Original Research Article

EFFECT OF DIFFERENT PROCESSING METHODS ON THE ANTI-NUTRITIVE COMPONENTS OF SELECTED INDIGENOUS VEGETABLES

ABSTRACT

Indigenous vegetables are widely utilized due to their high nutritional profiles, easy availability, and accessibility in rural areas. The consumption of indigenous vegetables is limited by their high perishability nature which causes high post-harvest losses. Also, the presence of anti-nutritive components which tend to affect the bioavailability of micronutrients, poses a challenge in availing their full nutritional potential to consumers. This study aimed to determine the effect of boiling, fermentation, solar and sun drying (with and without blanching) on the anti-nutritive components of the leaves of Cassava (*Manhot esculenta Crantz*), Black jack (*Bidens pilosa*) and Bitter lettuce (*Launaea cornuta*). The raw, dried, boiled and fermented vegetables were evaluated directly after being subjected to their corresponding treatments. Total oxalate and hydrogen cyanide (HCN) were analyzed using titrimetric methods and phytate was determined using the UV spectrophotometric method. From the results, oxalic acid ranged from 180.2 ±1.56 to 26.3 ± 2.34mg/100g, phytate ranged from 18.8 ± 1.07to 0.7 ± 1.11mg/100g and hydrogen cyanide ranged from 357.1 ± 10.56to 4.1 ± 2.49mg /100g across the treatments. All processing methods significantly ($P<0.05$) reduced hydrogen cyanide and oxalic acid content in all vegetable samples. Phytate was significantly reduced ($P<0.05$) after boiling and fermentation while, all drying treatments resulted in non-significant changes in phytate content. In consequence, all processing methods studied proved to be effective in the reduction of hydrogen cyanide and oxalic acid. Boiling and fermentation showed their effectiveness in the reduction of phytate. Therefore, it is recommended that these plants should be eaten boiled or fermented to increase the bioavailability of micronutrients.

Keywords: Indigenous vegetables, boiling, anti-nutritive components, blanching, fermentation, solar drying, sun drying

INTRODUCTION

Micronutrient deficiency happens when the body is not getting enough of the vital vitamins and minerals it needs to function properly. Common micronutrient deficiencies include a lack of iron, vitamin A, iodine, calcium, and zinc, which can result in several health problems that impact development, immunity, and general human well-being (Contii*et al.*, 2021). The deficiency of micronutrients affects almost half of children under five worldwide and pregnant women, making it a serious health concern (Stevens *et al.*, 2022). Low or middle-income countries bear the disproportionate burden of micronutrient deficiencies. Tanzania suffers a serious problem with micronutrient deficiencies, which cost the nation more than US$ 518 million a year, or 2.65% of its GDP in health care and nutritional interventions (Noor, 2019).

According to the Ministry of Health *et al.* (2022), the prevalence of anemia is 59% in 6 to 59 months' children in Tanzania, where 26% have mild anemia, 31% have moderate anemia and 2% have severe anemia, also, the prevalence of anemia is 42% in women aged between 15 to 49 years. Iron deficiency is highest in the Eastern zone of Tanzania, at 70% (Ministry of Health *et al.*, 2022). According to Nicholaus *et al.* (2020), 23.1% of adolescents in boarding high schools in Kilimanjaro Tanzania are anemic. This was associated with diets with inadequate key micronutrients such as iron, zinc, and calcium. Also, the study done by John *et al.* (2023) found a 37.8% prevalence of iron deficiency among pregnant women in the Mbeya Region. This shows that micronutrient deficiency is still a public health concern in Tanzania.

Micronutrient deficiency may result from inadequate consumption of micronutrient-dense foods or problems associated with the absorption of vital minerals and vitamins by the body (Kiani *et al.*, 2022). Poor dietary practices, food insecurity, and poverty are some of the reasons that can lead to an inadequate intake of micronutrient-dense foods, whereas infections, chronic inflammation, and other medical problems that may influence the digestive system can cause decreased absorption and availability of minerals (Lopes *et al.*, 2023; Angeles-Agdeppa *et al.*, 2021). The former cause of micronutrient deficiency may also be caused by the consumption of micronutrient-dense foods that are poorly processed. Foods that have been inappropriately processed, primarily vegetables, may preserve the concentration of anti-nutritive ingredients that bind to minerals and make them difficult for the body to absorb, also, they may lose minerals and phytochemicals.

Micronutrient deficiency can be addressed by the consumption of micronutrient-dense foods. One group of the micronutrient-dense foods cheaply available is indigenous vegetables. Indigenous vegetables are plant species that are native to a specific regionor that have been introduced to that area long enough to have evolved through natural processes (Chadha, 2003). In rural areas, indigenous vegetables have a bigger impact on improving food security and nutrition (Bokelmann*et al.*, 2022). Indigenous vegetables are a potent source of nutrients and play an important role in lowering micronutrient deficiencies (Oboh *et al.*, 2017). They contribute to a well-balanced diet, providing important minerals, vitamins and antioxidants. Through the inclusion of a range of indigenous vegetables in their diet, people can increase their consumption of important micronutrients such as magnesium, potassium, zinc, iron, copper, folate (vitamin B9), vitamin A, vitamin C, vitamin E and vitamin K (Sarkar *et al.*, 2023). These support overall health and aid in treating micronutrient deficiencies, particularly in regions where micronutrient deficiencies are prevalent.

The high perishability of indigenous vegetables, however, can limit their availability and intake. Indigenous vegetables have a short shelf lifeand begin to lose their freshness as soon as they are harvested (Smith and Eyzaguirre, 2007). According to Gogo *et al.*, (2018),vegetable losses during postharvest stages might reach 50%. Vegetables lose their wholesomeness through physical damage, inadequate processing and their high perishability nature due to moisture content. Vegetable losses lead to the loss of nutrients as well, for instance, Gogo *et al.*, (2017) found that along the African nightshade supply chain in Kenya, a loss of micronutrient and macronutrient range from 3.2% -29.4% and for chlorophyll and carotenoid range from 70.9% - 90.9% and 70.4% - 91.9% respectively. This implies that the nutritional value of vegetables is also reduced in addition to the financial losses due to poor postharvest handling and processing.

Furthermore, indigenous vegetables contain anti-nutritive components such as phytate, oxalates, tannins, hydrocyanic acid, nitrates, saponins and protease inhibitors (Katosh, 2022). These anti-nutritive components frequently combine minerals such as iron, calcium and zinc which as a result, decreases their absorption into the body following digestion. This in turn leads to micronutrient deficiencies (Samtiya*et al*., 2020). When taken in large quantities, anti-nutritive components have negative health impacts such as decreased nutrition intake, absorption and utilization, at low concentrations, however, they have various health benefits (Ali *et al*., 2022; Dey *et al*., 2022).

Fortunately, using appropriate processing techniques like fermentation, boiling and drying may assist in solving issues with anti-nutritive components and post-harvest losses in vegetables. The concentration of anti-nutritive components can be reduced, the shelf life of vegetables may be increased and the optimal intake of important compounds can be guaranteed with the use of appropriate processing techniques (Samtiya*et al*., 2020). Also, appropriate processing can help ensure that these vegetables preserve their valuable ingredients until consumption because inadequate postharvest handling can cause loss of minerals and retain anti-nutritive components which can negatively impact the nutritional value of the vegetables (Sivakumar *et al.,* 2020).

Therefore, this study aimed to determine the effect of boiling, sun drying and solar drying (with or without blanching), and fermentation on three vegetables (bitter lettuce, black jack and cassava leaves) that are commonly consumed in Mkuranga District, in the coastal region on the eastern part of Tanzania on anti-nutritive components (phytate, hydrogen cyanide and oxalic acid). This study will help to give an insight towards zero hunger and good health and well-being. The results obtained will further inform the respective community on the choice of appropriate processing methods that may reduce anti-nutritive components.

MATERIALS AND METHODS

Description of the study area

This study was conducted in Mkuranga District, which is located in the Pwani Region in the eastern part of Tanzania**.** Mkuranga District has a total surface area of 2,827 of which 1985 km^2 is on the mainland and 447 km^2 is covered by the Mafia channel. Mkuranga is located on the latitude of 7.1219° South and longitude of 39.2° East. It is bordered to the North by Dar es Salaam's Kigamboni, Temeke and Ilala Districts. To the East, it is flanked by the Mafia Channel, to the South by Kibiti District and to the West by Kisarawe District. The area of the mainland that is covered by forest natural reserves is 52 km^2. 1934 km^2 of land is suitable for cultivation, whereas 1662.3 km^2 of the arable land is under cultivation. The Mkuranga District has 25 Wards and among those two (Mkamba and Kisegese) were purposely selected for sample collection.

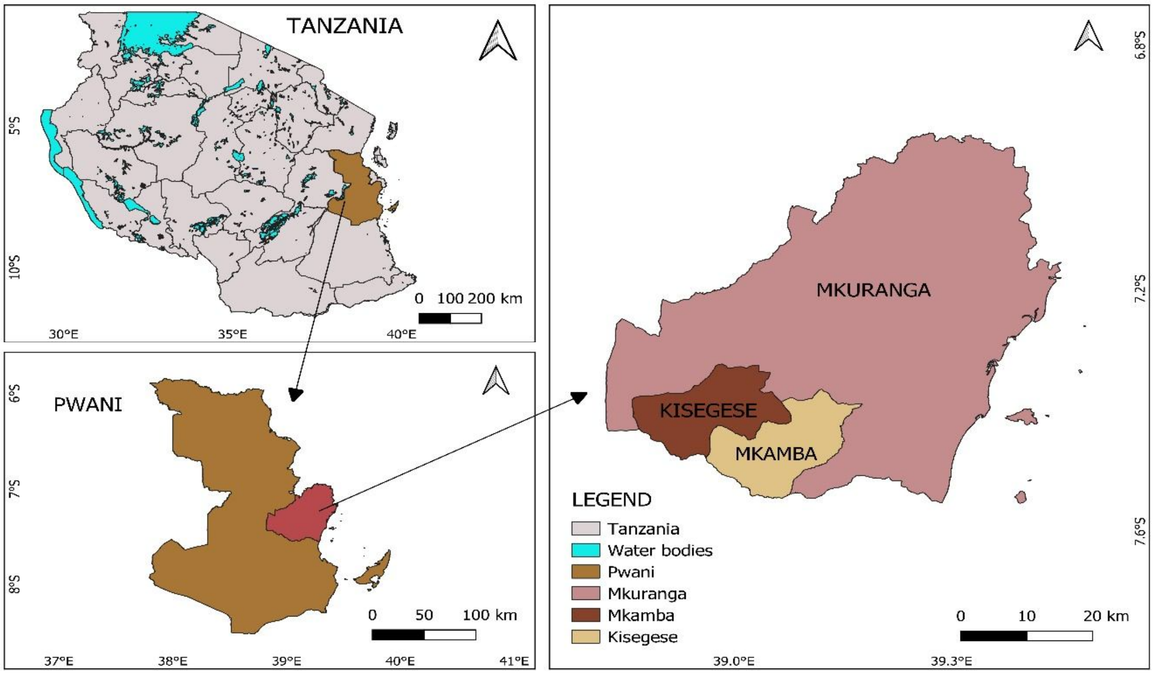

Figure 1: Map of Mkuranga District showing the study area, (Source; Author)

Sample collection

Three indigenous vegetables (black jack leaves, cassava leaves and bitter lettuce leaves) that are commonly consumed in Mkuranga District were used in this study. Vegetable samples were purposively selected due to their availability and accessibility during the study period.A total of 4 kg ofeach vegetable sample wascollected from two production areas in each ward (Mkamba and Kisegese) with the help of the natives. Vegetable samples were harvested, cleaned to remove dust, and put in sealed plastic bags. The samples were then placed in a cool box and transported to the laboratory at Sokoine University of Agriculture, where they were stored at 4^{o}C for one day before further processing and laboratory analysis.

Figure 2:Pictures of the three vegetables taken from the selected farms (A: Bitter lettuce, B: Cassava leaves, C: Black jack)

Sample preparation and treatment

Before processing, vegetable samples were sorted, washed with distilled water and left to drain water. The portions of vegetables were subjected to boiling, fermentation, solar drying with blanching, sun drying with blanching, solar drying without blanching and sun drying without blanching. The processing methods were carried out as follows:

Boiling

Five hundred grams (500 g) of vegetables (black jack, cassava leaves and bitter lettuce) were cut into 4-8 mm pieces and put in 1 liter of distilled water and boiled separately to 100^{o}C for 15 minutes before the analysis of anti-nutritive components (da Silva Santos *et al.*, 2020; Ekpo and Baridia, 2020).

Fermentation

The fermentation process was carried out according to Vatansever *et al.*, (2017) with some modification, five hundred (500) g of raw vegetables were shredded into 2 cm thick pieces and placed into jars. The jars with the vegetables were filled with 15% salt (NaCl). The amount of salt was sufficient to cover the sliced vegetables completely. The jars were then covered with screw caps and kept at room temperature for 14 days. The vegetables were subjected to pH measurement after every one week. The fermented vegetables were analyzed for anti-nutritive components.

Sun drying and solar drying of vegetables

Approximately one kilogram (1 kg) of each vegetable sample was divided into two equal portions and one portion was subjected to blanching at 95^{o}C for 5 minutes and immediately cooled under running distilled water to avoid further cooking and the other portion was left without blanching. The blanched and non-blanched portions of each vegetable were left to dry under the sun for two consecutive days before analyzing anti-nutritive components, after measuring the moisture content. The same procedures were conducted for solar-dried samples, where the two portions were subjected tothe walk-in/greenhouse-solar driers of which temperature varied for 5-7 hours in a single day. In both cases, the samples were constantly turned to avert fungal growth (Mongi and Ngoma, 2022; Mepba*et al.*, 2007).

Figure 3: Pictures A and B show Sun drying and solar drying of vegetables respectively

Determination of phytate

Phytate was determined according to Okiki*et al.*, (2015) by adding one gram of the sample to 10ml of 3% of Trichloroacetic acid (TCA). In a solution, 0.1% of Ammonium Ferric sulfate was added to precipitate phytate as ferric phytate. The precipitate was converted to ferric hydroxide and sodium phytate by adding 10ml of 0.5 sodium hydroxide. The residue was boiled and dissolved with the addition of dilute nitric acid. The absorbance of the sample was taken at 519nmand the phytic acid content of the samples was calculated using the standard calibration curve.

Determination of oxalic acid

Oxalate ions were determined by using the AOAC (1998) Official Method, where one gram of sample was measured and placed in a 300ml conical flask, to each flask 250ml of 1M H_2SO_4 (sulphuric acid) was added, the burette was filled with 0.1M $KMnO_4$ (potassium permanganate) solution and the initial volume was noted. Oxalate mixtures in the flasks were boiled up to 80^{o}C to 90^{o}C and were kept above 70^{o}C throughout the process of titration. The mixture of vegetable samples mixed with sulphuric acid was titrated against potassium permanganate solution while stirring frequently up to the endpoint where an extremely pale pink color persisted in the solution for 15 seconds. Oxalate content was calculated by using the formula:

$$Oxalate\ in\ mg/kg = \frac{(A-B)x\ M\ xMwt\ x100}{Swt\ x1000\ xA}$$

where;

A = Amount (g) of $KMnO_4$ used for sample

B = Amount (g) of $KMnO_4$ used for blank

M = Molarity of $KMnO_4$ (0.1)

Mwt= Mass (g) of $KMnO_4$ equivalent to 0.1M

Swt = Amount of sample taken (g) for analyses

Determination of hydrogen cyanide

This was done according to AOAC (2000) Official Method 915.03, in which ten-gram grams of the sample were placed in a Kjeldahl flask, and 200 ml of distilled water was added and let to stand for 2-4 h (autolysis had to be conducted with apparatus completely connected for distillation), 150 ml of distillate was collected in sodium hydroxide solution (0.025 M NaOH). To 100ml distillate (it is preferable to dilute 250 ml and titrate 100 ml aliquot), 8 ml 6 N NH4OH and 2ml 5% KI solution were added and titrated with 0.02 N $AgNO_3$until the end point of faint but permanent turbidity and may easy to be recognized especially against black background observed.

1ml 0.02N AgNO$_3$=1.08 HCN (equivalent to 2 CN)

Data analysis

All data on anti-nutritive components were analyzed using the Statistical Package for Social Sciences (SPSS) statistical software, version 25. One-way analysis of variance (ANOVA) test was performed to determine if there was a significant difference in assessed parameters among different processing methods. It was thenfollowed by a post hoc test, Turkey (HSD) with significant differences being determined at a 5% level of significance ($P<0.05$) to identify which processing methods differ from each other. All results were expressed as mean ± standard variation of triplicate values.

RESULTS AND DISCUSSION

Anti-nutritive components of the selected vegetables

The content of anti-nutritive components of vegetables before and after the following treatments: boiling, fermentation, direct solar drying, direct sun drying, sun drying with pre-treatment blanching, and solar drying with pre-treatment blanching in the three indigenous vegetables are presented in table 1.

Table 1: Anti-nutritive components (mg/100g) of raw and processed cassava leaves, black jack leaves and bitter lettuce leaves

Vegetables	Processing methods	Oxalic acid (mg/100g)	Phytate (mg/100g)	Hydrogen cyanide (mg/100g)
Cassava leaves	Raw	136.5± 0.06^{d}	18.8 ± 1.07^{b}	357.1 ± 10.56^{f}
	Boiling	61.3±3.86^{ab}	0.7 ± 1.11^{a}	146.3 ± 0.06^{d}
	Fermentation	89.5±4.31^{c}	4.5 ± 1.97^{a}	215.7 ± 0.05^{e}
	Blanching-solar drying	77.4 ± 4.43^{bc}	17.8 ± 1.18^{b}	40.4 ±8.27^{c}
	Blanching-sun drying	64 ± 5.71^{ab}	14.6 ± 0.95^{b}	4.1 ± 2.49^{a}
	Direct solar drying	51.1±3.69^{a}	17.3±2.38^{b}	12.15 ± 0.82^{ab}
	Direct sun drying	87.5 ± 4.32^{c}	14.3 ± 0.58^{b}	26.4 ± 4.21^{bc}
Bitter lettuce	Raw	163.0 ± 0.08^{d}	16.8 ± 1.80^{b}	116.4 ± 0.01^{f}
	Boiling	103.9 ± 5.41^{c}	2.65 ± 0.27^{a}	38.7 ± 0.27^{d}
	Fermentation	95.7 ± 6.45^{c}	3.7 ± 0.67^{a}	77. 2 ± 0.84^{e}
	Blanching-solar drying	67.7 ± 3.78^{b}	15.4 ± 3.15^{b}	11.6 ± 0.02^{ab}
	Blanching-sun drying	46.5 ± 1.25^{a}	13.6 ± 0.93^{b}	19. 3 ± 2.56^{bc}
	Direct solar drying	46.9 ± 4.52^{a}	12.9 ± 2.21^{b}	28.5± 7.39^{c}
	Direct sun drying	49.8 ± 1.47^{a}	12.5 ± 2.46^{b}	9.9 ± 2.51^{a}
Black jack	Raw	180.2 ±1.56^{e}	16.8 ± 1.23^{b}	84. 9 ± 0.41^{d}
	Boiling	26.3 ± 2.34^{a}	3.9 ± 0.47^{a}	42.5 ± 0.34^{c}
	Fermentation	102.6 ± 0.02^{d}	2.1 ± 0.38^{a}	42. 4 ± 0.36^{c}
	Blanching-solar drying	50.2 ± 4.17^{b}	15.7± 1.38^{b}	11.5 ±0.07^{a}
	Blanching-sun drying	31 ± 4.53^{a}	12.8 ± 2.33^{b}	8.8 ± 4.13^{bc}

Direct solar drying	64.6 ± 3.74^{c}	16.8 ± 1.73^{b}	14.4 ± 4.15^{c}
Direct sun drying	71.3 ± 1.97^{c}	14.4 ± 2.79^{b}	22.2 ± 1.66^{b}

Values are expressed as mean ± SD (n = 3). Mean values with different superscript letters along the columns are significantly different at $P < 0.05$

Oxalic acid

The levels (mg/100g) of oxalic acid ranged from 51.1±3.69to 136.5± 0.06in cassava leaves, 46.5 ± 1.25to 163.0 ± 0.08 in bitter lettuce and 31 ± 4.53to 180.2 ±1.56in black jack.The highest levels (mg/100g) of oxalic acid were recorded in raw black jack (180.2 ±1.56) followed by raw bitter lettuce (163.0 ± 0.08) and lastly raw cassava leaves (136.5± 0.06).There was a significant reduction ($P<0.05$) in oxalic acid in the processed vegetables. The trends in the levels of oxalic acid were: Raw> Fermentation> Direct sun drying> Blanching-solar drying> Blanching-sun drying> Boiling> Direct solar drying in cassava leaves. In bitter lettuce the levels of oxalic acid were observed in the following order: Raw> Boiling> Fermentation> Blanching-solar drying> Direct sun drying> Direct solar drying >Blanching-sun drying. Furthermore, oxalic acid levels in black jack were observed in the following trend: Raw> Fermentation> Direct sun drying> Direct solar drying> Blanching-solar drying> Blanching-sun drying> Boiling. The trend in the reduction of oxalic acid contents after different processing operations varied among vegetable samples and this could be attributed to the differences in the morphology and structure of the vegetable samples used.

Oxalic acid forms oxalates when it is combined with its salts such as calcium. Many green leafy vegetables contain oxalic acid in their cell sap as soluble salts of potassium and sodium and insoluble salts of calcium, magnesium and iron, or as a combination of these two types(Natesh*et al.*, 2017). Soluble oxalates combined with dietary calcium and other minerals produce a strong chelate, the complex becomes indigestible and difficult for the body to absorb and assimilate, thus affecting its bioavailability (Radek and Savage, 2008).

The total oxalate content reported in this study for cassava leaves and black jack was below the levels reported by Nasaka*et al.*, (2022). The levels of oxalate for raw bitter lettuce were higher compared to the one reported by Chacha*et al.* (2020). The inconsistency in oxalate content could be attributed to differences in vegetable species, varieties and the growing conditions of the vegetables. From the findings, oxalate levels were less than the compounds' mean lethal (15-30g) for adults per body weight this implies that the vegetable varieties were safe for consumption (Tsai *et al*., 2005).

Because soluble oxalate leached into the cooking water during boiling, the concentration of oxalic acid was dramatically reduced ($P<0.05$) in the current study (Huynh *et al*., 2022). Similarly, Kasimala*et al*., (2018) observed a reduction in oxalate after 15 minutes, based on their investigation of the impact of boiling on oxalate in various vegetables. There have also been reports of oxalates being lost from parsley (28.33%) and spinach (40%) after 15 minutes of boiling (Mohamad *et al*., 2021). Furthermore, higher temperatures and longer cooking times can break down vegetable tissues and release oxalate (Wang *et al*., 2018). Their study found that oxalic acid concentrations decreased dramatically after cooking for three minutes and at all treated temperatures. The present study confirms earlier research that boiling vegetables and other foods high in oxalate before consuming them can greatly lower the quantity of oxalic acid to safe levels and improve the minerals' bioavailability. Boiling causes, the loss of total oxalate, insoluble oxalates and soluble oxalates (Wanyo *et al*., 2020). The decrease in oxalic acid in processed vegetables is linked to an increase in the bioavailability of vital minerals, which helps to avert micronutrient deficiencies (Ertop and Bektaş, 2018).

The findings of this investigation showed that when compared to fresh vegetable samples, all drying methods considerably ($P<0.05$) reduced the amount of oxalate in each sample. This might be the result of the intense heat during solar and open drying which breaks down the leaf cells and vaporizes oxalate (Gafar *et al*., 2012). These results are in line with those of Nasaka*et al*., (2022), who discovered that sun drying reduces the amount of oxalate. Additionally, they align with the findings published by Kandonga (2019), who observed a drop in oxalic acid following the drying of common bean leaves. Furthermore, Kirakou*et al*., (2017) demonstrated that cowpea leaves' oxalate can be decreased by solar drying. This demonstrates that drying vegetables is a useful method for lowering the content of ant-nutritive elements and increasing the bioavailability of micronutrients.

The outcome of blanching vegetable samples in advance of solar and sun drying was only significant in bitter lettuce and black jack and varied with vegetable samples. In black jack blanched-dried samples had lower oxalate content than unblanched samples, while blanched-dried bitter lettuce had higher oxalate content than unblanched samples. This is not in line with findings from other writers who discovered that blanching speeds up the removal or decrease of oxalate in the cowpea leaves

(Kirakou et al., 2017; Kandonga, 2019; Virginia *et al*., 2012). The variations in the vegetable samples as well as the morphological structures of the samples used in the investigation could be the cause of the discrepancy in the results.

Additionally, several studies have found that sun and solar drying, with or without blanching, increases the oxalate level of vegetables. This suggests that the drying procedure has varying impacts on oxalate content. For instance, a study on jute mallow reported an increase in oxalate content after sun drying than other processing methods and suggested it was due to the concentration of existing compounds accelerated by evaporation and the breakdown of certain compounds that contributed to the rise in oxalic acid levels (Igwilo*et al*., (2018); Musa and Ogbadoyi, 2012). Nevertheless, Musa and Ogbadoyi, (2012) reported that the extended drying time under the sun can result in the breakdown of organic compounds possibly resulting in higher oxalate concentration in the sun and solar-dried samples Also, Wanyo*et al*., (2018) and Kondareddy*et al*., (2020) reported a significant increase in oxalate after the drying operation while the study done by Alassane *et al*. (2022) reported a non-significant difference in the levels of oxalate between raw and dried leafy vegetables consumed in Northern cote d'Ivoire. This implies that the effect of drying on oxalate content varies among vegetables.

In the case of fermentation, the oxalate content decreased in both vegetable samples. These results are in line with earlier research that showed a significant ($P<0.05$) drop in oxalate levels following fermentation. According to a study by Ijeoma and Adeyemi (2020), the oxalate content of fermented fluted pumpkin leaves decreased. The action of microorganisms that convert oxalic acid to formic acid and carbon dioxide during the fermentation process is responsible for the decrease in oxalic acid after fermentation (Li *et al*., 2022). The amount of oxalate breakdown is greatly influenced by the presence of bacteria and fermentation conditions such as salt content and incubation time (Srihardvastuti*et al*., 2021). This demonstrates how fermentation harms the amount of oxalate present in vegetable samples. The effect of fermentation on oxalate varies with vegetables as some writers have noted non-significant changes in oxalate after the fermentation of local vegetables in Kenya (John *et al*., 2014).The variability is due to differences in the vegetable matrix and the specific microbial communities involved in the fermentation process. The decrease in oxalate content after fermentation is of great importance since the presence of oxalate in low concentration tends to spare the available minerals in vegetables that will be required by the body.\

Hydrogen Cyanide

The levels (mg/100g) of hydrogen cyanide (HCN) ranged from 4.1 ± 2.49to 357.1 ± 10.56 in cassava leaves, 9.9 ± 2.51 to 116.4 ± 0.01 in bitter lettuce and 8.8 ± 4.13to 84. 9 ± 0.41 in black jack.The highest levels (mg/100g) of hydrogen cyanide were recorded in raw cassava leaves (357.1 ± 10.56), followed by raw bitter lettuce (116.4 ± 0.01) and lastly raw black jack (84. 9 ± 0.41).In cassava leaves, there was a significant reduction ($P<0.05$) in hydrogen cyanide in all processing methods. The highest reduction in hydrogen cyanide was observed in blanched-sun-dried cassava leaves followed by direct solar drying, direct sun drying, blanching-solar drying, boiling and lastly fermentation. In bitter lettuce, there was a significant reduction ($P<0.05$) in hydrogen cyanide in all processed samples. Direct sun-driedsamples had the lowest content of hydrogen cyanide. The trend in the content of hydrogen cyanide in bitter lettuce were: raw> fermentation > boiling > direct solar drying > blanching-sun drying >blanching-solar drying > direct sun drying. In black jack, there was a significant reduction ($P<0.05$) in hydrogen cyanide in all processing methods. The highest reduction in hydrogen cyanide was observed in blanched-sun-dried black jack followed by blanched-solar dried samples, direct solar-dried samples, direct sun-dried samples, fermented samples and finally boiled samples. The effect of the pretreatment blanching showed a significant difference ($P<0.05$) in hydrogen cyanide. The trend in the content of hydrogen cyanide was inconsistent among the three vegetable samples and this observation could be attributed to the difference in sample morphology and structure.

Cyanide is a toxic substance that can be lethal to humans and it is naturally present in several plants. It is a secondary plant metabolite stored in cellular vacuoles of plant tissues and tends to release hydrogen cyanide to protect plants from microbial and insect attacks (Kassim *et al*., 2015). The release of hydrogen cyanide during the hydrolysis of cyanogenic substance is toxic since it reacts with iron ions making it impossible to perform its normal functions in the body (Yu *et al*., 2015).

This study found that hydrogen cyanide concentrations in raw cassava leaves and black jack leaves were high compared to the levels reported by Maitha*et al*. (2022) and Essack*et al*. (2018) respectively. The inconsistency in the concentration of hydrogen cyanide may be attributed to the differences in the varieties used in the study, plant maturity and the growing conditions. FAO/WHO, (2021) recommends the cyanide level in diet not to exceed 10 mgHCN/kg dry weight, the assessed vegetables were not within the acceptable level for consumption and hence thorough processing before consumption is recommended to reduce its toxicity.

All processing methods reduced the levels of hydrogen cyanide in all three vegetable samples, even though the final concentration was not within the safe levels. Boiling resulted in a significant decrease in hydrogen cyanide because, hydrogen cyanide is soluble in water and tends to leach in water and volatilize to lower levels (Bolarinwa *et al.*, 2018). The same effect of boiling in hydrogen cyanide was reported by Ojiambo *et al.* (2017) who did a study on the effect of boiling on hydrogen cyanide in sweet cassava leaves and found a reduction of hydrogen cyanide by 88.65% after 25 minutes. Perhaps boiling for more than 15 minutes could reduce the cyanide content to safe levels for consumption. Also, a study by Tambalo*et al.* (2023) found that boiling whole cassava leaves resulted in a 32.01% reduction in total hydrogen cyanide. In addition to that, cutting or slicing cyanogenic foods into small pieces tends to disrupt the structure of the plant, following cooking such as boiling water may reduce cyanide content (Samad *et al.*, 2018). This depicts that boiling is among the effective methods for reducing the hydrogen cyanide content in vegetables for human consumption.

The present study also found that hydrogen cyanide significantly decreased ($P<0.05$) after fermentation. This could be attributed to the bacterial-produced linamarase that activates the hydrolysis of cyanogenic glycosides to hydrogen cyanide (Ahaotu*et al.*, 2013). Most of the previous reports on fermentation are consistent with the findings of this study. Fermentation has been shown to decrease the hydrogen cyanide content in various food products significantly. Studies have demonstrated that the process of fermentation can lead to a substantial reduction in hydrogen cyanide content to safe levels. For example, in the case of cassava tubers, prolonged fermentation (5 to 6 days) was found to effect a tremendous reduction in hydrogen cyanide (Iwuoha *et al.*, 2013). Thus fermentation process can be regarded as an effective way to reduce cyanides in vegetables.

All drying techniques used in this study reduced hydrogen cyanide content in vegetable samples because of the volatility property of cyanide at an ambient temperature (Andama *et al.,* 2017). Also according to Oliveira*et al.* (2016), the combination of blanching as pretreatment before drying has an additional effect in the reduction of anti-nutritive components due to the double treatments the foods are subjected to. In this study, the blanching treatment showed a non-significant difference in hydrogen cyanide content between the blanched and unblanched samples subjected to solar and sun drying, except for solar-dried bitter lettuce which proved to have an additional effect in reducing hydrogen cyanide content. This is in agreement with the report of Ayele*et al.*, (2022) on dried cassava leaves after blanching. The reduction of hydrogen cyanide after different drying operations as per this study shows that drying is also an effective way of reducing anti-nutritive components in vegetables.

Phytate

The levels of phytate (mg/100g) ranged from 0.7 ± 1.11to 18.8 ± 1.07 in cassava leaves, 2.65 ± 0.27to 16.8 ± 1.80in bitter lettuce and 3.9 ± 0.47to 16.8 ± 1.73 in black jack. The highest levels (mg/100g) of phytate were recorded in raw cassava leaves (18.8 ± 1.07), followed by raw bitter lettuce (16.8 ± 1.80) and lastly raw black jack (16.8 ± 1.23).The effect of the pretreatment blanching showed a non-significant difference in phytate content when compared to the drying treatment without pretreatment blanching in all three vegetable samples. Boiling treatment was observed to be effective in reducing the content of phytate among all processing operations in cassava leaves and bitter lettuce.In all vegetable samples, there was a significant decrease ($P<0.05$) in phytate after boiling and fermentation processes and there was a non-significant difference in phytate between raw samples and the sun solar dried samples with and without pretreatment blanching. The trend in the levels (mg/100g) of phytate in cassava leaveswas: blanching-solar drying > direct solar drying > blanching-sun drying> direct sun drying >raw> fermentation> boiling. Moreover, the levels of phytate in bitter lettuce were observed in the following order: raw> blanching-solar drying>blanching-sun drying>direct solar drying>direct sun drying> fermentation> boiling.Furthermore, the following trend was noted regarding the effect of different processing on phytate in black jack: direct solar drying>raw>blanching-solar drying>direct sun drying>blanching-sun drying >boiling>fermentation. The effects of pretreatment blanching showed a non-significant difference ($P<0.05$) in phytate content when compared to the drying treatment with and without pretreatment blanching in all three vegetable samples. The trend of the effect of different processing methods on phytate content varied among the three vegetable samples. This observation could be attributed to the nature of the vegetables analyzed, the initial concentration of phytate in the analyzed vegetables and the morphological structure of the analyzed vegetable.

Phytate refers to phytic acid made up of an inositol ring with six phosphate ester groups and its associated salts. Phytate is found in some indigenous vegetables and has diverse effects on the nutritional values of divalent and trivalent metal cations when it exceeds 20 mg/100g – 25 mg/100g (Nicodemas and Magoha, 2019). Phytate hinders protein digestibility but also affects the bioavailability of minerals such as iron, zinc and calcium since it is a negatively charged structure and can bind with positively charged ions such as zinc, iron and calcium to form complexes that are essentially non-absorbable and reduce their bioavailability (Al-hasan *et al*., 2016). The chelating property of phytate proves that phytate can cause mineral deficiencies in humans (Grases*et al*., 2017).

In this study, the average total phytate content reported for raw cassava leaves was low compared to the one reported by Tefere *et al,* (2022) and the phytate content of the raw black jack was higher than the one reported by Chatepaand Masamba, (2020). Moreover, bitter lettuce had a higher phytate level than the one reported by Chacha *et al*., (2020). The difference in vegetable samples used and growing environments for each vegetable may all have contributed to the inconsistent phytate levels in raw vegetable samples. The phytate content of boiled samples significantly decreased, this could be explained by phytate leaching into water and the development of insoluble complexes that reduce the amount of free phytate (Shimi and Hasnah, 2013). This observation aligns with research findings on grains and legumes reported by Lopez-Moreno *et al*., (2020) and on other traditional vegetables consumed in Malawi as reported by Issa *et al*., (2019). Furthermore, phytate content decreased significantly on heating dietary grains (Gupta *et al*., 2015). The reduction in phytate due to boiling can boost the bioavailability of minerals like calcium and iron which are otherwise blocked by phytate (Sathe and Venkatachalam, 2001).These findings support previous studies that boiling lowers the phytate content of vegetables, which is important for enhancing their nutritional value.

Additionally, this study found that the fermentation procedure greatly lowered the amount of phytate in vegetables. This may be related to the enzymatic breakdown of phytate during fermentation caused by bacteria secreting phytase enzymes (Wedad *et al*., 2008). According to the study on phytic acid in rice flour, phytase breaks the hexa form of phytic acid (IP6, Myo-inositol 1,2,3,4,5,6-hexakisphosphate) into lower forms during natural fermentation, which can result in a significant reduction in phytic acid (Gupta *et al.,* 2015). This could account for the decrease in phytate that occurs during fermentation in vegetable samples. Similar effects of fermentation on phytate have been reported by Terefe and Nduko, (2022) and Etsuyankpa *et al*. (2015). Due to low pH, the breakdown of phytate by phytase enzymes increases the bioavailability of minerals and other nutrients during fermentation (Jeyakumar and Lawrence, 2022). When phytate is reduced through boiling, it can increase the bioavailability of minerals like iron and calcium, which are otherwise hindered by phytate (Schlemmer*et al.*, 2009). This is vital for improving the nutritional quality of vegetables.

Furthermore, following drying operations, the present study reports a non-significant difference in phytate levels. The results contradict the earlier research that indicated a rise in phytate upon drying, which was be related to the concentration impact attributed to the water loss during the drying processes (Alassane*et al.,* 2022). Oulai *et al*., (2015) researched the impact of sun drying on phytate in several green vegetables and likewise reported a rise in phytate following different drying processes. Also, a study on *Amaranths Hybridus* and the leafy vegetables consumed in Northern Cote d'Ivoire reported an increase in phytate after drying (Alassane *et al*., 2022; Okafor and Agbam, 2023).Moreover, several earlier investigations have documented the drop in phytate following sun exposure and solar drying: (Ekpoand Baridia, 2020;Adegunwa*et al.* 2011;Nasaka*et al.*, 2022). According to Ademiluyi*et al*., (2018), vegetables lose phytate due to leaching brought on by the vaporization that happens during sun drying.

The effect of blanching before drying operations showed a non-significant difference in phytate in vegetables. The inconsistent outcomes could be ascribed to variations in the vegetable samples utilized in the study as well as variations in their morphological composition. These results show that drying methods do not affect the concentration of phytate in vegetables, moreover, vegetable types and the drying conditions influenced the obtained results.

CONCLUSION

This study demonstrated that boiling, fermentation, solar and sun drying (with and without blanching) have varied effects on the anti-nutritive components in the three indigenous vegetables. Through data analysis, it is obvious that processing methods can significantly decrease or have no effect on anti-nutritive components in the selected vegetables. Boiling and fermentation treatment was found to be efficient in the reduction of phytate, oxalic acid and hydrogen cyanide, this has a positive impact on the bioavailability of micronutrients in the selected vegetables. On the other hand, solar and sun drying of the selected vegetables have been found to decrease oxalic acid and hydrogen cyanide and have no effect on phytate. Blanching of vegetables before sun or solar drying has shown inconsistent effects among vegetables, but still, it is an important pretreatment as it increases the rate of drying and inactivates polyphenol oxidase enzymes.

Conclusively, this research highlights the effects of different commonly used processing methods on indigenous vegetables in local communities and hence it gives insights into the prevention of micronutrient loss as some of the processing methods assessed have shown how they can effectively reduce the concentration of anti-nutritive components which means enhancing micronutrients availability. Understanding these effects is crucial for optimizing food preparation techniques to preserve the nutritional value of indigenous vegetables.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of manuscripts.

ACKNOWLEDGEMENTS

The authors acknowledge the financial support from the FoCo-Active project. The project is supported by funds from the Federal Ministry of Food and Agriculture (BMEL) based on a decision of the parliament of the Federal Republic of Germany via the Federal Office for Agriculture and Food (BLE). The funders had no role in the study design, data collection, analysis or the decision to publish.

COMPETING INTERESTS

The authors have declared that no competing interests exist.

REFERENCES

Adegunwa, M. O., Alamu, E. O., Bakare, H. A., & Oyeniyi, C. O. (2011). Proximate and bioactive contents of some selected vegetables in Nigeria: Processing and varietal effects. *American Journal of Food and Nutrition*, **1**(4): 171-177.

Ademiluyi, A. O., Aladeselu, O. H., Oboh, G., &Boligon, A. A. (2018). Drying alters the phenolic constituents, antioxidant properties, α□amylase, and α□glucosidase inhibitory properties of the Moringa (Moringa oleifera) leaf. *Food science & nutrition*, **6**(8); 2123-2133.

Ahaotu, I., Ogueke, C. C., Owuamanam, C. I., Ahaotu, N. N., & Nwosu, J. N. (2013). Fermentation of undewatered cassava pulp by linamarase producing microorganisms: effect on nutritional composition and residual cyanide. *American Journal of Food and Nutrition*, **3**(1): 1-8.

Al Hasan, S. M., Hassan, M., Saha, S., Islam, M., Billah, M., & Islam, S. (2016). Dietary phytate intake inhibits the bioavailability of iron and calcium in the diets of pregnant women in rural Bangladesh: a cross-sectional study. *BMC Nutrition*, **2**(24**)**: 1-10.

Alassane, C. T., Abdoulaye, T., Fabrice, Z. A., Claude, K. A. L., Souleymane, M., &Adama, C. (2022). Effect of three drying modes on nutritive and antinutritive properties of leafy vegetables consumed in Northern Côte d'Ivoire. *EAS Journal of Nutrition and Food Sciences*, **4**(4): 102-111.

Ali, A., Devarajan, S., Manickavasagan, A., & Ata, A. (2022). Antinutritional Factors and Biological Constraints in the Utilization of Plant Protein Foods. In *Plant Protein Foods* (pp. 407-438). Cham: Springer International Publishing

Andama, M., Lejju, J. B., & Oloya, B. (2017). The potential of soaking and sun-drying in detoxifying toxic cassava root tubers. *International Journal of Food Science and Biotechnology*. **2**(4): 103-105

Angeles-Agdeppa, I., Toledo, M. B., & Zamora, J. A. T. (2021). Moderate and severe level of food insecurity is associated with high calorie-dense food consumption in Filipino households. *Journal of Nutrition and Metabolism*, **2021**;1-15

AOAC Official Method of Analysis, 15th ed. (1998). Official Methods of Analysis 19 Ed. Association of Analytical Chemists, Washington D.C.

AOAC. 2000. Official Methods of Analysis. (Ed.): Horwitz, W. 17th AOAC International, Arlington, VA, USA.

Ayele, H. H., Latif, S., & Müller, J. (2022). Pretreatment of the Leaves of Ethiopian Cassava (Manihot esculenta Crantz) Varieties: Effect of Blanching on the Quality of Dried Cassava Leaves. *Applied Sciences*, **12**(21): 11231.

Bokelmann, W., Huyskens-Keil, S., Ferenczi, Z., & Stöber, S. (2022). The role of indigenous vegetables to improve food and nutrition security: Experiences from the project HORTINLEA in Kenya (2014–2018). *Frontiers in Sustainable Food Systems*, **6**: 806420.

Bolarinwa, I. F., Olaniyan, S. A., Olatunde, S. J., Ayandokun, F. T., &Olaifa, I. A. (2016). Effect of processing on amygdalin and cyanide contents of some Nigerian foods. *Journal of Chemical and Pharmaceutical Research*, **8**(2): 106-113.

Chadha, M. L., & Oluoch, M. O. (2003). Home-based vegetable gardens and other strategies to overcome micronutrient malnutrition in developing countries. *Food Nutrition and Agriculture*, **32**: 17-23.

Chatepa, L. E. C., & Masamba, K. G. (2020). Proximate and phytochemical composition of selected indigenous leafy vegetables consumed in Malawi. *African Journal of Food Science*, **14**(9): 265-273.

Conti, M. V., De Giuseppe, R., Monti, M. C., Mkindi, A. G., Mshanga, N. H., Ceppi, S., ... & Cena, H. (2021). Indigenous vegetables: a sustainable approach to improve micronutrient adequacy in Tanzanian women of childbearing age. *European Journal of Clinical Nutrition*, **75**(10): 1475-1482.

Da Silva Santos, B. R., Silva, E. F. R., Minho, L. A. C., Brandao, G. C., dos Santos, A. M. P., dos Santos, W. P. C., ... & dos Santos, W. N. L. (2020). Evaluation of the nutritional composition in the effect of processing cassava leaves (Manihot esculenta) using multivariate analysis techniques. *Microchemical Journal*, **152:** 104271.

Dey, S., Saxena, A., Kumar, Y., Maity, T., & Tarafdar, A. (2022). Understanding the antinutritional factors and bioactive compounds of kodo millet (Paspalumscrobiculatum) and little millet (Panicumsumatrense). *Journal of Food Quality*, **2022:** 1-19.

Ekpo, U. A., & Baridia, D. F. (2020). Effect of Processing on the Chemical and Antinutritional Properties of Cassava Leaves (Sweet and bitter varieties). *ARC Journal of Nutrition and Growth*, **6**(2): 6-12.

Ertop, M. H., & Bektaş, M. (2018). Enhancement of bioavailable micronutrients and reduction of antinutrients in foods with some processes. *Food and Health*, **4**(3): 159-165.

Essack, H. (2018). Screening of traditional South African leafy vegetables for selected anti-nutrient factors before and after processing (Doctoral dissertation).

Etsuyankpa, M. B., Gimba, C. E., Agbaji, E. B., Omoniyi, K. I., Ndamitso, M. M., & Mathew, J. T. (2015). Assessment of the effects of microbial fermentation on selected anti-nutrients in the products of four local cassava varieties from Niger state, Nigeria. *American Journal of Food Science and Technology,***3**(3): 89-96.

Gafar, M. K., Itodo, A. U., &Senchi, D. S. (2012). Nutritive and anti-nutritive composition of Chancapiedra (stone breaker). *Journal of Food and Public Health*, **2**(2): 21-27

Gogo, E. O., Opiyo, A. M., Ulrichs, C., &Huyskens-Keil, S. (2017). Nutritional and economic postharvest loss analysis of African indigenous leafy vegetables along the supply chain in Kenya. *Postharvest Biology and Technology*, **130**: 39-47.

Gogo, E. O., Opiyo, A., Ulrichs, C., &Huyskens-Keil, S. (2018). Loss of African indigenous leafy vegetables along the supply chain. *International Journal of Vegetable Science*, **24**(4): 361-382.

Grases, F., Prieto, R. M., & Costa-Bauza, A. (2017). Dietary phytate and interactions with mineral nutrients. In: Gutiérrez, O., Kalantar-Zadeh, K., Mehrotra, R. (eds) *Clinical aspects of natural and added phosphorus in foods*, Nutrition and Health. Springer, New York, NY, 175-183.

Gupta, R. K., Gangoliya, S. S., & Singh, N. K. (2015). Reduction of phytic acid and enhancement of bioavailable micronutrients in food grains. *Journal of food science and technology*, **52**: 676-684.

Huynh, N. K., Nguyen, D. H., & Nguyen, H. V. (2022). Effects of processing on oxalate contents in plant foods: A review. *Journal of Food Composition and Analysis*, **112**:104685.

Igwilo, I. O., Iwualla, L. C., Igwilo, S. N., Agbara, A. C., Okpala, C. O., &Ezeigwe, C. O. (2018). Proximate analysis and phytochemical composition of fresh and dried fruit of Morinda Lucida. *The Bioscientist Journal*, **6**(1): 31-39.

Ijeoma, O., & Adeyemi, O. O. (2020). Effect of fermentation on some minerals and antinutrient content of TelfairaOccidentalis and GnetumAfricanum leaves. *International Journal of Advances in Scientific Research and Engineering.***6**(2): 6-14

Issa, J. Y., Onyango, A., Makokha, A. O., & Okoth, J. (2019). Effect of Boiling and Wet Frying on Nutritional and Antinutrient Content of Traditional Vegetables Commonly Consumed in Malawi. *Journal of Food Research*, **9**(1): 19-33.

Iwuoha, G. N., Ubeng, G. G., &Onwuachu, U. I. (2013). Detoxification effect of fermentation on cyanide content of cassava tuber. *Journal of Applied Sciences and Environmental Management*, **17**(4): 567-570

Jeyakumar, E., & Lawrence, R. (2022). Microbial fermentation for reduction of antinutritional factors. In *Current Developments in Biotechnology and Bioengineering* (pp. 239-260). Elsevier.

John, S. E., Azizi, K., Hancy, A., Twin'omujuni, A., Katana, D., Shine, J., ... &Masumo, R. M. (2023). The prevalence and risk factors associated with Iron, vitamin B12 and folate deficiencies in pregnant women: A cross-sectional study in Mbeya, Tanzania. *PLOS Global Public Health*, **3**(4): e0001828

John, W. A., Kimiywe, J., & Hudson, N. (2014, August). Determination of phytate and oxalate in selected recipes of underutilized local vegetables from the Lake Victoria Basin, Kenya. In XXIX International Horticultural Congress on Horticulture: Sustaining Lives, Livelihoods and Landscapes (IHC2014): **1102:** 275-286.

Joint, F. A. O., World Health Organization, & WHO Expert Committee on Food Additives. (2011). Evaluation of certain food additives and contaminants: seventy-fourth [74th] report of the Joint FAO/WHO Expert Committee on Food Additives. World Health Organization.

Kandonga, A. (2019). *Effect of blanching and drying on micronutrients and anti-nutritional factors in false sesame and common bean leaves* (Doctoral dissertation, NM-AIST).

Kasimala, M. B., Tedros, B., Weldeyeyus, M., Imru, H., &Tsighe, N. K. (2018). Determination of oxalates and investigation of the effect of boiling on oxalate content from selected vegetables commonly grown in Eritrea. *Journal of Atoms and Molecules*, **8**(4): 1175-1180.

Kassim, M. A. (2015). Hydroxynitrilelyase activity in non-commercialised plants (Doctoral dissertation, School of Molecular and Cell Biology, Faculty of Science, University of the Witwatersrand, Johannesburg).

Katoch, R. (2022). Nutritional and Anti-Nutritional Constituents in Forages. In *Nutritional Quality Management of Forages in the Himalayan Region* (pp. 193-223). Singapore: Springer Singapore.

Kiani, A. K., Dhuli, K., Donato, K., Aquilanti, B., Velluti, V., Matera, G., Iaconelli, A., Connelly, S. T., Bellinato, F., Gisondi, P., & Bertelli, M. (2022). Main nutritional deficiencies. *Journal of preventive medicine and hygiene*, **63**(2 Suppl 3), E93–E101.

Kirakou, P. S., Hutchinson, J. M., Ambuko, J., & Owino, W. O. (2017). Efficacy of blanching techniques and solar drying in maintaining the quality attributes of cowpea leaves. *African Journal of Horticultural Science*. **11**:18-34.

Kondareddy, R., Sivakumaran, N., Radhakrishnan, K., & Nayak, P. K. (2020, March). Performance analysis of solar tunnel dryer with thermal storage and Photovoltaic system for drying star fruit. In IOP Conference Series: Earth and Environmental Science (Vol. 463, No. 1, p. 012138). IOP Publishing.

Li, X., He, T., Mao, J., & Sha, R. (2022). Effects of lactic acid bacteria fermentation on physicochemical properties, functional compounds and antioxidant activity of edible grass. *Fermentation*, **8**(11): 647.

Lopes, Sílvia Oliveira, LíviaCarvalhoSetteAbrantes, Francilene Maria Azevedo, Núbia de Souza de Morais, Dayane de Castro Morais, Vivian Siqueira Santos Gonçalves, Edimar Aparecida Filomeno Fontes, Sylvia do Carmo Castro Franceschini, and Silvia Eloiza Priore. (2023) "Food Insecurity and Micronutrient Deficiency in Adults: A Systematic Review and Meta-Analysis." *Nutrients*, **15 (5)**: 1074.

López-Moreno, M., Garcés-Rimón, M., & Miguel, M. (2022). Antinutrients: Lectins, goitrogens, phytates, and oxalates, friends or foe? *Journal of Functional Foods*, **89**: 104938.

Maitha, P. M., Kamau, S., Kimatu, J. N., &Hunja, C. W. (2022). An Analysis of the Hydrogen Cyanide Concentration in Four Cassava Varieties Grown in Lukenya University Farm, Makueni County, Kenya. *Journal of African Interdisciplinary Studies*, **6**(11): 225 – 237

Mepba, H. D., Eboh, L., &Banigo, D. E. B. (2007). Effects of processing treatments on the nutritive composition and consumer acceptance of some Nigerian edible leafy vegetables. *African Journal of Food, Agriculture, Nutrition and Development*, **7**(1): 2-18

Ministry of Health (MoH) [Tanzania Mainland], Ministry of Health (MoH) [Zanzibar], National Bureau ofStatistics (NBS), Office of the Chief Government Statistician (OCGS), and ICF. 2022. *Tanzania Demographicand Health Survey and Malaria Indicator Survey 2022 Final Report.* Dodoma, Tanzania, and Rockville,Maryland, USA: MoH, NBS, OCGS, and ICF

Mohamad, A. A., &Zehouri, J. A. (2021). The effect of the boiling process on the Oxalic acid content of some vegetables in the Syrian local market. *Research Journal of Pharmacy and Technology*, **14**(10): 5341-5344.

Mongi, R. J., & Ngoma, S. J. (2022). Effect of solar drying methods on proximate composition, sugar profile and organic acids of mango varieties in Tanzania. *Applied Food Research*, **2**(2): 100140.

Musa, A., &Ogbadoyi, E. O. (2012). Effect of cooking and sun drying on micronutrients, antinutrients and toxic substances in Corchorusolitorius (Jute Mallow). *Journal of Nutrition and Food Science*, **2**(14): 2-9.

Nasaka, J., Nizeyi, J. B., Okello, S., & Katongole, C. B. (2022). Sun-drying is an effective strategy to reduce the total oxalate and phytate contents of plant leaves commonly used in quail feeding in Uganda. *Tropical Agriculture*, **99**(2): 11-11.

Natesh, H. N., Abbey, L., &Asiedu, S. K. (2017). An overview of nutritional and antinutritional factors in green leafy vegetables. *Horticulture International Journal*, **1**(2): 58-65.

Nicholaus, C., Martin, H. D., Kassim, N., Matemu, A. O., &Kimiywe, J. (2020). Dietary practices, nutrient adequacy, and nutrition status among adolescents in boarding high schools in the Kilimanjaro region, Tanzania. *Journal of Nutrition and Metabolism*, **2020**(7929);1-14.

Nicodemas, D., Tungarazafweja, L. W., &Magoha, H. S. (2019). Evaluation of the Contribution of Cassava Staple to the Recommended Dietary Allowance of Selected Nutrients Among the Under Five Children in Mtwara Rural District, Tanzania. *Current Research in Nutrition & Food Science*, **7**(1): 190-201

Noor, R. A. (2019). Micronutrient Deficiencies Among Vulnerable Populations in Tanzania: Evidence for Interventions and Programmatic Implications (Doctoral dissertation, Harvard University).

Oboh, G., Oyeleye, S. I., &Ademiluyi, A. O. (2017, November). The food and medicinal values of indigenous leafy vegetables. In *African Vegetables Forum* **1238**: 137-156.

Ojiambo, O. C., Nawiri, M. P., & Masika, E. (2017). Reduction of cyanide levels in sweet cassava leaves grown in Busia County, Kenya based on different processing methods. *Food Research*, **1**(3): 97-102.

Okafor, U. M., &Agbam, E. F. (2023). The effect of sun and oven drying methods on the antinutrient content of amarantushybridus, talinumtriangulare and teifairiaoccidentalis. *Nnadiebube Journal of Education in Africa*, **8**(3):65-73

Okiki, P. A., Osibote, I. A., Balogun, O., Oyinloye, B. E., Idris, O. O., Adelegan, O., ... &Olagbemide, P. T. (2015). Evaluation of proximate, minerals, vitamins and phytochemical composition of Moringa oleifera Lam. cultivated in Ado Ekiti, Nigeria. *Advances in Biological Research*, **9**(6), 436-443.

Oliveira, S. M., Brandao, T. R., & Silva, C. L. (2016). Influence of drying processes and pretreatments on nutritional and bioactive characteristics of dried vegetables: A review. *Food Engineering Reviews*, **8**(2): 134-163.

Oulai, P. D., Zoué, L. T., Niamkey, A. J., &Niamké, S. L. (2015). Impact of Sun Drying on the Nutritive and Antioxidant Properties of Five Leafy Vegetables Consumed in Northern Côte d'Ivoire. *Asian Journal of Applied Sciences*, **3**(5): 628-637

Radek, M., & Savage, G. P. (2008). Oxalates in some Indian green leafy vegetables. *International Journal of Food Sciences and Nutrition*, **59**(3): 246-260.

Samad, S., Hasbullah, H. R., & Hasan, S. (2018). Chemical properties of high-quality cassava flour (HQCF) from several varieties of cassava. *Pakistan Journal of Nutrition*, **17**: 615-621.

Samtiya, M., Aluko, R. E., & Dhewa, T. (2020). Plant food anti-nutritional factors and their reduction strategies: an overview. *Food Production, Processing and Nutrition*, **2**: 1-14.

Sarkar, T., Salauddin, M., Roy, S., Chakraborty, R., Rebezov, M., Shariati, M. A., ... &Rengasamy, K. R. R. (2023). Underutilized green leafy vegetables: Frontier in fortified food development and nutrition. *Critical Reviews in Food Science and Nutrition*, **63**(33): 11679-11733

Schlemmer, U., Frølich, W., Prieto, R. M., &Grases, F. (2009). Phytate in foods and significance for humans: food sources, intake, processing, bioavailability, protective role and analysis. *Molecular nutrition & food research*, **53**(2): 330-375.

Shimi, G., & Hasnah, H. (2013). Does cooking affect the phytate content in local soy-based dishes? *International Food Research Journal*, **920**(5):2873-2880.

Sivakumar, D., Phan, A. D. T., Slabbert, R. M., Sultanbawa, Y., &Remize, F. (2020). Phytochemical and nutritional quality changes during irrigation and postharvest processing of the underutilized vegetable African nightshade. *Frontiers in Nutrition*, **7**: 576532.

Smith, I. F., & Eyzaguirre, P. (2007). African Leafy Vegetables: Their Role in the World Health Organization's Global Fruit and Vegetables. *African Journal of Food Agriculture Nutrition and development*; **7**(3): 1-17

Srihardyastuti, A., Prasetyawan, S., Firdaus, R. Z., Prayugo, F. B., Kresmonia, Y., Ananda, T. D., & Salamah, A. (2021). The effect of NaCl concentration and incubation time on oxalate and total acid in fermented cabbage using various microorganisms. *Journal of Pure and Applied Chemistry Research***10**(1): 27-36

Stevens, G. A., Beal, T., Mbuya, M. N., Luo, H., Neufeld, L. M., Addo, O. Y., ... & Young, M. F. (2022). Micronutrient deficiencies among preschool-aged children and women of reproductive age worldwide: a pooled analysis of individual-level data from population-representative surveys. *The Lancet Global Health*, **10**(11): 1590-1599.

Tambalo, F. M. Z., Capuno, R. B. A., Estrellana, C. D., Garcia, J. F., & Arcillas, L. S. N. (2023). Effect of Processing on the Antinutrient and Protein Contents of Cassava Leaves from Selected Varieties. *Philippine Journal of Science*, **152**(2); 561-570

Terefe, Z. K., Omwamba, M., & Nduko, J. M. (2022). Effect of microbial fermentation on nutritional and antinutritional contents of cassava leaf. *Journal of Food Safety*, **42**(3): e12969

Tsai, J. Y., Huang, J. K., Wu, T. T., & Lee, Y. H. (2005). Comparison of oxalate content in foods and beverages in Taiwan. *JTUA*, **16**(3), 93-98.

Vatansever, Serap, AnuradhaVegi, Julie Garden-Robinson, and CA, III Hall. "The effect of fermentation on the physicochemical characteristics of dry-salted vegetables. *Journal of Food Research*, **6**(5): 32-40.

Virginia, P., Swati, V., & Ajit, P. (2012). Effect of cooking and processing methods on oxalate content of green leafy vegetables and pulses. *Asian Journal of Food and Agro-Industry*, **5**(4): 311-314.

Wang, Z., Ando, A., Takeuchi, A., & Ueda, H. (2018). Effects of cooking conditions on the relationships among oxalate, nitrate, and lutein in spinach. *Food Science and Technology Research*, **24**(3): 421-425

Wanyo, P., Huaisan, K., Boothaisong, S., Nitisuk, P., Wongpreedee, P., &Chamsai, T. (2018). Effect of hot-air drying and vacuum drying on oxalate contents of Limnophilaaromatica and Limnophilageoffrayi. *Food and Applied Bioscience Journal*, **6**(2): 65-75.

Wedad, H. A., El Tinay, A. H., Mustafa, A. I., & Babiker, E. E. (2008). Effect of fermentation, malt-pretreatment and cooking on antinutritional factors and protein digestibility of sorghum cultivars. *Pakistan Journal of Nutrition*, **7**(2): 335-341.

Yu, X. Z. (2015). Uptake, assimilation and toxicity of cyanogenic compounds in plants: facts and fiction. *International Journal of Environmental Science and Technology*, **12**: 763-774.