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Quantifying Turkana's wild edible plants' contribution to critical micronutrient and dietary diversity among women of reproductive age

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ABSTRACT

This study explored wild edible plants' (WEPs) contribution to dietary diversity and micronutrient intakes of women in Turkana County using a multi-method quantitative research design. In addition to the nutrient composition analysis of four vegetable plants and one edible fruit collected from the wild, two survey rounds were conducted – in 2020 during COVID ($n = 360$) and in 2022 during extreme drought ($n = 600$), to collect dietary intake data of women using 24-h recall. The study revealed that WEPs contribute 12% to 30% of the total daily food intake among women, and 0.6 to 1.4 food groups to dietary diversity, depending on the season. All the five WEPs tested contained on average 0.5 mg zinc, 6.4–25.5 mg iron, and 97.8–330.8 mg calcium per 100 g edible portion. This study demonstrates the significance of WEPs' nutritional contribution to the Turkana communities' diets, and their pivotal role during times of food scarcity, and recommends their promotion alongside measures to prevent their overexploitation.

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Wild edible plants; Turkana county; nutrient composition; dietary intakes; drought; micronutrient; dietary diversity; carotenoids

Introduction

The Kenyan drylands face extreme food insecurity, with at least 2 million people affected every year (IPC Global Partners 2021, 2023). Erratic rainfall, poor agricultural production, high food prices and extreme poverty are the main drivers of food insecurity (IPC Global Partners 2021, 2023). In Turkana County, 21% of children are stunted, and only 28% of children and 6.8% of women consume a sufficiently diversified diet (Bioversity International, 2020; Ministry of Health-Kenya, 2023).

Wild edible plants (WEPs) present a unique and under-explored group of crops within dryland ecosystems (Borelli, Hunter, Powell, et al., 2020; Koffi et al., 2020). The use of wild species for food security and nutritional improvement is recognized by international policies and agreements, such as the 2030 Agenda for Sustainable Development (SDG2, Target 2.5). WEPs play a crucial role in the food security and livelihoods of communities, particularly during famines and droughts (Feyssa et al., 2011; Guyu & Muluneh, 2015; Ogoye-Ndegwa, 2003; Teklehaymanot & Giday, 2010) and food price spikes (de Beurs & Brown, 2013).

Studies on the nutrient composition of WEPs, albeit few, demonstrate their huge potential for supporting dietary and nutritional diversity. For instance, species *Grewia ferruginea* Hochst. ex A. Rich. and *Diospyros mespiliformis* Hochst. ex A. DC. widely found in Ethiopia have shown high nutrient values comparable to the energy values, protein, and fat contents of widely consumed cereals such as barely, corn, wheat, and teff (Bahir Dar University, 2016). Similarly, high mineral contents have been reported by many researchers in

wild foods (Bahir Dar University, 2016; Fentahun & Hager, 2009; Singh et al., 2018). In the Kenyan drylands, the widely distributed Turkana Doum Palm (*Hyphaene coriacea* Gaertn.) has been reported as an excellent source of iron (28.9 mg/100 g) and a reasonable dietary source of zinc (3.4 mg/100 g), essential amino acids, and dietary fiber (Lokuruka, 2007). Additionally, recent studies have highlighted the nutritional importance of WEPs across various regions. In Northeast India, Ngurthankhumi et al. (2024) analyzed seven wild edible fruits and found them to be rich sources of various nutrients, including vitamins, minerals, and antioxidants. Similarly, Jiru et al. (2023) examined four underutilized wild edible fruits in Ethiopia and reported significant levels of nutrients and antioxidants, with some species showing higher nutritional composition compared to similar fruits in other parts of the world. Talang et al. (2023) analyzed 14 wild edible plant species from Northeast India and found that several wild edible plants showed higher nutrient concentrations than commercial crops.

The contribution of WEPs to dietary diversity has also been documented. Cheek et al. (2023) conducted a study in rural India and found that women who consumed wild foods had 12–15% higher average dietary diversity scores during lean seasons. Wild foods significantly improved dietary diversity, especially for women with very low dietary diversity scores. The study also highlighted the economic implications of WEP consumption, as these foods provided access to nutritious options when market prices for vegetables were highest. These studies demonstrate WEPs' potential in adding to the dietary diversity and enhancing food

security and micronutrient intakes of vulnerable communities.

Despite these promising studies, significant gaps remain in our understanding of WEPs' specific contributions to dietary diversity and micronutrient intakes in many regions, including Turkana region of Kenya. There is a notable lack of quantitative data on WEPs' contribution to dietary diversity and micronutrient intake, especially during periods of environmental and economic stress. This gap is compounded by limited nutrient composition analyses of locally important WEP species in Turkana, which hinders a comprehensive assessment of their nutritional potential. Furthermore, our understanding of how WEPs' utilization and importance may shift during challenging periods, such as the COVID-19 pandemic or extreme drought events, remains insufficient.

An improved understanding of WEPs' nutritional contribution to food security, livelihoods, and dietary intakes is crucial for enhancing communities' engagement in conserving these valuable resources. Lack of information about wild foods' nutrient composition and dietary benefits has been identified by many researchers as a major bottleneck to their use (Borelli, Hunter, Powell, et al., 2020; Duguma, 2020).

This study aims to address these knowledge gaps by providing a comprehensive analysis of WEPs in Turkana County. We offer the first quantitative assessment of WEPs' contribution to dietary diversity and intake across two economically challenging seasons: the COVID-19 pandemic and an unprecedented drought. Additionally, we present new nutrient composition data for selected locally important WEP species, significantly expanding the available information on these plants' nutritional profiles. Through this multifaceted approach, our research offers unique insights into WEPs' potential as a resilience strategy for food security in the face of increasing climate variability. By examining WEPs' role during both acute (pandemic) and chronic (drought) stressors, we provide a better understanding of their importance in maintaining nutritional security under diverse challenging conditions.

Our findings have important implications for local and national food security policies, particularly in light of increasing climate variability in the region. This study not only contributes to efforts to improve the Turkana people's food security and livelihoods while safeguarding their cultural heritage, but also aligns with several Sustainable Development Goals, specifically combating poverty (SDG1), hunger (SDG2), climate change (SDG13) and biodiversity loss (SDG15) (UN, 2023). By examining WEPs' buffering role during extreme events, the research offers insights into potential climate change adaptation strategies for food security in dryland ecosystems.

Materials and methods

Description of the study context

The study was conducted in Loima and Turkana South sub-counties of Turkana County, Kenya. The Turkana County population principally consists of the Turkana people, a Nilotic community who have traditionally practiced nomadic pastoralism. Wild edible foods have played a vital role in

the Turkana diet and are still considered part of their cultural heritage (Oduor et al., 2023).

Turkana County is characterized by high temperatures, poor rainfall, recurrent droughts, high levels of poverty and inequality and poor infrastructural development (KNBS, 2013; Shanguhya, 2021). With 80% of the population living below the poverty line (KNBS, 2020), Turkana County is a major food insecurity and malnutrition hotspot in Kenya (WFP and FAO, 2023).

Data was collected at two significant times for the Turkana community. The first round was conducted in August 2020, 5 months after the first-reported case of COVID-19 in Kenya and immediately following the lifting of countrywide lockdowns and travel bans. The COVID-19 containment measures negatively affected the communities' livelihoods through closure of livestock and food markets, movement restrictions, supply chain disruptions, reduced healthcare delivery and lost income from complementary livelihoods (Duba & Hailu, 2022; Griffith et al., 2021). The second survey round was conducted in July 2022, during a catastrophic drought in Eastern Africa – the worst in 40 years – following five consecutive failed rains (IOM, 2022; NDMA, 2022). The drought caused the death of millions of livestock, destroying pastoralist communities' livelihoods, and was further compounded by high inflation and economic difficulties resulting from the Ukraine war (Hassen & Hamid, 2022).

Study design and sampling approach

This study employed a multi-method quantitative simultaneous research design (Lartey et al., 2016; Mark, 2015) to explore the contribution of WEPs to women's diets in the Turkana community (Figure 1). The study combined repeated 24-h dietary intake recalls across two seasons with laboratory analysis of food composition and phytochemical profiling of selected WEPs. The study is embedded within a larger experimental research project evaluating community-based participatory approaches to enhance agrobiodiversity use for dietary improvement, enhanced resilience and diversifying income opportunities (Oduor, 2020). This overarching project employs a baseline–endline design with treatment and comparison study arms.

Quantitative household data were collected through two cross-sectional surveys (baseline and endline) of the experimental study, encompassing household-level information and individual dietary data. These were complemented by food compositional analysis of selected wild edible plants harvested from the study area.

The sampling procedure utilized a multi-stage approach, first selecting sub-counties, then community health units, and finally individual households within these units. This method ensured a representative sample of the Turkana population, including both pastoral and agro-pastoral livelihood zones. Random selection was employed at each stage to minimize bias except in the first stage where two sub-counties, Turkana South and Loima, were purposively selected out of the seven sub-counties in Turkana County due to ongoing organizational operations and existing project implementations in these areas. While this selection was based on logistical considerations, these sub-counties are representative of the broader Turkana region in terms of livelihood patterns, cultural practices and food consumption

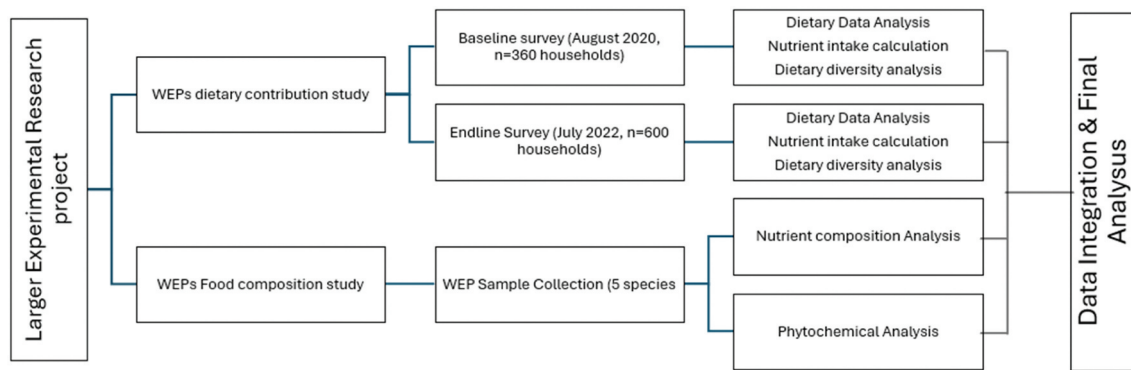


Figure 1. Flow diagram for multi-method quantitative research design for assessing the contribution of WEPs to dietary intake and food compositional potential of WEPs.

habits. From these two sub-counties, 20 community health units were initially chosen for the study. However, due to safety concerns, three units were excluded, resulting in a final sample of 17 community health units participating in this study. Of these, 10 units were from Loima and 7 from Turkana South. Ten of the 17 units received interventions as part of the broader research project.

The study was conducted in two survey rounds. In the first round, 360 households were sampled, while the second round expanded to include 600 households. This increase in sample size for the second round allowed for a more comprehensive dataset and improved statistical power in the broader project. For a more detailed description of the sampling methodology, including the selection criteria for households and individuals within households, readers are directed to F. O. Oduor et al. (2023)

The study protocols were reviewed and approved by the AMREF Ethics and Scientific Review Committee (ESRC P688/2019), and participants' informed consent was obtained prior to their involvement in the study.

Collection and analysis of dietary intake data

Dietary intake data from women of reproductive age (16–49) were collected using a 24-h dietary intake recall methodology, repeated among half of the survey participants during both survey rounds. Data collected included the kind of foods consumed, ingredients used, ingredient quantities and quantity of foods consumed. Quantities were estimated using direct weighing, household measures, play dough models, monetary values, and graduated measuring cylinders. This information was used to compute the amounts of each ingredient consumed in grams per food. These data were entered in Lucille food intake program, a software that calculates calorie and nutrient intakes based on quantities of foods consumed and food composition data.

Nutrient intakes were calculated by combining the quantity of each food item consumed, as reported in the 24-h dietary recalls, with its nutrient composition. Composition data from the Kenya Food Composition Table (FCT) (FAO/GoK, 2018) was used and supplemented with data from other food composition databases, including the Tanzanian FCTs (Lukmanji & Hertzmark, 2008), the FAO/INFOODS Food Composition Database (Charrondiere et al., 2013), and published articles on WEP nutrient composition (Al-Bukhaiti et al., 2018; Aly & Jules, 2011; Ayessou et al., 2014; Idirs et al., 2010; Petropoulos et al., 2019; Yimer et al., 2023). In

cases where specific nutrients were not found in any literature, arithmetic means of related wild foods' nutrient composition were adopted.

The nutrient composition data presented in the Results section (Tables 2, 3, and 4) were derived from the combination of reported food intake data from the 24 h recalls and the food composition information from the sources described above. These calculations represent estimated actual nutrient intakes based on reported consumption, not theoretical values. Usual nutrient intakes were computed using the Multiple Source Method (German Institute of Human Nutrition Potsdam-Rehbruecke, 2023), which estimates and removes intra-individual variability in dietary intake.

Usual nutrient intakes were computed using the Multiple Source Method (German Institute of Human Nutrition Potsdam-Rehbruecke, 2023), which estimates and removes intra-individual variability in dietary intake. Statistical analyses were conducted using IBM SPSS Statistics (version 23). Descriptive statistics included means, and standard deviations for continuous variables, and percentages for categorical variables. Proportions were compared using chi-square tests, while means were compared using independent sample t-tests. All statistical tests were two-tailed, with a significance set at $p < .05$.

To assess the nutritional adequacy of the diets, we compared the mean nutrient intakes from each survey round and the pooled sample to the Recommended Dietary Allowances (RDAs) for women of reproductive age. We used the RDA values for age groups 14–18 years, 19–30 years, and 31–50 years as our reference values, sourced from (Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids, 2005). The percentage of RDA met was calculated by dividing the mean intake by the highest RDA value for each nutrient across age groups and multiplying by 100. This comparison was conducted for key nutrients including calcium, iron, magnesium, zinc, vitamins A and C, thiamin, riboflavin, niacin, folate, carbohydrate, and protein.

The contribution of WEPs to dietary diversity was assessed using the individual Dietary Diversity Scores (DDS) derived from the framework of the Minimum Dietary Diversity for Women of reproductive age (MDD-W) indicator, a validated measure of dietary quality (FAO, 2021). The DDS, a continuous variable ranging from 0 to 10, was calculated by summing the number of food groups consumed by an individual woman over a 24-h recall period. These food groups include: (1) grains, white roots, tubers, and plantains;

(2) pulses; (3) nuts and seeds; (4) dairy; (5) meat, poultry, and fish; (6) eggs; (7) dark green leafy vegetables; (8) other vitamin A-rich fruits and vegetables; (9) other vegetables; and (10) other fruits. The DDS were then compared between WEP consumers and non-consumers to evaluate the impact of WEP consumption on dietary diversity.

To quantify WEPs' contribution to both food consumption and nutrient intakes, a two-step calculation process among WEP consumers was employed. First, the mean consumption of WEPs, and the mean nutrient intake derived from WEPs were calculated. Next, the percentage contribution was determined by dividing these WEP-specific means by the total mean food consumption and total mean nutrient intake, respectively, among WEP consumers and multiplying by 100%. This approach allowed the expression of WEPs' contribution as a percentage of overall dietary intake among WEP consumers.

The calculations can be represented as follows:

For food consumption: $(\text{Mean consumption from WEPs} / \text{Total mean food consumption among WEP consumers}) \times 100\%$

For nutrient intakes: $(\text{Mean nutrient intake from WEPs} / \text{Total mean nutrient intake among WEP consumers}) \times 100\%$

To account for potential seasonal variations and to enhance the robustness of our findings, the analyses were stratified by survey round. This stratification allowed the examination of whether the contribution of WEPs to diet varied between different time points of data collection, potentially reflecting seasonal availability or other temporal factors affecting WEP consumption.

Sample collection and food composition analysis

Originally, it was planned to collect five fruit and five vegetable samples from Turkana County; however, due to drought conditions, three fruits and one vegetable were not available in sufficient amounts. In April 2021, the vegetables *Corchorus olitorius* L., *Amaranthus hybridus* L., *Amaranthus graecizans* L., and *Cleome gynandra* L. were collected. Samples of the fruits *Ziziphus mauritiana* Lam. and *Balanites rotundifolia* (Tiegh.) Blatt. were collected in October 2021.

One kilogram of edible part per plant was collected. The edible material was obtained through a random sampling procedure. For the leafy vegetables (*Corchorus olitorius*, *Amaranthus hybridus*, *Amaranthus graecizans*, and *Cleome gynandra*), only the leaves were collected. The collector walked through the collection site, stopping at random intervals to harvest leaves from plants. This method ensured samples were collected from various locations within the site to achieve representativeness. The leaves were harvested at the same maturity stage as typically used for local consumption. For fruits (*Ziziphus mauritiana* and *Balanites rotundifolia*), a similar approach was used, with whole ripe fruits hand-picked from various trees encountered during the walk through the sampling area. Care was taken to select fruits at similar stages of maturity.

The samples were sorted, gently washed, packaged in zip-lock polythene bags, and stored in cool boxes with frozen cooling elements for transport to Nairobi. Upon arrival, samples were deep-frozen for 1 week, freeze-dried at

−50°C and 0.50 h Pa for 4 days, and stored in polythene bags in a sealed carton box at the Alliance of Bioversity International and CIAT laboratories in Nairobi.

In April 2022, freeze-dried samples were transported to Goettingen University, Germany, for milling and nutrient content analysis. *Balanites rotundifolia* samples were discarded due to the inability to separate the edible part from the seed, which could have led to inaccurate nutrient assessments. The remaining samples were analysed for energy (kJ), protein, fat, fibre, and crude ash, applying Weende analysis (Flatt, 1988).

Dry matter content was determined by oven-drying at 105°C until constant weight. Energy was determined using adiabatic bomb calorimetry; protein content was calculated from total nitrogen using the Kjeldahl method with a conversion factor of 6.25; fat was determined by ether extraction; fibre was measured by the crude fibre method; and ash content was assessed by incineration at 550°C. Each analysis was performed once per sample.

The total carbohydrate content of each sample was calculated using the sum of Nitrogen-Free Extract (NFE) and Crude Fiber (CF), performed as follows:

$$\text{Total Carbohydrates(\%)} = \text{NFE(\%)} + \text{CF(\%)}$$

Initially, all results from the Weende analysis were reported on a dry matter basis. To convert the results to a fresh weight basis, the following formula was applied:

$$\text{Fresh Weight\%} = \text{Dry Matter\%} \times (\text{DM\%} \div 100)$$

where DM % is the dry matter percentage of each sample.

All final results are reported in grams per 100 g of the sample on a fresh weight basis.

The vitamin and mineral analyses were both done in duplicates. Mineral analysis (calcium, copper, iron, potassium, magnesium, manganese, phosphorus, sulphur, and zinc) was performed according to Koch et al. (2019). Briefly, samples were digested using a microwave-assisted acid digestion method, and the resulting solutions were analyzed using an ICAP 7000 Series ICP Spectrometer from Thermo Scientific at the Albrecht-Haller-Institute of the Georg-August-University Göttingen, Germany.

Carotenoids (lutein, zeaxanthin, (all-E)-β-carotene) were quantitated using a Shimadzu prominence HPLC system (Shimadzu, Kyoto, Japan) and the analysis was carried out at the Division of Quality and Sensory of Plant Products, Georg-August-Universität Göttingen, Germany following the procedure described by Bayer et al. (2022) and Laurenčíková et al. (2023). Briefly, carotenoids were extracted from freeze-dried samples using a mixture of methanol/tetrahydrofuran (1:1, v/v). The extracts were then analyzed using a reversed-phase HPLC with a C30 column and a photodiode array detector. Carotenoids were identified by comparing their retention times and absorption spectra with those of authentic standards. Quantification was performed using external calibration curves prepared with pure standards of lutein, zeaxanthin, and β-carotene.

Vitamins B1, B2, B5, B6, and B9 were analysed externally by Bilacon company, Berlin. Vitamin B1 (thiamine), B2 (riboflavin), B5 (pantothenic acid), and B6 (pyridoxine) were determined using the PV-SA-158 method, which employs liquid chromatography-tandem mass spectrometry (LC-MS

/MS). Vitamin B9 (folate) was analyzed using the VitaFast® Folsäure rapid testing toolkit, a microbiological method that measures the total folate content.

Results

Out of the 960 households initially recruited, 953 completed the surveys (357 in the first round in August 2020 and 569 in the second round in July 2022). After excluding households without a woman within the target age range of 16–49 years, 914 participants were included in the dietary intake study (345 from the first round and 569 from the second round). The sample distribution across livelihood zones was as follows: 42.1% in the peri-urban zone, 36.3% in the agro-pastoralist zone, and 21.6% in the pastoralist zone. The mean age of the surveyed women was 29.63 ± 7.1 years (range 16–49 years). Overall, 51 women (5.6%) reported consuming WEPs during the 24-h dietary intake recall period, with no statistically significant difference in the proportion of WEP consumers between the two survey rounds. Table 1 presents the descriptive statistics for the dietary intake survey participants, stratified by the survey round.

Contribution of wild edible plants to diets

The mean of DDS in the pooled sample was 2.51 ± 1.19 food groups, with a significantly higher mean in the first survey round (2.81 ± 1.0) compared to the second survey round (2.32 ± 1.2) ($p < .001$). Although there was no statistically significant difference in mean DDS between WEP consumers (2.71 ± 0.9) and non-WEP consumers (2.49 ± 1.2) in the

pooled sample ($p = .216$), excluding WEPs from the score reduced the WEP-consumers' mean DDS to 1.78 ± 0.8 food groups, significantly lower than that of non-WEP consumers ($p < .001$). Three WEP consumers would have recorded a DDS of zero if WEPs were excluded. Figure 2 illustrates that WEPs contributed to a significantly higher proportion of women consuming "Dark green leafy vegetables" (56.9% vs. 30.2%; $p = .001$) and "Other fruits" (39.2% vs. 1.4%; $p < .001$) compared to non-WEP consumers.

During the first survey round, WEP consumers recorded a mean DDS of 3.05 ± 0.8 food groups compared to 2.80 ± 1.1 food groups among non-WEP consumers. In the second survey round, WEP consumers recorded a mean DDS of 2.48 ± 1.0 food groups, while non-WEP consumers recorded a mean of 2.31 ± 1.2 food groups. The differences in means were not statistically significant in either round ($p > .05$). Excluding WEPs' contribution reduced the mean DDS of WEP consumers by 1.4 food groups in the first survey round (mean = 1.65 ± 0.7) and by 0.60 food groups in the second survey round (mean = 1.88 ± 0.9). The difference in mean scores between WEP and non-WEP consumers when WEPs were excluded was statistically significant only in the first survey round ($p < .001$).

Tables 2, 3, and 4 present WEPs' contribution to women's total food consumption and mean energy, macro-, and micro-nutrient intakes based on reported dietary intake and established food composition data. Table 2 shows the results for the pooled sample ($n = 914$), while Tables 3 and 4 present data from the first survey round in August 2020 ($n = 345$) and the second survey round in July 2022 ($n = 569$), respectively. Mean food consumption significantly dropped from 1277.14

Table 1. Descriptive statistics of the dietary intake data for the first (August 2020) and second (July 2022) survey and combined data of both surveys.

Variable		1 st survey (n = 345)	2 nd survey (n = 569)	Overall (N = 914)
Sub-county	Loima (%)	60.9	56.9	58.4
	Turkana South (%)	39.1	43.1	41.6
Dominant livelihood type	Pastoral (%)	21.7	21.4	21.6
	Agro-pastoral (%)	37.4	35.7	36.3
	Peri-urban (%)	40.9	42.9	42.1
Household size	mean (SD)	6.13 (2.3)	6.52 (2.2)	6.38 (2.2)
Age of woman in years	mean (SD)	28.62 (6.5)	30.2 (7.5)	29.63 (7.1)
Woman consumed wild food in 24 h	Yes (%)	5.8	5.4	5.6

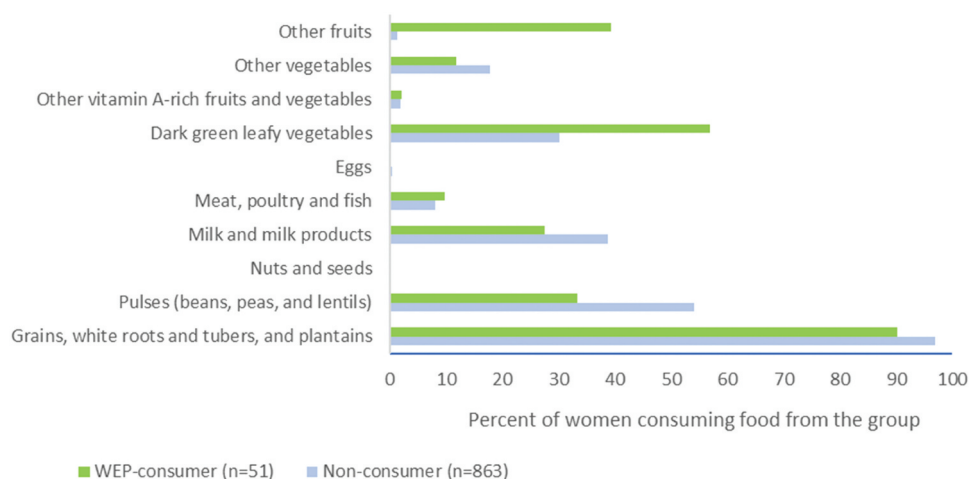


Figure 2. Comparison of food group consumption in the pooled sample between WEP and non-WEP consumers.

Table 2. WEPs' contribution to women's total food consumption and nutrient intakes (pooled sample, n = 914) *.

Nutrient/Food component (unit)	All participants (n = 345)	Non-WEP consumers (n = 325)	WEPs consumers (n = 20)	P-value [†]	Intakes from WEPs	WEPs Contribution (%) [‡]
	Mean intakes, [SD]	Mean intakes, [SD]	Mean Intakes, [SD]		Mean, [SD]	
Total food consumption (g)	796.55, [696.86]	793.23, [698.1]	852.75, [679.72]	0.554	158.55, [166.88]	18.59
Energy (kcal)	1271.39, [890.94]	1266.39, [892.29]	1355.98, [871.94]	0.486	202.15, [299.91]	14.91
Carbohydrate (g)	208.22, [144.61]	205.63, [144.29]	252.12, [144.37]	0.026	54.51, [62.96]	21.62
Protein (g)	29.58, [36.42]	29.66, [37.14]	28.2, [20.74]	0.781	6.15, [11.74]	21.79
Fat (g)	35.27, [35.17]	35.38, [35.45]	33.45, [30.32]	0.704	2.2, [2.57]	6.58
Vitamin A (µg RAE)	142.39, [299.64]	124.81, [196.46]	439.87, [937.24]	0.000	399.58, [1096.49]	90.84
Thiamin (mg)	0.69, [1.42]	0.49, [0.55]	3.94, [4.48]	0.000	3.52, [4.67]	89.27
Riboflavin (mg)	0.89, [1.25]	0.74, [0.64]	3.55, [3.75]	0.000	3.11, [3.86]	87.67
Niacin (mg)	12.65, [13.29]	11.96, [12.55]	24.4, [19.01]	0.000	14.81, [18.8]	60.71
Folate (µg)	63.81, [102.92]	62.44, [99.24]	87.02, [151.81]	0.098	70.51, [270.58]	81.03
Vitamin C (mg)	14.46, [38.31]	10.43, [28.39]	82.75, [88.69]	0.000	81.99, [89.45]	99.08
Calcium (mg)	330.06, [382.57]	330.82, [383.88]	317.17, [363.03]	0.805	238.32, [618.13]	75.14
Iron (mg)	12.73, [13.84]	11.5, [11.9]	33.58, [24.29]	0.000	27.12, [25.78]	80.77
Magnesium (mg)	163.66, [133.35]	163.68, [134.65]	163.28, [110.29]	0.983	55.7, [73.14]	34.11
Zinc (mg)	7.75, [14.62]	7.19, [6.3]	17.23, [55.85]	0.000	11.5, [56.59]	66.73

*Values represent means of usual nutrient intakes, calculated from repeated quantitative 24-hour dietary. Standard deviations are shown in square brackets [].

[†]P-value for comparison between WEP consumers and non-consumers.

[‡]Percentage contribution of WEPs to total nutrient intake among WEP consumers.

Table 3. WEPs' contribution to women's total food consumption and nutrient intakes during the first survey round (August 2020, n = 345)*.

Nutrient/Food component (unit)	All participants (n = 345)	Non-WEP consumers (n = 325)	WEPs consumers (n = 20)	P-value [†]	Intakes from WEPs	WEPs Contribution (%) [‡]
	Mean intakes, [SD]	Mean intakes, [SD]	Mean Intakes, [SD]		Mean, [SD]	
Total Food consumption (g)	1277.14, [820.59]	1271.27, [825.02]	1372.51, [757.85]	0.593	166.59, [226.22]	12.14
Energy (kcal)	1536.49, [940.03]	1526.69, [942.94]	1695.77, [898.96]	0.436	90.5, [117.67]	5.34
Carbohydrate (g)	245.84, [161.85]	243.5, [161.65]	283.88, [164.62]	0.279	15.49, [26.95]	5.46
Protein (g)	34.96, [25.88]	34.87, [26.26]	36.33, [19.14]	0.808	7.6, [10.91]	20.92
Fat (g)	45.58, [37.83]	45.42, [38.37]	48.25, [28.37]	0.745	0.5, [0.58]	1.04
Vitamin A (µg RAE)	169.59, [355.16]	133.16, [178.84]	761.6, [1160.49]	0.000	808.23, [1546.97]	100.00
Thiamin (mg)	0.66, [0.64]	0.64, [0.64]	1.0, [0.63]	0.014	0.41, [0.97]	41.00
Riboflavin (mg)	0.94, [0.66]	0.93, [0.67]	1.08, [0.56]	0.307	0.63, [1.01]	58.33
Niacin (mg)	13.5, [9.76]	13.6, [9.89]	11.93, [7.36]	0.458	2.65, [5.32]	22.21
Folate (µg)	74.16, [111.99]	70.89, [100.93]	127.3, [224.09]	0.029	138.1, [425.92]	100.00
Vitamin C (mg)	11.48, [31.57]	9.31, [22.53]	46.75, [89.45]	0.000	47.0, [93.29]	100.00
Calcium (mg)	423.56, [424.79]	416.85, [421.74]	532.75, [469.77]	0.237	476.03, [941.91]	89.35
Iron (mg)	12.74, [10.35]	12.12, [9.76]	22.92, [14.12]	0.000	17.12, [17.8]	74.69
Magnesium (mg)	189.06, [147.97]	187.94, [150.11]	207.35, [108.62]	0.570	93.51, [84.05]	45.10
Zinc (mg)	8.16, [6.01]	8.2, [6.13]	7.64, [3.54]	0.687	1.79, [3.49]	23.43

*Values represent means of usual nutrient intakes, calculated from repeated quantitative 24-hour dietary. Standard deviations are shown in square brackets [].

[†]P-value for comparison between WEP consumers and non-consumers.

[‡]Percentage contribution of WEPs to total nutrient intake among WEP consumers.

Table 4. WEPs' contribution to women's total food consumption and nutrient intakes during the second survey round (July 2022, n = 569) *.

Nutrient/Food component (unit)	All participants (n = 345)	Non-WEP consumers (n = 325)	WEPs consumers (n = 20)	P-value [†]	Intakes from WEPs	WEPs Contribution (%) [‡]
	Mean intakes, [SD]	Mean intakes, [SD]	Mean Intakes, [SD]		Mean, [SD]	
Total food consumption (g)	505.16, [383.95]	504.46, [387.01]	517.43, [331.65]	0.855	153.36, [118.05]	29.64
Energy (kcal)	1110.65, [819.86]	1109.15, [822.08]	1136.76, [792.89]	0.856	274.18, [357.03]	24.12
Carbohydrate (g)	185.42, [127.95]	182.75, [127.53]	231.64, [128.33]	0.038	79.68, [66.91]	34.40
Protein (g)	26.32, [41.2]	26.51, [42.1]	22.96, [20.31]	0.641	5.21, [12.33]	22.69
Fat (g)	29.02, [31.9]	29.31, [32.11]	23.9, [27.97]	0.358	3.3, [2.76]	13.81
Vitamin A (µg RAE)	125.9, [259.23]	119.77, [206.37]	232.3, [705.39]	0.019	149.12, [597.73]	64.19
Thiamin (mg)	0.7, [1.73]	0.41, [0.47]	5.84, [4.87]	0.000	5.52, [5.02]	94.48
Riboflavin (mg)	0.86, [1.5]	0.62, [0.59]	5.13, [4.07]	0.000	4.7, [4.18]	91.69
Niacin (mg)	12.14, [15.02]	10.97, [13.83]	32.45, [19.93]	0.000	22.66, [20.22]	69.84
Folate (µg)	57.54, [96.56]	57.34, [97.94]	61.02, [69.48]	0.837	26.9, [46.05]	44.08
Vitamin C (mg)	16.27, [41.8]	11.1, [31.41]	105.98, [81.37]	0.000	103.43, [81.23]	97.60
Calcium (mg)	273.36, [342.69]	278.85, [349.35]	178.1, [170.03]	0.112	84.95, [113.79]	47.70
Iron (mg)	12.73, [15.59]	11.13, [13.01]	40.46, [27.06]	0.000	33.58, [28.24]	82.99
Magnesium (mg)	148.26, [121.23]	149.03, [122.22]	134.85, [103.29]	0.527	31.3, [53.59]	23.21
Zinc (mg)	7.5, [17.93]	6.58, [6.34]	23.41, [71.34]	0.000	17.76, [72.29]	75.85

*Values represent means of usual nutrient intakes, calculated from repeated quantitative 24-h dietary. Standard deviations are shown in square brackets [].

[†]P-value for comparison between WEP consumers and non-consumers.

[‡]Percentage contribution of WEPs to total nutrient intake among WEP consumers.

(±820.59) grams in the first survey round to 505.16 (±383.95) grams in the second round. WEPs accounted for 12.14% of consumers' total food consumption during the first survey round, 29.64% in the second round, and 18.59% in the pooled

sample. WEP consumers had higher mean intakes for most nutrients, with WEPs contributing 7% to 99% of mean nutrient intakes and accounting for more than 50% of the most micro-nutrient intakes during both survey rounds.

Comparison of nutrient intakes to dietary recommendations

Table 5 presents a comparison of mean nutrient intakes from both survey rounds and the pooled sample to the RDAs for women aged 14–50 years. Overall, the results indicate that nutrient intakes fell short of recommendations for most nutrients across both survey rounds. Carbohydrate intake consistently exceeded the RDA, while protein and most micronutrient intakes were below recommended levels. Notably, intakes of vitamin A, folate, vitamin C, calcium, and magnesium were substantially below RDA levels in both rounds and the pooled data. Iron and zinc intakes, while below RDA, were closer to meeting recommendations compared to other micronutrients.

Nutrient composition analysis

Table 6 shows the micronutrient content of the four leafy vegetables and one fruit collected from the wild in Turkana County. Similar vegetables and fruits consumed locally and their nutrient content (as reported in the Kenya or Tanzania Food Composition Tables) are shown for comparison. In particular, the iron content of the Turkana wild vegetables was much higher than the cultivated amaranth leaves or white cabbage, and the folic acid (vitamin B9) content of wild edible leaves was higher than that of white cabbage. The wild fruit *Ziziphus mauritiana* had a much higher magnesium content and a slightly higher iron content than cultivated fruits such as mango or apple and was also richer in zinc than apples (Table 6). For completeness, the five WEPs' macronutrients are compared to cultivated fruits and vegetables (Table 7). The protein content of the wild leafy vegetables was similar to that of cultivated amaranth leaves and much higher than that of white cabbage.

As fruits and vegetables are also a source of bioactive compounds, in this study, the vegetables and fruit samples were further analysed for the carotenoid β -carotene, lutein, and zeaxanthin. The β -carotene content of the WEPs analysed varied from 18.16 $\mu\text{g}/100\text{ g}$ of fresh matter in *Cleome gynandra*, 19.65 $\mu\text{g}/100\text{ g}$ in *Amaranthus hybridus*, 78.80 $\mu\text{g}/100\text{ g}$ in *Corchorus olitorius* to 85.74 $\mu\text{g}/100\text{ g}$ in *Amaranthus graecizans*. Similarly, lutein and zeaxanthin content were lower in *Cleome gynandra* and *Amaranthus hybridus* and

much higher in *Corchorus olitorius* and only partly so for *Amaranthus graecizans* (Table 8).

Discussion

Poor dietary diversity is widely associated with increased risk of undernutrition, particularly among vulnerable groups, including women (Aboagye et al., 2021; Khamis et al., 2019; Korir et al., 2023). This issue is especially pronounced in the dryland ecosystems globally, where food insecurity and malnutrition are exacerbated by cyclical droughts and climate change. Turkana County in Kenya exemplifies these challenges, having a persistent history of poor diets and high malnutrition levels (M. Lokuruka, 2021). Consistent with other studies in similar environments in Kenya (Gitagia et al., 2019), our study found that women in Turkana County have alarmingly low dietary diversity, averaging only 2.5 food groups per day. Recent surveys in the region corroborate these findings, indicating that up to 80% of women not meeting the minimum recommended dietary diversity of at least five food groups per day (Turkana County Government 2023, 2024).

Our analysis of nutrient intake reveals concerning inadequacies in several micronutrients. Specifically, the intake of vitamin A, folate, and calcium was alarmingly low, meeting only 20.3%, 16.0%, and 25.4% of the recommended daily intakes, respectively. These deficiencies are consistent with the observed low dietary diversity and underscore specific nutritional gaps in the population's diet. Comparable inadequacies have been reported in other resource-limited settings. For example, a study in rural Kyrgyzstan found insufficient intake of essential micronutrients such as vitamins B1, B2, B6, and C, as well as folic acid, calcium, and magnesium among women of reproductive age (Otunchieva et al., 2022). Similarly, a recent review of dietary diversity and micronutrient intake among women of reproductive age in low- and middle-income countries highlights similar deficiencies (Islam et al., 2023).

This situation has been further exacerbated by recent global events. The COVID-19 pandemic severely disrupted food supply networks, including last-mile food markets and traders' supply chains, worsening both the quantity and quality of available food (Duba & Hailu, 2022; GAIN, 2021; Griffith et al., 2021). Our study also documented a decline in

Table 5. Comparison of mean nutrient intakes to recommended dietary allowances (RDAs) for women ages 14–50 years.

Nutrient (unit)	RDA	1st Round		2nd Round		Pooled	
		Mean Intake	% RDA met	Mean Intake	% RDA met	Mean Intake	% RDA met
Energy (kcal)	2200*	1536.49	69.8	1110.65	50.5	1271.39	57.8
Carbohydrate (g)	130	245.84	189.1	185.42	142.6	208.22	160.2
Protein (g)	46	34.96	76.0	26.32	57.2	29.58	64.3
Vitamin A (μg RAE)	700	169.59	24.2	125.9	18.0	142.39	20.3
Thiamin (mg)	1.1	0.66	60.0	0.7	63.6	0.69	62.7
Riboflavin (mg)	1.1	0.94	85.5	0.86	78.2	0.89	80.9
Niacin (mg)	14	13.5	96.4	12.14	86.7	12.65	90.4
Folate (μg)	400	74.16	18.5	57.54	14.4	63.81	16.0
Vitamin C (mg)	75	11.48	15.3	16.27	21.7	14.46	19.3
Calcium (mg)	1300**	423.56	32.6	273.36	21.0	330.06	25.4
Iron (mg)	18	12.74	70.8	12.73	70.7	12.73	70.7
Magnesium (mg)	360***	189.06	52.5	148.26	41.2	163.66	45.5
Zinc (mg)	11****	8.16	74.2	7.5	68.2	7.75	70.5

*Energy RDA is based on the average energy allowance for females 19–50 years from Image 4.

**Calcium RDA is highest for ages 14–18 years (1300 mg)

***Magnesium RDA is highest for ages 14–18 years (360 mg)

****Zinc RDA is highest for ages 14–18 years (11 mg)

Table 6. Micronutrient content of vegetables and fruit in Turkana County, Kenya, per 100 g edible portion on fresh weight.

Local name	Scientific name	Edible part(s)	Ca	Fe	K	Mg	P	Zn	Vit B1	Vit B2	Vit B5	Vit B6	Vit B9
			mg	mg	mg	mg	mg	mg	mg	mg	mg	mg	µg
Fruits and vegetables collected in 2021 in Turkana County and analysed by the project (freeze-dried plant material analysed)													
Miere	<i>Corchorus olitorius</i>	Leaves	97.8 ± 0.8	25.5 ± 4.0	394.2 ± 1.7	47.1 ± 0.4	44.2 ± 0.2	0.5 ± 0.0	0.06 ± 0.02	0.27 ± 0.08	0.05 ± 0.02	0.08 ± 0.03	43.9 ± 9.79
Dodo	<i>Amaranthus hybridus</i>	Leaves	218.6 ± 0.0	9.2 ± 0.2	571 ± 10.8	63.7 ± 0.0	51.8 ± 0.3	0.5 ± 0.0	0.002 ± 0.001	0.17 ± 0.05	0.05 ± 0.02	0.05 ± 0.02	31.9 ± 7.11
Lokilton	<i>Amaranthus graecizans</i>	Leaves	330.8 ± 8.7	6.4 ± 0.2	362.4 ± 5.3	119.4 ± 0.8	47.2 ± 0.6	0.3 ± 0.0	0.002 ± 0.001	0.18 ± 0.05	0.05 ± 0.02	0.08 ± 0.03	35.1 ± 7.82
Akio	<i>Cleome gynandra</i>	Leaves	162.3 ± 4	6.5 ± 1.0	305.2 ± 6.6	32.5 ± 1.2	78.9 ± 0.8	0.4 ± 0	0.05 ± 0.02	0.16 ± 0.05	0.06 ± 0.02	0.08 ± 0.03	25.0 ± 5.56
Ngakalio	<i>Ziziphus mauritiana</i>	Fruit pulp	45.5 ± 0.5	0.6 ± 0.1	138.7 ± 3.6	11.3 ± 0.4	13.9 ± 0.7	0.7 ± 0.0	0.02 ± 0.006	0.03 ± 0.01	0.03 ± 0.01	0.02 ± 0.01	2.5 ± 0.56
Fruits and vegetables consumed in Turkana County – data from Kenya Composition Tables (Tanzania Composition Table for Vit B5 and Vit B6) (raw plant material analysed)**													
Mchicha	<i>Amaranthus</i> spp.	Leaves	280.0	6.8	597.0	122.0	89.0	0.92	0.03	0.22	0.1	0.2	64.0
Sukuma wiki (Ethiopian kale)	<i>Brassica carinata</i>	Leaves	254.0	1.6	348.0	32.7	55.0	0.39	0.11	0.35	0.37	0.15	62.0
Kabichi	<i>Brassica oleracea</i> var. <i>capitata</i>	Leaves	47.0	0.5	313.0	9.0	40.0	0.2	0.04	0.04	0.2	0.1	15.0
Maembe	<i>Mangifera indica</i>	Fruit pulp	14.0	0.2	186.0	9	17.0	0.14	0.03	0.04	0.2	0.1	54.0
Apple	<i>Malus domestica</i>	Fruit	6.0	0.3	100.0	4.0	9.0	0.07	0.02	0.01	0.1	-	5.0

**Values from Food Composition Tables used here for comparison, no standard deviations reported.

Table 7. Macronutrient content of vegetables and fruit collected in 2021 in Turkana County, Kenya, per 100 g.

Local name	Scientific name	Edible part(s)	Total carbohydrates	Energy (kJ)	Protein (g)	Fat (g)	Fibre (g)	Ash (g)
Fruits and vegetables collected in 2021 in Turkana County and analysed by the project (freeze-dried plant material analysed)								
Mrere	<i>Corchorus olitorius</i>	Leaves	5.64	144.7	3.34	0.44	0.77	1.64
Dodo	<i>Amaranthus hybridus</i>	Leaves	5.62	133.3	2.66	0.38	1.04	2.30
Lokiliton	<i>Amaranthus graecizans</i>	Leaves	5.04	133.0	3.14	0.47	0.96	2.29
Akio	<i>Cleome gynandra</i>	Leaves	5.70	142.0	3.08	0.49	0.93	1.79
Ngakalalio	<i>Ziziphus mauritiana</i>	Fruit pulp	9.40	143.4	0.94	0.33	0.86	0.57
Fruits and vegetables consumed in Turkana County – data from Kenya Composition Tables								
Mchicha	<i>Amaranthus</i> spp.	Leaves	1.3	150.0	3.7	0.2	7.2	3.1
Sukuma wiki (Ethiopian kale)	<i>Brassica carinata</i>	Leaves	1.2	179.91	2.92	1.49	4.1	1.54
Kabichi	<i>Brassica oleracea</i> varr. <i>capitata</i>	Leaves	2.2	76.0	1.1	0.1	2.2	0.7
Maembe	<i>Mangifera indica</i>	Fruit pulp	14	272.0	0.6	0.3	1.6	0.5
Apple	<i>Malus domestica</i>	Fruit	12.4	121	0.3	0.1	2.3	0.25

Values represent single measurements. Standard deviations are not available as only one sample per species was analyzed.

Table 8. Carotenoid content ($\mu\text{g}/100\text{g}$ fresh weight) of wild edible vegetables and fruit from Turkana, Kenya.

Vegetable	Lutein	Zeaxanthin	(all-E)- β -Carotene
<i>Cleome gynandra</i>	528.50 \pm 101.08	671.20 \pm 23.46	18.16 \pm 6.24
<i>Amaranthus hybridus</i>	637.04 \pm 17.60	553.35 \pm 20.20	19.65 \pm 2.56
<i>Corchorus olitorius</i>	1,086.19 \pm 184.64	1,116.47 \pm 163.73	78.80 \pm 7.82
<i>Amaranthus graecizans</i>	1,217.86 \pm 120.38	562.65 \pm 1.32	85.74 \pm 7.64
Fruits and vegetables consumed in Turkana County – data from Kenya Composition Tables **			
<i>Amaranthus</i> spp.	3913.0*	–	–
<i>Brassica carinata</i>	2870.0	–	–
<i>Brassica oleracea</i> varr. <i>capitata</i>	Trace	–	–
<i>Mangifera indica</i>	1105.0*	–	–
<i>Malus domestica</i>	14.0*	–	–

*Beta-carotene equivalents (including beta-carotene, alpha-carotene and beta-cryptoxanthin).

**Values from Food Composition Tables used here for comparison, no standard deviations reported.

Missing values not reported in the Composition Tables.

women's dietary diversity between the first and second survey rounds, which coincided with one of the most severe droughts in the study area in 40 years (IOM 2022; NDMA, 2022). The seasonal impact on nutrient intake was substantial. For instance, energy intake decreased from 69.8% of the recommended daily intakes in the first survey round to 50.5% in the second round, aligning with the period of severe drought. This dramatic reduction highlights the population's vulnerability to environmental stressors and underscores the urgent need for resilient food systems.

These findings are consistent with studies elsewhere. For example, a study in rural Ethiopia reported a 12% decrease in proportion of women meeting the minimum recommended dietary diversity during the lean season compared to the post-harvest season (Baye et al., 2022). The drought's severe impacts on the predominantly pastoralist community included reduced water and pasture availability, livestock deaths, increased community conflicts, and disruptions in food supply chains. These factors contributed to skyrocketing food prices, rendering food unaffordable for many (Elegbeleye et al., 2023; UNHCR and WHO, 2022).

In this challenging context, WEPs may play a crucial yet underexplored role in local nutrition. Our study provides novel insights into the nutritional contribution and potential of WEPs to the diets of women in Turkana County, offering a unique perspective on the role of WEPs in food security and nutrition in dryland ecosystems across two economically challenging periods. By quantifying WEPs' contribution to dietary diversity and nutrient intakes of women in Turkana County, an area rich in WEP diversity (Oduor et al., 2023), our study significantly advances the current knowledge in this field.

Consistent with recent studies across various geographical contexts (Bellows et al., 2023; Jiru et al., 2023;

Ngurthankhumi et al., 2024; Talang et al., 2023; Tharmabalan, 2021; Yimer et al., 2023), we found WEPs to be vital sources of limited micronutrients in the diets of Turkana communities. The wild edible leafy vegetables evaluated generally had comparable or superior micronutrient values to commonly consumed kales and cabbages. Notably, *Amaranthus hybridus* and *Amaranthus graecizans* were particularly rich in calcium, potassium, and magnesium, aligning with findings by Mih et al. (2017) and Sarker et al. (2020, 2022) regarding high mineral and vitamin content of *Amaranthus* species. *Corchorus olitorius* stood out for its exceptional iron content, containing 25 mg/100 g edible portion – 50 times more iron than white cabbage. This finding corroborates recent studies by Adesina et al. (2022) and Akter S et al. (2024) on *Corchorus olitorius* from West Africa.

Moreover, all four tested vegetables and the fruit averaged 0.5 mg of zinc per 100 g edible portion, surpassing the zinc content of commonly consumed produce like kales, cabbages, mangoes, and apples. These results underscore the potential of WEPs to address micronutrient deficiencies in resource-poor settings. For instance, consuming 60 g of *Corchorus olitorius* leaves or 170 g of *Amaranthus hybridus* leaves per day would be sufficient for a woman aged 19–25 years to reach her recommended iron intake of 15 mg/day, assuming average bioavailability. While fulfilling the recommended zinc intake solely through local fruits and vegetables is less easy, consuming 500 g of raw leafy vegetables (*Corchorus olitorius*, *Amaranthus hybridus*, or *Cleome gynandra*) or 350 g of *Ziziphus mauritiana* per day would contribute about one-third of a 19–25-year-old woman's recommended zinc intake, including pregnant women.

Although a single local fruit or vegetable cannot fully address the nutrition gap, a modelling study in Turkana

County demonstrated that incorporating just three wild fruits and vegetables or three wild vegetables in women's or children's diets could fulfil the recommended intakes of zinc and iron while reducing diet costs by 30–70% (Sarfo et al., 2020). These findings align with observations in other resource-poor settings (Duguma, 2020; Iannotti et al., 2024; Moore et al., 2022), emphasizing the potential of WEPs to address micronutrient deficiencies and improve dietary diversity in challenging environments like Turkana County.

Our study's demonstration of the nutritional superiority of WEPs over conventional vegetables aligns with recent research. For instance, Talang et al. (2023) reported that wild edible plants in Northeast India had higher nutrient concentrations compared to conventional crops, while Jiru et al. (2023) found comparable or superior nutritional composition in underutilized wild edible fruits in Ethiopia. Collectively, these studies, including our own findings, highlight the significant potential of WEPs to address nutritional challenges and improve food security in resource-poor settings.

Despite their nutritional advantages, local WEPs like *Ziziphys mauritiana* are often overshadowed by imported fruits such as apples, which are not even grown in Turkana County. This preference highlights the critical need for disseminating information about the nutritional value of local foods. Integrating nutrition education into agricultural and health extension activities (Waswa et al., 2015) could effectively convey this information to local populations. By incorporating this knowledge into existing community health systems and agricultural practices, we can foster discussions about the benefits of local fruits and vegetables and their potential to improve nutrition and integrate into local farming systems. This approach is consistent with recommendations to promote neglected and underutilized species to enhance nutrition and food security (Li et al., 2020; Naresh et al., 2021; Talucder et al., 2024). Emphasizing the value of local WEPs and incorporating them into existing community frameworks could significantly contribute to improving dietary diversity and resilience in resource-limited settings.

Beyond their micronutrient content, WEPs offer valuable sources of health-promoting carotenoids, known for their protective role against oxidative stress. β -carotene, the primary precursor for Vitamin A, is crucial for human health (Johra et al., 2020; Mrowicka et al., 2022) and has been linked to the prevention, treatment, and improved prognosis of chronic diseases (Anand et al., 2022). In our study, *Amaranthus graecizans* leaves exhibited the highest concentration of lutein (1,217.86 $\mu\text{g}/100\text{ g}$ fresh weight) and β -carotene (85.74 $\mu\text{g}/100\text{ g}$ fresh weight). Meanwhile, *Corchorus olitorius* leaves demonstrated high levels of both lutein (1,086.19 $\mu\text{g}/100\text{ g}$ fresh weight) and zeaxanthin (1,116.47 $\mu\text{g}/100\text{ g}$ fresh weight).

These findings are particularly significant given the growing body of evidence supporting the role of carotenoids in human health. Lutein and zeaxanthin, major components of the macular pigment in the human retina, are associated with a reduced risk of age-related macular degeneration and cataracts (Eisenhauer et al., 2017). The exceptionally high levels of lutein in *Amaranthus graecizans* and *Corchorus olitorius* suggest that their consumption could contribute significantly to eye health in the Turkana population.

However, the β -carotene levels in our freeze-dried samples may be lower than their potential maximum due to

prolonged storage and nutrient degradation. Immediate freeze-drying would have better preserved the original nutrient profiles. Fresh samples are expected to show higher β -carotene levels, as observed in similar studies (Mugera et al., 2015). Future research should focus on minimizing nutrient loss during storage to obtain more accurate results and fully capture the nutritional potential of these WEPs.

Despite this, the β -carotene levels we observed are still noteworthy. *Amaranthus graecizans* and *Corchorus olitorius*, with β -carotene levels of 85.74 and 78.80 $\mu\text{g}/100\text{ g}$ fresh weight, respectively, show potential as good sources of pro-vitamin A. Although direct comparisons with other wild edible plants are limited due to sparse literature, our results fit within the broader spectrum of carotenoid research. For instance, the β -carotene levels in *Amaranthus hybridus* (19.65 $\mu\text{g}/100\text{ g}$) and *Cleome gynandra* (18.16 $\mu\text{g}/100\text{ g}$) are comparable to those in some cultivated leafy greens. Onyambu (2021) reported β -carotene levels in fresh African indigenous vegetables ranging from 8.57 ± 0.50 to $29.99 \pm 3.80\text{ mg}/100\text{ g}$ dry weight, with *Amaranthus* specifically containing $29.99 \pm 3.80\text{ mg}/100\text{ g}$. This indicates that these WEPs could serve as valuable alternatives or supplements to cultivated vegetables in terms of pro-vitamin A content.

The variability in carotenoid content among different WEP species presents both a challenge and an opportunity. While it complicates standardization efforts, it also suggests the potential for selecting and promoting high-carotenoid varieties. Future research could explore the genetic and environmental factors influencing carotenoid synthesis in these plants, potentially leading to the development of nutrient-dense cultivars suitable for local cultivation.

In addition to their impressive nutrient profiles and potential health benefits, WEPs play a crucial role in enhancing dietary diversity, which is key to overall nutritional adequacy. Although only 5.6% of the participants reported consuming WEPs during the 24-h dietary intake recall period, their contribution was significant. Excluding WEPs from the analysis resulted in a marked reduction in mean dietary diversity among WEP consumers – by approximately 1.4, 0.6, and 0.9 food groups in the first survey round, second survey round, and pooled sample, respectively. This finding is consistent with Cheek et al. (2023), who reported that women consuming wild foods in rural India had 12–15% higher average dietary diversity scores during lean seasons. Notably, for the three participants in our study, WEPs were the sole source of food during the recall period, providing 100% of their energy and nutrient intakes.

The increased reliance on WEPs during periods of food scarcity, particularly during the severe drought observed in the second survey round, aligns with findings from other studies. Cheek et al. (2023) documented greater reliance on wild foods during lean seasons in rural India, noting their substantial contribution to dietary diversity, especially for women with very low dietary diversity scores. Similarly, Paumgarten et al. (2018) observed that despite the impacts of extreme events like prolonged droughts on wild foods, they still contributed to food security because some are drought-resistant and fruit even during dry periods. This underscores the potential role of WEPs in climate change adaptation strategies for food security in dryland ecosystems.

WEPs' significant contribution to micronutrient intakes, particularly during the drought period, emphasizes their

potential in meeting the nutritional requirements of food-insecure communities. This aligns with the findings of Borelli, Hunter, Padulosi, et al. (2020), who highlighted the potential of neglected and underutilized species, including WEPs, in addressing malnutrition and food insecurity. Our findings also align with recent research by Bellows et al. (2023) and Ngurthankumi et al. (2024), who demonstrated that wild foods make significant contributions to dietary quality and nutritional security in various ecological contexts, including tropical and subtropical regions. WEP consumers reported eating more foods in the “Dark green leafy vegetables” and “Other fruits” food groups compared to non-WEP consumers. These food groups are often underrepresented in diets worldwide, yet fruits and vegetables contribute to basic nutritional needs and have several health-promoting effects (Wallace et al., 2020). Overall, WEPs contributed 19% to the total food consumption of consumers in terms of grams per day, with their contribution increasing from 12% in the first survey round to 30% during the extensive drought period. This increase is significant considering that many families’ livelihoods have been impacted by the drought, reducing or completely impeding their capacity to purchase adequate food.

The comparison of nutrient intakes to RDAs (Table 5) further underscores the potential importance of WEPs in addressing nutritional deficiencies in this population. Given the nutrient density of many WEPs identified in this study, increased consumption of these plants could contribute significantly to closing these nutrient gaps. For instance, the high iron content found in *Corchorus olitorius* (25.5 mg/100 g) could help address the suboptimal iron intakes observed in our study population, where mean intakes only met 70.7% of the RDA. Similarly, the severe inadequacies in vitamin A, folate, and calcium intakes revealed by our analysis implies that targeted interventions to increase consumption of WEPs rich in these nutrients should be prioritized. For example, promoting the consumption of *Amaranthus* species could address multiple nutrient gaps simultaneously. Similar approaches have been successful in other regions; a study in Kenya found that promotion of African leafy vegetables led to increased consumption and improved micronutrient intakes.

Despite the clear benefits of WEPs, ensuring their continued availability requires promoting their utilization alongside countermeasures against overexploitation. Recent studies echo this need for sustainable management. For instance, Bajgai et al. (2023) found that in southeastern Bhutan, the most preferred conservation strategies for WEPs were domestication/cultivation on farms and cultivation in forests. Similarly, Chauhan et al. (2018) recommended that conservation efforts be extended to village landscapes in addition to forests, as many species are collected from anthropogenic habitats.

This study has many strengths, including applying multi-methods simultaneous approach to quantify WEPs’ potential contribution to the study community’s dietary intakes and using a large study sample to estimate this contribution to actual intakes. However, it also has some limitations. The handling of vegetable and fruit samples may have affected the measured nutrient content, particularly for heat – sensitive nutrients like carotenoids. Additionally, our composition analysis of the macronutrients (proteins, fats, carbohydrates,

and fiber) was based on single measurements for each species due to drought conditions and resource constraints but also because our study’s focus was mainly on the micronutrient composition of the WEPs. While this provides valuable initial data on the nutritional potential of these wild edible plants, it limits our ability to assess the variability in nutrient content. Future studies should aim to analyze multiple samples of each species to better understand this variability.

The use of 24-h dietary recall to assess WEPs’ contribution to women’s diets may not fully capture the consumption of episodically consumed foods like WEPs, potentially underestimating their contribution to diets. Other researchers have reported that non-habitually consumed food is among the most commonly forgotten foods during recalls due to memory lapse (Raneri et al., 2023), which may be more pronounced in communities where these foods are associated with poverty, as is the case of WEPs in Turkana (Oduor et al., 2023).

In conclusion, this study demonstrates that the WEPs found in Turkana are rich in essential micronutrients missing in the study sample’s diets and contribute significantly to women’s dietary diversity and micronutrient intakes, especially during times of scarcity. These findings underscore the potential of WEPs in addressing food insecurity and malnutrition in dryland ecosystems, particularly in the context of climate change. The implications of these findings for policy and practice in Turkana County and similar dryland ecosystems are significant. Local and national policymakers should consider incorporating WEPs into their food security and nutrition strategies, potentially through promoting cultivation and sustainable harvesting as part of agricultural development programs. There is a need for targeted nutrition education programs that highlight the nutritional value of local WEPs, which could help shift preferences from imported foods to more nutritious local alternatives.

Given the importance of WEPs, especially during times of scarcity, conservation efforts should be initiated to protect these valuable resources, including community-based conservation programs and integration of WEPs into agroforestry systems. The resilience of many WEPs to drought conditions suggests their potential role in climate change adaptation strategies, and policies should encourage the use and preservation of drought-resistant WEP species as part of broader climate adaptation plans.

Future research should focus on developing sustainable management practices for WEPs, exploring their potential for domestication and integration into local farming systems, and investigating their role in climate change adaptation strategies. Additionally, efforts to preserve and promote traditional knowledge about WEPs, as highlighted by Jhamta et al. (2019), will be crucial for ensuring their continued use and conservation. By recognizing the value of WEPs and implementing policies to promote their use and conservation, Turkana County and similar dryland ecosystems can enhance their food security, improve nutrition, and build resilience against environmental challenges.

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