1}$ indicating taro leaves are rich sources of magnesium, with the intermediate moisture regime (60 % FC) having the highest Mg values (Figure 3). Mg is a mineral element that is a part of bones and teeth and serves as an enzyme indicator, thus, taro leaves' high magnesium content highlights their significance in the human diet (Azubuike *et al.*, 2018). According to Özenç *et al.* (2014), adults should consume 400 mg of magnesium daily.

Calcium (Ca) was the third abundant mineral element in the taro leaves with an average value of 1678.2 mg kg $^{-1}$. Calcium is important for healthy bone structure. The recommended dietary allowance (RDA) for calcium in adults is 1000 mg day $^{-1}$ (Duruibe *et al.*, 2007). Proper Ca intake is essential for overall human health. Insufficient calcium can lead to rickets in children and osteoporosis in adults (Azubuike *et al.*, 2018). Across the various watering schedules for the two seasons, manganese readings were at an average of 1264.27 mg kg $^{-1}$. The mineral manganese (Mn) is necessary for intracellular processes. Its deficit is unusual, and it is essential for growth, digestion, reproduction, the creation of energy, and the immune system (Chen *et al.*, 2018). Mn is a mineral that the human body requires in trace levels, hence the recommended dietary allowance for manganese is 2.3 mg day $^{-1}$ (Özenç *et al.*, 2014).

Iron (Fe) abundance in taro leaves in this study ranged from 758.35 mg kg $^{-1}$, 690.4 mg kg $^{-1}$, and 762.1 mg kg $^{-1}$ for the 30 % FC, 60 % FC, and 100 % FC watering regimes, respectively (Figure 3). Fe absorption in the human body can be improved by eating foods high in vitamin C (Clifford *et al.*, 2015). According to Temesgen and Retta, (2015), taro corms and leaves are rich sources of vitamin C, which aids in the absorption of iron. Özenç *et al.* (2014) recommend a daily intake of 8 mg. Leafy vegetables can help prevent or control hypertension, lowering the risk of stroke and heart disease (Amagloh and Nyarko, 2012). Taro leaves have low sodium levels (732 mg kg $^{-1}$ on average), affirming this finding. The recommended dietary allowance for sodium per day is 1500 mg (Koubová *et al.*, 2018).

In this study, zinc (Zn) concentrations in taro leaves varied depending on the watering regimes: 210.4 mg kg $^{-1}$, 208.8 mg kg $^{-1}$, and 213.8 mg kg $^{-1}$ for the 30 %, 60 %, and 100 % field capacities, respectively. Zn is a crucial micronutrient for growth, immunity, and enzyme function, and its continuous dietary intake is necessary for these activities (Sangeetha *et al.*, 2022). The usage of taro leaves should be encouraged since they are one of the few non-animal sources of zinc. Zinc deficiency is associated with child stunting and the recommended daily intake of zinc is 11 mg per kilogram (Koubová *et al.*, 2018).

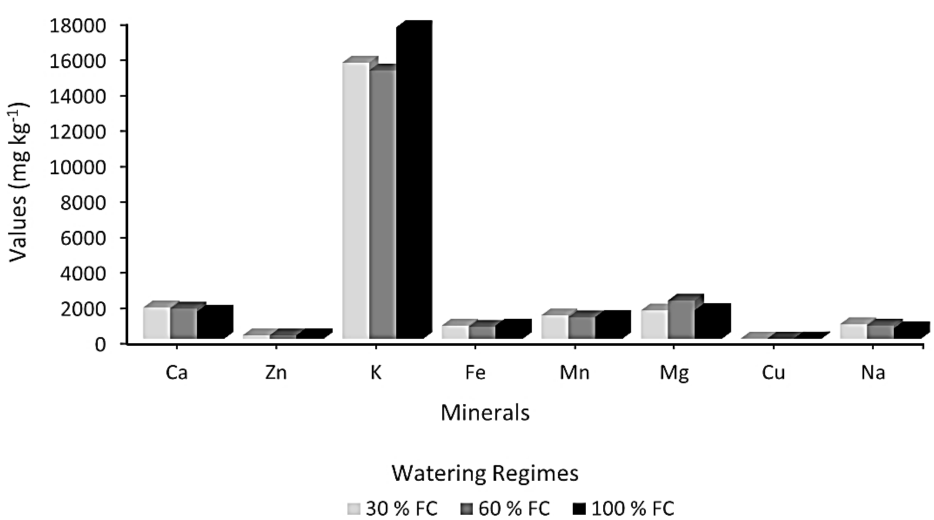

Figure 3. Mineral composition of taro (*Colocasia esculenta*) leaves, pooled from the LR 2021 and SR 2021/2022 growing season averages, under varying watering regimes at KALRO Embu.

Copper (Cu) was the least abundant mineral element in the taro leaves with values of < 30 mg kg $^{-1}$. It is essential for various processes in the human body, including the formation of connective tissues and blood vessels, the maintenance of the neurological and immunological systems, and brain growth (NIH, 2022). However, excessive amounts of Cu are toxic, and therefore the recommended dietary allowance is 3.5 mg kg^{-1} (Chove *et al.,* 2006).

The mineral nutritional profile of taro stems and their use as an animal feed

The prevalence of mineral elements in taro stems as represented in Table 3 below, is similar to that seen with taro leaves with potassium being the most abundant mineral element and copper being the least abundant. The calcium and iron content of taro recorded in this study (Table 3) is higher than values for calcium (490 mg kg $^{-1}$) and iron (9 mg kg $^{-1}$) documented in FAO, (2003) in East Asia and the mineral differences can be attributed to the variety, growing condition, soil type, moisture, maturity at harvest, and post-harvest handling (Alam *et al.,* 2019).

Taro by-products have been utilized for animal consumption and offers a lot of potential as animal feed particularly as a staple diet for pigs in the tropics and subtropics (Toan and Preston, 2010). Taro cultivation by-products include leaves, petioles, and corm peels. These by-products are good energy sources for livestock, and with proper preservation procedures, they could be beneficial to the livestock farming community and ease the burden of food competition between humans and animals (Lan *et al.,* 2021). In Cambodia, Chinese taro variety petioles are harvested, cooked, and consumed by locals, while wild taro variety petioles are used as pig feeds after cooking, but never used for human consumption because they are poisonous and allergic (Buntha *et al.,* 2008b).

Animal feed made from taro leaves, stems/petioles/leaf stalks, and corms are utilized occasionally, with most studies focusing on taro leaves (Buntha *et al.,* 2008a; Temesgen, 2017; Toan and Preston, 2010). The leaves, petioles, and corms, however, are problematic due to the presence of calcium oxalate hence viewed as being unfit for direct use as animal feed (Toan and Preston, 2010). The acridity issue is to blame for this restricted use because it makes the taro unusable without expensive, time-consuming processing (FAO, 2003). This can be greatly reduced through various processes including high-temperature exposure or fermentation during ensiling (Valverde Lucio *et al.,* 2023).

According to a study by Hang *et al.* (2013) in Vietnam, processing taro petioles and leaves by soaking them in water or cooking them can dramatically reduce the soluble oxalate content, producing a processed product with only modest levels. The authors further recommended taro leaves and petioles as vegetables in the diet when mixed with other food components, however, further research was suggested. So far, most research on taro has been focused on its tuber production, and there are very few reports on the plants leaf production, and their chemical composition. Further, information on the consumption of *Colocasia esculenta* petioles is lacking and therefore further investigations are required to identify the optimum mineral constituents and their appropriate use for animal or human consumption.

The mineral nutrient profile of taro corms as influenced by the cropping season, watering regimes and planting density

Table 4 shows significant ($P < 0.001$) differences in potassium levels between seasons. The highest value (5427.8 mg kg $^{-1}$) was recorded with the intermediate watering regime (60 % FC), with a trend of 60 % FC > 100 % FC > 30 % FC. Table 4 shows that the highest potassium values (5207 mg kg $^{-1}$) were recorded with a 1 m × 0.5 m plant density, with the lowest density (1 m × 1 m) recording the lowest (5155 mg kg $^{-1}$). Potassium was the most abundant nutritional element, with values of < 4,500 mg kg $^{-1}$.

Previous studies also found potassium to be the most prevalent mineral element in taro corms (Alcantara, 2013; Mulugeta and Tebeka, 2017; Gerrano *et al.,* 2021). According to the International Potash Institute, (2013), increasing potassium consumption may help regulate blood pressure, and eating more potassium-rich foods would probably be helpful for most children. Higher potassium intake also reduces the negative effects of sodium on blood pressure (Azubuike *et al.,* 2018).

Table 3. Mineral composition of taro (*Colocasia esculenta*) stems/petioles, pooled from the LR 2021 and SR 2021/2022 growing seasons.

Ca	Zn	K	Fe	Mn	Mg	Cu	Na
mg kg $^{-1}$							
1575.25	182.2	14645.79	733.06	1189.82	1627.57	22.83	671.25

Magnesium was the second most abundant mineral constituent in taro corms in this study. The SR 2021/2022 season recorded higher magnesium values (1120.7 mg kg $^{-1}$) though no significant differences were recorded (Table 4). The watering regime followed a trend of 60 % FC > 30 % FC > 100 % FC while the plant density had a trend of 1 m × 1 m > 1 m × 0.5 m > 0.5 m × 0.5 m. Magnesium is essential for numerous physiological functions (Fiorentini *et al.*, 2021), and aids in the functioning of nucleic acids (Gröber *et al.*, 2015). Magnesium values recorded under the different watering regimes and plant density were < 950 mg kg $^{-1}$, enough to meet its recommended dietary allowance (400 mg day $^{-1}$) (Özenç *et al.*, 2014).

Table 4 shows that the first season (LR 2021) had the highest calcium value (123.8 mg kg $^{-1}$) compared to the second (SR 2021/2022) (64.7 mg kg $^{-1}$), and the lowest watering regime (30 % FC) and medium plant density (1 m × 0.5 m) recorded the highest calcium values of 113.1 mg kg $^{-1}$ and 118.3 mg kg $^{-1}$ respectively. Saturated conditions (100 % FC) and low density (1 m × 1 m) had the lowest calcium content (< 83 mg kg $^{-1}$). Calcium values recorded in this study were slightly lower than those observed by Gerrano *et al.* (2021), but were within the recommended rates (Temesgen and Retta, 2015). Calcium in the human body is essential for the formation of bones and teeth, as well as blood clotting, and its deficiency would result in osteoporosis in adults and the development of rickets in children (Azubuike *et al.*, 2018). Duruibe *et al.* (2007) noted that the recommended dietary allowance for calcium is 1000 mg day $^{-1}$ and this shows that taro corms are not a rich source of calcium, hence augmenting by either increasing consumption or complementing with other sources is recommended.

The LR 2021 season had significantly higher sodium values (277.9 mg kg $^{-1}$) in comparison to the SR 2021/2022 season (214.3 mg kg $^{-1}$) ($P = 0.017$). The intermediate watering regime (60 % FC) (265.9 mg kg $^{-1}$) and the medium plant density (1 m × 0.5 m) (278.6 mg kg $^{-1}$) recorded the highest sodium values (Table 4), similar to potassium and calcium. According to Strazzullo and Leclerrcq (2014), sodium is a crucial mineral needed in small doses to regulate blood pressure and ensure proper nerve and muscle function. However, excessive sodium intake is linked to high blood pressure (World Health Organization, 2012). The corms have sodium values below the daily allowance (1500 mg) (Koubová *et al.*, 2018), indicating low sodium content.

Manganese (31.5 mg kg $^{-1}$) and iron (74.8 mg kg $^{-1}$) were abundant in the SR 2021/2022 season in comparison to the LR 2021, meaning that lower rainfall amounts, hence lower soil moisture, recorded in SR 2021/2022 season (Figure 2) favoured their abundance. Manganese had significant interactions between season and watering regime ($P = 0.031$) and season and plant density ($P = 0.026$), with iron recording no significant differences (Table 4). Manganese and iron are both trace elements required for proper body functioning. Manganese is necessary for appropriate protein, carbohydrate, and lipid metabolism as well as the activation of essential enzyme systems, while iron is required by the body for the formation of oxygen-carrying protein molecules in red blood cells, haemoglobin (Mergedus *et al.*, 2015; Gerrano *et al.*, 2021). Iron deficiency is a common nutritional problem around the world, leading to anaemia (Wimbley and Graham, 2011).

In terms of zinc, there were significant differences between growth seasons ($P < 0.001$), with the LR 2021 having a greater concentration (18.9 mg kg $^{-1}$). The medium density (1 m × 0.5 m) and the 100 % FC watering regime had higher zinc concentrations of 17.3 mg kg $^{-1}$ (Table 4). Zinc is essential for healthy human growth and development, contributing to the creation of proteins, enzymes, hormones, and other elements that support physical and mental development. It is necessary for healthy insulin action, immune system function, tissue repair and wound healing, reproduction, vision, and taste. Zinc deficiency can impair growth and development (Mergedus *et al.*, 2015; Azubuike *et al.*, 2018). Copper was the least prevalent mineral (< 4.2 mg kg $^{-1}$) with no significant differences identified (Table 4). Copper is a component of numerous enzymes and is linked to bone growth and formation, iron uptake and utilization (Araya *et al.*, 2007). The recommended dietary allowance for copper is 3.5 mg kg $^{-1}$, and exceeding this amount can result in Wilson's disease (Azubuike *et al.*, 2018).

The proximate analysis of taro corms as influenced by cropping season, watering regimes, and planting density

Moisture (%)

No significant differences were noted in the moisture content between the seasons, watering regimes and planting density (Table 5). The first season (LR 2021) recorded a higher value of moisture content (58.33 %) compared to the second season (SR 2021/2022) (58.0 %). The lowest watering regime (30 % FC) and the medium plant density (1 m × 0.5 m) recorded the highest moisture content, both with values of 58.6 %. The watering regime followed a trend of 30 % FC > 60 % FC > 100 % FC while the plant density had a trend of 1 m × 0.5 m > 1 m × 1 m > 0.5 m × 0.5 m.

Table 4. The mineral profile (Potassium, Calcium, Sodium, Magnesium, Manganese, Iron, Zinc, and Copper contents) of the taro corms as affected by the season, watering regime and planting density in Embu, Kenya.

	Potassium	**Calcium**	**Sodium**	**Magnesium**	**Manganese**	**Iron**	**Zinc**	**Copper**
				mg kg $^{-1}$				
Season								
LR 2021	5857.3	123.8	277.9	1075.9	27.1	58.7	18.9	4.0
SR 2021/2022	4508.0	64.7	214.3	1120.7	31.5	74.8	13.4	4.0
Watering Regime (WR)								
100 % FC	5128.4	82.2	252.0	1036.2	36.8	65.2	17.3	4.3
60 % FC	5427.8	87.5	265.9	1221.8	29.0	71.8	15.9	3.8
30 % FC	4991.8	113.1	220.5	1036.8	22.0	63.2	15.4	3.9
Planting Density (PD)								
1m × 1m	5155.0	79.2	243.7	1218.7	23.9	72.4	15.4	4.2
1m × 0.5m	5207.4	118.3	278.6	1108.8	31.7	71.0	17.3	3.9
0.5m × 0.5m	5185.6	85.4	216.1	967.3	32.3	56.8	15.8	3.9
Significant Levels								
Season	<0.001	0.049	0.017	0.764	0.192	0.100	<0.001	0.780
WR	0.492	0.701	0.381	0.190	0.306	0.661	0.127	0.814
PD	0.980	0.414	0.328	0.219	0.222	0.382	0.219	0.875
WR × PD	0.035	0.392	0.557	0.285	0.031	0.289	0.108	0.866
Season × WR	0.939	0.561	0.276	0.393	0.026	0.696	0.154	0.574
Season × PD	0.923	0.487	0.168	0.726	0.344	0.638	0.720	0.427
Season × WR × PD	0.773	0.601	0.647	0.879	0.143	0.838	0.538	0.730

Where, FC = Field Capacity, LR = Long Rains, SR = Short Rains, WR = Watering Regime, PD = Planting Density.

Table 5. Proximate analysis (moisture, fat, proteins, fibre, ash, carbohydrates, and energy levels) of the taro corms as affected by the season, watering regime, and planting density in Embu, Kenya (Fresh weight basis).

	Moisture (%)	Fat (%)	Proteins (%)	Fibre (%)	Ash (%)	Carbohydrates (%)	Energy (Kcal/100g)
Season							
LR 2021	58.33	0.491	2.54	1.573	1.204	35.81	157.9
SR 2021/2022	58.00	0.57	1.35	1.215	1.366	37.55	160.8
Watering Regime (WR)							
100 % FC	58.03	0.517[ab]	1.84	1.386	1.25	36.93	159.8
60 % FC	58.02	0.331[a]	1.98	1.542	1.264	36.89	158.4
30 % FC	58.60	0.744[b]	2.01	1.254	1.34	36.23	159.8
Planting Density (PD)							
1m × 1m	58.37	0.42	1.53	1.463	1.343	36.9	157.7
1m × 0.5m	58.60	0.578	2.12	1.449	1.272	35.98	157.8
0.5m*× 0.5m	57.52	0.593	2.17	1.27	1.24	37.16	162.6
Significant Levels							
Season	0.691	0.617	<0.001	0.014	0.065	0.077	0.405
WR	0.985	0.034	0.721	0.553	0.762	0.945	0.985
PD	0.741	0.221	0.089	0.576	0.777	0.666	0.632
WR × PD	0.594	0.011	0.391	0.666	0.781	0.67	0.490
Season × WR	0.334	0.959	0.975	0.742	0.693	0.392	0.267
Season × PD	0.622	0.948	0.422	0.783	0.192	0.651	0.789
Season × WR × PD	0.283	0.72	0.018	0.378	0.871	0.622	0.270

Where, FC = Field Capacity, LR = Long Rains, SR = Short Rains, WR = Watering Regime, PD = Planting Density, Different letters within columns indicate significant differences at a $p < 0.05$ probability level

The moisture content of taro corm in this study was lower (< 60 %) than in similar studies by Ndabikunze *et al.* (2011); Mulugeta and Tebeka, (2017); Temesgen, (2017); and Chandrakar *et al.* (2022) conducted in other regions (60 – 83 %). Taro is a root crop with a high moisture content that accounts for two-thirds of the total weight of fresh harvests (Onwueme, 1999) and its moisture content varies according to variety, growth environment, and harvest period (Huang *et al.*, 2007). A lower-than-normal taro moisture content, similar to those recorded in this study (< 60 %), can be attributed to the different environmental conditions and agronomic practices under which the taro plants were cultivated (Alam *et al.*, 2019). Controlling the moisture content helps in maintaining the quality and extending the shelf life of taro tubers. Furthermore, moisture content can result in a soft texture and reduced crispiness when cooked or processed (Boampong *et al.*, 2019; Ferdaus *et al.*, 2023). Moisture content plays a significant role in the proximate analysis of taro tubers. A lower moisture content (< 80 %) is helpful for transport and storage of corms at ambient temperatures (Wondimu Fufa *et al.*, 2021; Ferdaus *et al.*, 2023).

Fat (%)

The fat composition of taro corms varied significantly ($P = 0.034$) within the three different watering regimes, and there was a significant interaction ($P = 0.011$) between the watering regime and planting density (Table 5), meaning that the watering regimes influenced the fat content depending on the plant densities within the plots. In comparison to the 60 % FC (0.331 %) and the 100 % FC (0.517 %), the 30 % FC watering regime had the highest fat content (0.744 %). The plant density showed a trend of 0.5 m × 0.5 m > 1 m × 0.5 m > 1 m × 1 m. Similar to many other root and tuber crops, taro has a relatively low fat content that is primarily made of cell membrane lipids and varies between cultivars (Temesgen and Retta, 2015). A review on taro production by Alercia, (2013) showed that the taro root fat content usually ranges between 0.2 - 0.7 %. Due to the low-fat percentages found in this study, taro corms could be recommended for lipid-lowering and hypoglycemic diets as recommended by Koffi *et al.* (2020).

Protein (%)

The first season (LR 2021) had the highest protein content (2.54 %) compared to the second (1.35 %) ($P < 0.001$), similar to the moisture content. Its watering regime trend was similar to that of the moisture content while the planting density trend was similar to the fat content. A significant interaction ($P = 0.018$) was noted between season, watering regime, and planting density (Table 5), indicating that the season played a significant role in influencing the protein content under the different watering regimes and planting densities. The watering regime and planting density values observed had significant differences between the two seasons due to the higher rainfall recorded in the LR 2021 (99.9 mm) compared to the SR 2021/2022 season (88.4 mm) (Figure 2).

Taro samples have low protein samples ranging from 1.3 to 4.1 %. Therefore, it is advisable to use taro as a source of starch to obtain a purer carbohydrate (Sánchez Chino *et al.,* 2021). Huang *et al*. (2007) in Taiwan found upland taro (2.14 %) to have higher protein content compared to taro paddy cultivation (1.88 %), indicating its nutritional superiority. Chandrasekara and Kumar, (2016) and Temesgen, (2017) reported that taro root and rhizome contains more protein than other root crops due to the presence of soil, which repair and raise nitrogen levels in the corms and leaves. This makes taro a highly nutritious food source. However, because taro corms have low protein content, food products made from them should be improved by combining them with other high-protein sources for optimal nutritive value (Sefa-Dedeh and Agyir-Sackey, 2004). Taro leaves and stems have the potential to be animal feeds, notably for pigs, due to their high protein content (Setyawan *et al.*, 2021), however proximate analysis of taro leaves and stems was not done in this study.

Fibre (%)

Significant differences (*P = 0.014*) were noted between the two seasons, with the LR 2021 and SR 2021/2022 having values of 1.573 % and 1.215 % respectively (Table 5). The intermediate watering regime (60 % FC) had the highest fibre content (1.542 %), with a decreasing trend of 60 % FC > 100 % FC > 30 % FC. The lowest plant density recorded the highest fibre content (1.463 %) compared with the high (1.27 %) and medium (1.449 %) densities. In Cameroon and Chad, a study on six varieties of taro found that the fibre content of taro varied from 0.3 to 3.8 % (Onwueme, 1999).

Taro has been reported to have the highest dietary fibre content among tropical crops, and hence numerous food preparations have been made with taro (Ferdaus *et al.,* 2023). Specialty food preparations can prevent allergic conditions. According to Sefa-Dedeh and Agyir-Sackey, (2004), adding fibre from *Colocasia* species into ice cream sherbet efficiently stimulates the action of intestinal bifidobacteria for optimal digestion and vitamin synthesis. In addition to aiding glucose metabolism and nutrient delivery, fibre also reduces harmful dietary components like cholesterol, lowers postprandial blood sugar and insulin levels, prevents constipation, buffers excessive stomach acid, boosts food stability, and increases satiety (Njoku and Ohia, 2007; Temesgen and Retta, 2015).

Ash (%)

No significant differences were noted among all the parameters under analysis for ash (Table 5). The watering regime followed a trend similar to that seen under the protein content while the planting density recorded the highest value under the high plant density (1.343 %) and recorded a similar trend to that of fibre content. The ash contents found in this study were higher than those found in an upland taro study by Huang *et al.* (2007) in Taiwan and lower than dryland and wetland taro studies in Tanzania and Uganda by Ndabikunze *et al.* (2011). Differences in the ash content of taro corms are attributed to their species origin, soil fertility, geographical origin, or planting period (Huang *et al.*, 2007). The ash content in the corms helps to determine the amount and type of minerals in taro (Alam *et al.*, 2019).

Carbohydrates (%)

Similar to fat and ash content, the carbohydrates were highest in the second season (SR 2021/2022) (37.55 %), though no significant differences were recorded (Table 5). Saturated conditions (100 % FC) increased the carbohydrates in the taro corms (36.93 %) with the low moisture conditions having the opposite effect (36.23 %). High plant density recorded high values of carbohydrates (37.16 %), with a trend of 0.5 m × 0.5 m > 1 m × 1 m > 1 m × 0.5 m. The high amounts of carbohydrates observed in this study (35 – 39 %) correspond with a study by Onwueme, (1999) in Thailand that like other roots and tubers, the principal nutrient given by taro is nutritional energy delivered by carbohydrates (Rashmi *et al.*, 2018). This can be used to make a variety of food products with medicinal value, such as carbohydrate-based foods to lower the risk of allergy-related diseases (Ndabikunze, *et al.*, 2011). Taro contains more than twice the carbohydrate content of potatoes and a yield of 35 kcal per 100g (Temesgen and Retta, 2015). The high carbohydrate content in taro tubers makes them an excellent source of calories that are anti-marasmus, especially for baby nutrition (Messou *et al.,* 2018). Taro corms are excellent sources of carbohydrates for diabetics and persons with gastrointestinal problems (Soudy *et al.,* 2016).

Energy (Kcal 100g $^{-1}$)

The high calorific energy was recorded in the second season (SR 2021/2022) (160.8 Kcal 100g $^{-1}$), compared to the first season (LR 2021) (157.9 Kcal 100g $^{-1}$) with no recorded significant differences (Table 5). This could be attributed to differences in rainfall amounts between the two seasons (Figure 2). In terms of watering regimes, the highest values were recorded under the 100 % FC and 30 % FC (159.8 Kcal $100g^{-1}$), with the lowest values noted under the intermediate moisture conditions (158.4 Kcal $100g^{-1}$). The planting density followed a similar trend to that of carbohydrates. The energy value of foods is determined by their carbohydrate, fat, and protein contents (Afifah *et al.*, 2023). Values observed in this study were 50 % lower than Koffi *et al.* (2020) in Côte d'Ivoire due to the corresponding low values of carbohydrates, protein, and fat noted.

The influence of water and soil on the mineral nutritional profile of taro corms and leaves under varying planting densities and watering regimes

Plant mineral content is closely related to water quality, and high sodium concentration in irrigation water can limit mineral uptake from the soil (El-Sharkawi *et al.*, 2004; Akter and Oue, 2018). The quality of the irrigation water in this study met the standards for irrigation water and therefore no restrictions in the uptake of minerals as a result of water quality were expected (Table 2). Figure 4 shows the percentage reductions of the analyzed soil chemical parameters before planting (LR 2021) and after harvest (SR 2021/2022).

The growth and development of taro crops heavily rely on the soil condition, which impacts plant moisture and nutrient availability. This, in turn, influences plant physiology, biosynthesis, and assimilate portioning (Mwenye *et al.,* 2011; Mergedus *et al.*, 2015). Macro and micronutrients in the soil are essential for crop growth throughout the growing season. Reduction in the post-harvest chemical analysis is evidence of this fact (Figure 4). Macronutrients like nitrogen, phosphorous, and potassium, promote root and tuber crop yield and nutritional quality.

Mergedus *et al.* (2015) in Vanuatu observed higher potassium contents in the whole taro plant and the corm. This study further confirms that high potassium values in both taro leaves and corms result in a reduction in soil potassium concentration after harvest (Figure 4). This study also observed a reduction in soil mineral constituents such as phosphorus, magnesium, zinc, and manganese (Figure 4). Therefore, it suggests that soil fertility status significantly impacts the mineral constituents of taro leaves and corms. For taro plants to achieve optimal growth, high-quality leaves, and tubers, healthy and fertile soil are an absolute must. Successful taro production hinges on implementing effective soil management practices.

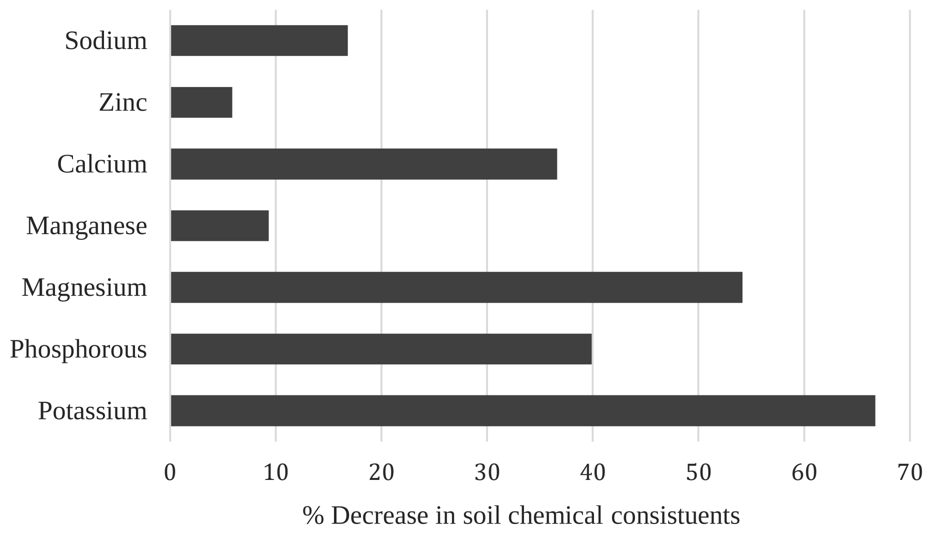

Figure 4. Decrease (%) in soil chemical properties before planting and after harvest at KALRO Embu Centre for the LR 2021 and SR 2021/2022 seasons.

CONCLUSION

Taro leaves recorded high values of potassium, magnesium, calcium, manganese, iron, copper, and zinc and can therefore be recommended as leafy vegetables to fight against malnutrition and promote human nutrition in Kenya. The proximate analysis and nutrient constituents of taro corms varied within the different watering regimes and plant densities, with significant differences in seasons recorded for protein, fibre, potassium, calcium, sodium, and zinc. The high values for carbohydrates, energy, potassium, magnesium, calcium, sodium, and manganese in this study emphasize taro's nutritional importance and show it can promote food security in rural communities. Due to its high carbohydrate content, taro represents one of the main sources of energy in many parts of the tropics and its production can be recommended in sub-humid areas in Kenya.

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Data availability. The data is available with the corresponding author – Joyce Wambui Njuguna joycenjuguna20@gmail.com upon reasonable request.

Author contribution statement (CRediT). A.N. Karuma - Conceptualization, project administration, funding acquisition, supervision, validation, review and editing; **J.W. Njuguna** - Conceptualization, formal analysis, methodology, visualization, software, writing – original draft, review and editing; **P. Gicheru** - Conceptualization, project administration, supervision, validation, review and editing; **F. Kaburu** – Methodology, investigation, and validation.

REFERENCES

AECOM, 2021. *Climate Change Action in the Water Sector in Kenya*. [online] Available at: https://publications.aecom.com/media/files/ClimateActionWaterSectorKenyaStatusReview.pdf [Accessed 18 August 2023].

Afifah, D.N., Imanianti, A., Rachmawati, T., Nindita, Y., Anjani, G., Syauqy, A. and Pratiwi, S.N., 2023. The characteristics of noodles produced from tuber and leaf of taro (*Colocasia esculenta* L. Schott). *Food Research*, 7(2), pp.154–163. https://doi.org/10.26656/fr.2017.7(2).807

AgriInfo., 2018. *Criteria for Scheduling Irrigation or Approaches for Irrigation Scheduling*. https://agriinfo.in/criteria-for-scheduling-irrigation-or-approaches-for-irrigation-scheduling-20/

Akter, M. and Oue, H., 2018. Effect of saline irrigation on accumulation of Na^+, K^+, Ca^{2+}, and Mg^{2+} ions in rice plants. *Agriculture* 8(10), p.164. https://doi.org/10.3390/agriculture8100164

Akwee, P.E., Netondo, G., Kataka, J.A. and Palapala, V.A., 2015. A critical review of the role of taro *Colocasia esculenta* L. (Schott) to food security: A comparative analysis of Kenya and Pacific Island taro germplasm. *Scientia Agriculturae*, [online] 9(2), pp.101–108. https://doi.org/10.15192/PSCP.SA.2015.9.2.101108

Alam, K.S., Phookan, D.B., Kalita, P., Barooah, M., Talukdar, M.C., Kumar, R. and Alam, S., 2019. Nutritional and anti-nutritional assessment of some upland taro (*Colocasia esculenta* L. Schott) cultivars in North East India. *Journal of Pharmacognosy and Phytochemistry*. 8(3), pp.3784–3789. Available at: https://www.phytojournal.com/archives/2019/vol8issue3/PartBD/8-3-447-625.pdf [Accessed 29 November 2023].

Alcantara, R., 2013. The Nutritional Value and Phytochemical Components of Taro [*Colocasia esculenta* (L.) Schott] Powder and its Selected Processed Foods. *Journal of Nutrition & Food Sciences*, 3(03), p.1000207. https://doi.org/10.4172/2155-9600.1000207

Alercia, A., 2013. *Nutritious underutilized species - Taro*. Bioversity International. CGIAR Consortium. Available at: https://cgspace.cgiar.org/bitstream/handle/10568/105089/Nutritious_underutilized_species_-_Taro_1685.pdf?sequence=3 [Accessed 1 July 2023].

Amagloh, F.K. and Nyarko, E.S. 2012. Mineral Nutrient Content of Commonly Consumed Leafy Vegetables in Northern Ghana. *African Journal of Food Agriculture Nutrition and Development*, 12(5).

Ansah, S., 2016. *Evaluation of Different Soil Amendments on Growth and Yield of Three Accessions of Taro (Colocasia Esculenta).*

[online] Kwame-Nkrumah University of Science and Technology. Available at: https://ir.knust.edu.gh/server/api/core/bitstreams/3d3e0754-74a7-428b-bf89-f92992ce92e5/content [Accessed 16 September 2023].

AOAC., 2006. Official Methods of Analysis. 18th Edn., Association of Official Analytical Chemists Inc., Arlington, TX., USA.

Araya, M., Olivares, M. and Pizarro, F., 2007. Copper in Human Health. *International J.ournalEnvironment and Health*, [online] 1(4), pp.608–620. Available at: https://www.inderscience.com/offers.php?id=18578 [Accessed 29 November 2023].

Ayers, R.S. and Westcot, D.W., 1994. *Water quality for agriculture*. [online] Rome. Available at: https://www.fao.org/3/t0234e/T0234E00.htm#TOC [Accessed 17 November 2023].

Azubuike, N.C., Maduakor, U.C., Ikele, I.T., Onwukwe, O.S., Onyemelukwe, A.O., Nwanjiobi, D.U., Chukwu, I.J. and Achukwu, P.U., 2018. Nutritional profile, proximate composition and health benefits of *Colocasia esculen*ta leaves: An underutilized leafy vegetable in Nigeria. *Pakistan Journal of Nutrition*, 17(12), pp.689–695. https://doi.org/10.3923/PJN.2018.689.695

Beato, Z, Gitonga, L., Amonsou, E., and Reddy, V. 2024. Nutritional evaluation of *Colocasia esculenta* (L.) Schott leaves and corms from KwaZulu-Natal, South Africa. *Journal of Food Composition and Analysis*, 126, p. 105831. https://doi.org/10.1016/j.jfca.2023.105831

Boampong, R., Aboagye, L.M., Nyadanu, D., Essilfie, M.E. and Adu Amoah, R., 2019. Biochemical Charcterization of Some Taro (*Colocasia esculenta* L. Schott) Germplasm in Ghana. *Advances in Agriculture*, 2019, p. 1965761. https://doi.org/10.1155/2019/1965761

Buke, T. and Gidago, G., 2016. The Effect of Np Fertlizer Rates on the Yield and Yield Components of Taro (*Colocasia esculenta* (L.) Schott.) in Boloso-Sore Woreda Wolaita Zone, Snnpr, Ethiopia. *International Journal of Agriculture Innovations and Research*, [online] 5(3), pp.2319–1473. Available at: https://ijair.com/administrator/components/com_jresearch/files/publications/IJAIR_2124_FINAL.pdf

Buntha, P., Borin, K., Preston, T.R. and Ogle, B., 2008a. Digestibility and nitrogen balance studies in pigs fed diets with ensiled taro (*Colocasia esculenta*) leaves as replacement for fish meal. *Livestock Research for Rural Development*, [online] 20. Available at: http://www.lrrd.org/lrrd20/supplement/bunt2.htm [Accessed 29 November 2023].

Buntha, P., Borin, K., Preston, T.R. and Ogle, B., 2008b. Survey of taro varieties and their use in selected areas of Cambodia. *Livestock Research for Rural Development*, [online] 20. Available at: http://www.lrrd.org/lrrd20/supplement/bunt1.htm [Accessed 29 November 2023].

Chandrakar, S., Patel, S., Khokhar, D. and Mishra, N.K., 2022. The Pharma Innovation Journal 2022; 11(9): pp. 98-100 Physico-chemical properties of the taro (*Colocasia esculenta*) root. [online] Available at: https://faostat.fao.org

Chandrasekara, A. and Josheph Kumar, T., 2016. Roots and tuber crops as functional foods: A review on phytochemical constituents and their potential health benefits. *International Journal of Food Science*, 2016, p. 3631647. https://doi.org/10.1155/2016/3631647

Chen, P. Bornhorst, J.B. and Aschner, M., 2018. *Manganese metabolism in humans*. *Frontiers in Bioscience Landmark* , 23, 1655-1679. Available at: https://doi.org/10.2741/4665

Chivenge, P., Mabhaudhi, T., Modi, A.T. and Mafongoya, P., 2015. The Potential Role of Neglected and Underutilised Crop Species as Future Crops under Water Scarce Conditions in Sub-Saharan Africa. *International Journal of Environmental Research and Public Health*, [online] 12(6), p.5685. https://doi.org/10.3390/IJERPH120605685

Chove, B.E., Ballegu, W.R. and Chove, L.M., 2006. Copper and lead levels in two popular leafy vegetables grown around Morogoro Municipality, Tanzania. *Tanzania Health Research Bulletin*, 8(1), pp.37–40. https://doi.org/10.4314/THRB.V8I1.14269

Clifford, J., Niebaum, K. and Bellows, L., 2015. Iron Needs and Recommendations. *Colorado State University Extension*, [online] Fact sheet 9. Available at: https://extension.colostate.edu/docs/pubs/foodnut/09356.pdf [Accessed 16 August 2023].

Cruz, F.J.R., Prado, R. de M., Felisberto, G., Santos, Á.S. and Barreto, R.F., 2018. Potassium Nutrition in Fruits and Vegetables and Food Safety through Hydroponic System. In: *Potassium - Improvement of Quality in Fruits and Vegetables Through Hydroponic Nutrient Management*. InTech. https://doi.org/10.5772/intechopen.71742

Dong, Y. (2023). Irrigation Scheduling Methods: Overview and Recent Advances. In M. Sultan and F. Ahmad (Eds.), *Irrigation and Drainage—Recent Advances*. IntechOpen. https://doi.org/10.5772/intechopen.107386

Duruibe, J., Ogwuegbu, M. and Egwurugwu, J., 2007. Heavy Metal Pollution and Human Biotoxic Effects. *International Journal of the Physical Sciences*, [online] 2(5), pp.112–118. Available at: https://academicjournals.org/article/article1380209337_Duruibe%20et%20al.pdf

El-Sharkawi, H., Irshad, M., El-Serfy, A.M., Honna, T., Hassan, A.K.S., Mohamed, T., Mahmoud, E., Yamamoto, S. and Zahoor, A., 2004. Effect of Water Quality on Grain Yield and Nutrient Uptake of Rice (*Oryza sativa* L.). *Acta Agronomica Hungarica*, 52(2), pp.141–148. https://doi.org/https://doi.org/10.1556/AAgr.52.2004.2.4

Embu County Government, 2019. Embu County Government County Integrated Development Plan 2018-2022 A Vibrant and Prosperous County. [online] Available at: https://www.embu.go.ke/wp-content/uploads/2019/09/APPROVED-CIDP-2018-2022.pdf [Accessed 19 August 2021].

Enwelu, I.A., Asogwa, N.P., Nwanlieji, H.U. and Ezeano, C.I., 2014. Assessment of Constraints to Cocoyam Consumption in Selected Communities of Enugu State, Nigeria. *International Journal of Research in Applied, Natural and Social Sciences*, 2(3), pp.31–40.

FAO, 2003. *Edible Aroids: Post-harvest Operations-Post-harvest Operations*. [online] New Zealand. Available at: https://www.fao.org/fileadmin/user_upload/inpho/docs/Post_Harvest_Compendium_-_Edible_aroids.pdf

Ferdaus, Md.J., Chukwu-Munsen, E., Foguel, A. and da Silva, R.C., 2023. Taro Roots: An Underexploited Root Crop. *Nutrients*, [online] 15(15), p.3337. https://doi.org/10.3390/nu15153337

Fiorentini, D., Cappadone, C., Farruggia, G. and Prata, C., 2021. Magnesium: Biochemistry, nutrition, detection, and social impact of diseases linked to its deficiency. *Nutrients*, 13(4), p.1136. https://doi.org/10.3390/nu13041136

Gerrano, A.S., Mathew, I., Shayanowako, A.I., Amoo, S., Mellem, J.J., Van Rensburg, W.J., Bairu, M.W. and Venter, S.L., 2021. Variation in mineral element composition of landrace taro (*Colocasia esculenta*) corms grown under dryland farming system in South Africa. *Heliyon*, 7(4), p. e06727. https://doi.org/10.1016/j.heliyon.2021.e06727

Gröber, U., Schmidt, J. and Kisters, K., 2015. Magnesium in prevention and therapy. *Nutrients*, 7(9), pp. 8199-8226. https://doi.org/10.3390/nu7095388

Hang, D.T., Vanhanen, L. and Savage, G., 2013. Effect of simple processing methods on oxalate content of taro petioles and leaves grown in central Viet Nam. *Lwt*, [online] 50(1), pp.259–263. https://doi.org/10.1016/j.lwt.2012.05.015

Huang, C.C., Chen, W.C. and Wang, C.C.R., 2007. Comparison of Taiwan paddy- and upland-cultivated taro (Colocasia esculenta L.) cultivars for nutritive values. *Food Chemistry*, 102(1), pp.250–256. https://doi.org/10.1016/J.FOODCHEM.2006.04.044

International Potash Institute, 2013. *Nutrition and Health − the Importance of Potassium*. https://doi.org/10.3235/978-3-905887-08-2

IUSS Working Group WRB. (2015). *World reference base for soil resources 2014:* International soil classification system for naming soils and creating legends for soil maps. FAO. https://www.fao.org/3/i3794en/I3794en.pdf

Kangai, R., Chitechi, W., Koske, J., Waswa, B. and Ngare, I., 2021. Determinants of climate change adaptation and perceptions among small-scale farmers of Embu County, Eastern Kenya. *African Journal of Environmental Science and Technology*, 15(4), pp.167–178. https://doi.org/10.5897/AJEST2020.2943

Katerji, N., Van Hoorn, J.W., Hamdy, A. and Mastrorilli, M., 2003. Salinity effect on crop development and yield, analysis of salt tolerance according to several classification methods. *Agricultural Water Management*, 62(1), pp.37–66. https://doi.org/10.1016/S0378-3774(03)00005-2

Kisaka, M.O., Mucheru-Muna, M., Ngetich, F.K., Mugwe, J.N., Mugendi, D. and Mairura, F., 2015. Rainfall Variability, Drought Characterization, and Efficacy of Rainfall Data Reconstruction: Case of Eastern Kenya. *Advances in Meteorology*, 2015, p. 380404. https://doi.org/10.1155/2015/380404

Koffi, A.H., Agbo, A.E., Nguessan, K.F., Loukou, A.L., K., E. and mand, A., 2020. Biochemical Characteristics of Taro (*Colocasia esculenta*) Cultivated in Côte d'Ivoire according to Maturity Stage. *International Journal of Current Microbiology and Applied Sciences*, 9(12), pp.2675–2690. https://doi.org/10.20546/ijcmas.2020.912.317

Koubová, E., Sumczynski, D., Šenkárová, L., Orsavová, J. and Fišera, M., 2018. Dietary intakes of minerals, essential and toxic trace elements for adults from Eragrostis tef L.: A nutritional assessment. *Nutrients*, 10(4), p.479. https://doi.org/10.3390/nu10040479

Lan, L.T.T., Hung, L.T., Thu, N.T.A., Loc, H.T., Liang, J.B., Thiet, N. and Ngu, N.T., 2021. Effects of substituting taro (Colocasia esculenta) wastes silage in diets on growth and nutrient digestibility in pigs. *Journal of Animal Health and Production*, 9(2), pp.112–118. https://doi.org/10.17582/journal.jahp/2021/9.2.112.118

Mergedus, A., Kristl, J., Ivancic, A., Sober, A., Sustar, V., Krizan, T. and Lebot, V., 2015. Variation of mineral composition in different parts of taro (*Colocasia esculenta*) corms. *Food Chemistry*, 170, pp.37–46. https://doi.org/10.1016/j.foodchem.2014.08.025

Messou, T., Bi, Y., Clément, Y., N'zué Yao, B., Clémence, K.L. and Kablan, T., 2018. Physical and biochemical characteristics of red and black beans varieties of *Phaseolus lunatus* (L.) consumed in south and east of Côte d'Ivoire. *Global Scientific Journals*, [online] 6(11), pp-40-62. Available at: https://www.globalscientificjournal.com/researchpaper/Physical_and_biochemical_characteristics_of_red_and_black_beans_varieties_of_Phaseolus_lunatus_L_consumed_in_south_and_east_of_C_te_d_Ivoire.pdf

Msanya, B.M., Kimaro, D.N., Kileo, E.P., Kimbi, G.G. and Mwango, S.B., 2001. *Land Suitability Evaluation for the Production of Food Crops and Extensive Grazing: A Case Study of Wami Plains in Morogoro Rural District, Tanzania*. Soils and Land Resources of Morogoro Rural and Urban Districts, Volume 1. Department of Soil Science, Faculty of Agriculture, Sokoine University of Agriculture, Morogoro, Tanzania.

Mulugeta, M. and Tebeka, T., 2017. Proximate and Some Minerals Analysis of *Colocasia esculenta* (Taro) Tuber in Southern Ethiopia. *International Journal of Pharmacy and Pharmaceutical Research*, 10(2), pp.1-12. Available at: https://ijppr.humanjournals.com/wp-content/uploads/2017/10/1.Million-Mulugetaa-Tesfaye-Tebeka.pdf [Accessed 10 August 2023].

Ndabikunze, B.K., Talwana, H., Mongi, R. and Issa-Zacharia, A., 2011. Proximate and mineral composition of cocoyam (*Colocasia esculenta* L. and *Xanthosoma sagittifolium* L.) grown along the Lake Victoria Basin in Tanzania and Uganda. Available at: http://www.academicjournals.org/ajfs [Accessed 10 August 2023].

Ngetich, A., Runo, S., Ombori, O., Ngugi, M., Kawaka, F., Perpetua, A., Nkanata, G. and Dalcorso, G., 2015. Low Cost Micropropagation of Local Varieties of Taro (*Colocasia esculenta* spp.). *Biotechnology Journal*, 6(4), pp.136–145. https://doi.org/10.9734/BBJ/2015/15614

NIH. National Institute of Health. 2022. *Copper Fact Sheet for Consumers*. Available at: http://ods.od.nih.gov

Njoku. P.C and Ohia. C.C, 2007. Spectrophometric Estimation Studies of Mineral Nutrient in Three Cocoyam Cultivars. *Pakistan Journal of Nutrition*, 6, pp.616–619. https://doi.org/10.3923/pjn.2007.616.619

Njuguna, J.W., Karuma, A.N. and Gicheru, P., 2023b. Water Use Efficiency of Taro (*Colocasia esculenta*) under Varying Watering Regimes and Planting Densities in Embu, Kenya. *Tropical and Subtropical*

Agroecosystems, [online] 26(3), p.075. https://doi.org/10.56369/tsaes.4847

Njuguna, J.W., Karuma, A.N., Gicheru, P. and Onwonga, R., 2023a. Effects of Watering Regimes and Planting Density on Taro (*Colocasia esculenta*) Growth, Yield, and Yield Components in Embu, Kenya. *International Journal of Agronomy*, 2023, p. 6843217. https://doi.org/10.1155/2023/6843217

Okalebo, J.R., Gathua, K.W. and Woomer, P.L., 2002. *Laboratory Methods of Soil and Plant Analysis: A Working Manual. Sacred African Publishers*, Nairobi, Kenya. Available at: https://www.researchgate.net/publication/313605698_Laboratory_Methods_of_Soil_and_Plant_Analysis_A_Working_Manual [Accessed 23 March 2023].

Onwueme, I., 1999. *Taro Cultivation in Asia and the Pacific*. Food and Agriculture Organization of the United Nations Regional Office for Asia and the Pacific Bangkok, Thailand. Available at: http://www.bio-nica.info/biblioteca/Onwueme1999TaroCultivation.pdf [Accessed 20 November 2023].

Oxfarm, 2021. New arrow-roots Varieties that grows on Simple Moisture Beds – *Oxfarm*. Available at: http://oxfarm.co.ke/crop-farming/arrow-root-farming/arrow-roots-variety-that-grows-on-beds/ [Accessed 19 September 2023].

Özenç, N., Bender Özenç, D. and Duyar, Ö., 2014. Nutritional composition of hazelnut (Corylus avellana L.) as influenced by basic fertilization. *Acta Agriculturae Scandinavica Section B: Soil and Plant Science*, 64(8), pp.710–721. https://doi.org/10.1080/09064710.2014.953990

Palapala, V.A. and Akwee, P.E., 2016. Genetic Diversity Analysis of Kenyan Taro [*Colocasia esculenta* (L.) Schott] Accessions Using SSR Markers. *Sky Journal of Agricultural Research*, 6(10), pp.346-353. Available at: https://core.ac.uk/download/pdf/223128569.pdf [Accessed 25 August 2023].

Rashmi, D.R., Anitha, B., Anjum, S.R., Raghu, N., Chandrashekrappa, G.K. and Kanthesh, M.B., 2018. An overview of Taro (*Colocasia esculenta*): A review. *Academic Journal of Agricultural Research*. [online] https://doi.org/10.15413/ajar.2018.0144

Republic of Kenya, 2006. *Environmental Management and Co-ordination (Water Quality) Regulations*. Available at: https://www.waterfund.go.ke/watersource/Downloads/002.Water%20Quality%20Regulations%20Kenya.pdf [Accessed 17 November 2022].

Sánchez Chino, X.M., Corzo Ríos, L.J., Jiménez Martínez, C., Argüello García, E. and Martinez Herrera, J., 2021. Nutritional Chemical Analysis of Taro (*Colocasia esculenta* Schott) Accessions from the State of Tabasco, Mexico. *Agro Productividad*, https://doi.org/10.32854/agrop.v14i10.2074

Sangeetha, V.J., Dutta, S., Moses, J.A. and Anandharamakrishnan, C., 2022. Zinc nutrition and human health: Overview and implications. *eFood*, 3(5), p.e17. https://doi.org/10.1002/EFD2.17

Sefa-Dedeh, S. and Agyir-Sackey, E.K., 2004. Chemical composition and the effect of processing on oxalate content of cocoyam *Xanthosoma sagittifolium* and *Colocasia esculenta* cormels. *Food Chemistry*, 85(4), pp.479–487. https://doi.org/10.1016/S0308-8146(02)00244-3

Setyawan, H.B., Yulianto, R., Zelin, O. and Purnamasari, L., 2021. Potential of Three Taro (*Colocasia esculenta* L.) Cultivars as Animal Feed. *ASEAN Journal on Science and Technology for Development*, 38(3), pp.97–102. https://doi.org/10.29037/ajstd.716

Sibiya, S.Gugu., 2015. *Planting density effect on growth and yield of taro (Colocasia esculenta) landraces.* MSc. Thesis. University of KwaZulu-Natal, South Africa. Available at: https://researchspace.ukzn.ac.za/handle/10413/13427 [Accessed 17 October 2023].

Soudy, I.D., Delatour, P. and Grancher, D., 2016. Effects of traditional soaking on the nutritional profile of taro flour [*Colocasia esculenta* L. Schott) produced in Chad. *Revue de Médecine Vétérinaire*, 161(1), pp.37–42. Available at: https://www.researchgate.net/publication/288305750

Temesgen, M. and Retta, N., 2015. Nutritional Potential, Health and Food Security Benefits of Taro *Colocasia esculenta* (L.): A Review. *Food Science and Quality Management*, 36, pp.23-30. Available at: https://core.ac.uk/download/pdf/234683954.pdf [Accessed 10 August 2023].

Temesgen, M., 2017. Nutrient Constituents of Taro *(Colocasia esculenta*) Corm and Leaf for Infant Food Development and Chicken Feed Formulation. Addis Ababa University.

Toan, N.H. and Preston, T.R., 2010. Taro as a local feed resource for pigs in small scale household condition. *Livestock Research for Rural Development.*, 22, p.152. Available at: http://www.lrrd.org/lrrd22/8/toan22152.htm [Accessed 16 August 2023].

Tumuhimbise, R., Talwana, H. L., Serem, A. K., Ndabikunze, B.K. and Palapala, V., 2009. Growth and Development of Wetland-grown Taro Under Different Plant Populations and Seedbed Types in Uganda. *African Crop Science*, 17(1), pp.49–60. https://doi.org/10.4314/acsj.v17i1.54210

USDA. Food data central, 2018. *Taro leaves*. Available at: https://fdc.nal.usda.gov/ [Accessed 16 August 2023].

Valverde Lucio, A., Gonzalez-Martínez, A. and Rodero Serrano, E., 2023. Utilization of Cooked Cassava and Taro as Alternative Feed in Enhancing Pig Production in Ecuadorian Backyard System. *Animals*, 13(3), pp.356. https://doi.org/10.3390/ani13030356

Verma, V.K., Kumar, A., Rymbai, H., Talang, H., Chaudhuri, P., Devi, M.B., Singh, N.U., Hazarika, S. and Mishra, V.K., 2023. Assessment of ethnobotanical uses, household, and regional genetic diversity of aroid species grown in northeastern India. *Frontiers in Nutrition*, 10. pp.1–16. https://doi.org/10.3389/fnut.2023.1065745.

Wimbley, T.D. and Graham, D.Y., 2011. Diagnosis and management of iron deficiency anemia in the 21st century. *Therapeutic Advances in Gastroenterology*, 4(3), pp. 177–184. https://doi.org/10.1177/1756283X11398736

Wondimu Fufa., T., Ogba Oselebe, H., Veronica Nnamani, C., Azubuike Afiukwa, C. and Aniedi Uyoh, E., 2021. Systematic Review on Farmers' Perceptions, Preferences and Utilization Patterns of Taro [*Colocasia esculenta* (L.) Scott] for Food and Nutrition Security in Nigeria. *Journal of Plant Sciences*, 9(4), p.224. https://doi.org/10.11648/j.jps.20210904.23

World Health Organization, (WHO) (2012). *Guideline: Sodium intake for adults and children*. Geneva. https://www.who.int/publications/i/item/9789241504836