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Assessment of different sources of irrigation water on the proximate and mineral nutritional properties of selected leafy vegetables in the Offinso Municipality of Ghana

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A B S T R A C T

The study aimed to determine how irrigation water from different sources affected the quality of three leafy vegetables in the Offinso Municipality of Ghana. For the study, a 5x3 factorial Completely Randomised Design (CRD) with three replications was used. Two factors were considered: irrigation water sources at five levels (wastewater, groundwater, tap water, well water, and rainwater), and leafy vegetables at three levels (cabbage, lettuce, and amaranthus). The proximate and mineral nutritional compositions of three leafy plants were analyzed. This study assessed the impact of various irrigation water sources on the nutritional quality of three leafy vegetables commonly cultivated in the Offinso Municipality of Ghana. Proximate and mineral compositions were analyzed, with significant differences found among vegetable types and irrigation water sources. Cabbage irrigated with tap water recorded the highest crude fibre, while amaranthus irrigated with rainwater recorded the highest carbohydrate and zinc contents. Wastewater irrigation significantly increased calcium content in amaranthus but corresponded to lower Vitamin C levels. Findings highlight the nutritional trade-offs associated with wastewater irrigation, underscoring the need to carefully consider water-source selection for vegetable farming. Further research should explore contamination risks and food safety implications.

Keywords: Irrigation water, Nutritional composition, Leafy vegetable, Wastewater, Food safety

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Introduction

A vegetable is commonly defined as a juicy plant or part of a plant, typically enjoyed as a complementary accompaniment to starchy foods (Natesh *et al.,* 2017). Vegetables hold paramount significance in the human dietary landscape, with a preference for their consumption in a fresh state (Neelesh and Arya, 2018). Vegetables are more abundant than other plants and are a great source of calcium, iron, and phosphorus, as well as vitamins A, C, and K (FAO, 2021). In comparison to their exotic leafy counterparts, they have significant levels of thiamine, niacin, riboflavin, carbs, and crude protein (Raza *et al.,* 2024). Vegetables can be categorically classified into five prominent groups: leafy vegetables, fruit vegetables, legume and seed vegetables, tuber vegetables, and a miscellaneous group that includes floral types (Nath, 2024). In Africa, homegrown vegetable species outnumber their exotic counterparts and readily adapt to the local environment. Notably, the local vegetable supply offers affordable and nutritious produce to both rural and urban dwellers. It is worth noting that these vegetables are a staple of the West African diet (Bua and Onang, 2017). Green, leafy vegetables such as amaranthus, jute mallow, and spinach are known for their provision of ascorbic acid, folic acid, calcium, β-carotene, and iron. The benefits of traditional vegetables to the rural population, in particular, are enormous. For instance, some traditional leafy vegetables are used for medicinal purposes, and others are employed in research activities within the agricultural field (Moazma *et al.,* 2024). The FAO and the World Health Organization encourage the local cultivation and use of native vegetables to help combat malnutrition in African countries.

A group of plant-based foods known as vegetables can be consumed uncooked or in addition to the main course (Bvenura and Sivakumar, 2017). These remarkable edibles serve three vital purposes when consumed, acting as guardians of health, custodians of well-being, and defenders against diseases (Adeniyi *et al.,* 2012). Vegetables contain certain elements that are essential for body growth and repair (Abukutsa-Onyango, 2010). On top of that, vegetables are packed with vitamins A, B, and C, which are vital for keeping the body healthy and supporting its optimal functioning. Further, vegetables play a vital role in neutralizing acids in the stomach during digestion (Thompson and Kelly, 1990). Based on their edible parts, vegetables can be grouped into five, namely: Root, stem, leafy, fruit, and seed vegetables (Robinson, 1990). Each of the aforementioned vegetable types plays a specific function in our diet. For instance, root vegetables are rich in vitamin B and further provide the body with the needed energy. Additionally, Seed vegetables are good sources of carbohydrates and protein for the body. On the other hand, leaves, stems, and fruits and vegetables are known for their abundance in minerals, vitamins, water, and roughage.

African indigenous vegetables are forms of vegetables whose primary or secondary source is from the African continent (Schippers, 2000). As per the definition, two distinct categories of native vegetables can be identified. First, those vegetables that is typically from African land and those that originate from elsewhere but have become part of our local dishes. These vegetables, borne of secondary origins in Africa, earn their name "African traditional vegetables", symbolizing their profound assimilation into the African cultural fabric (Schippers, 2000). On the other hand, traditional leafy vegetables are an array of edible crops whose various parts are used for food in African jurisdictions (Vorster *et al.,* 2005). These crops require a significant amount of water during production, which makes their cultivation heavily reliant on irrigation water.

In the cultivation of crops and vegetables, "irrigation water" refers to the extra water required to augment natural rainfall (Bhavsar *et al.,* 2023). Irrigation has long been fundamental in agriculture and horticulture to optimize yields. Interestingly, while an individual's daily drinking water requirement is estimated to be 2-4 litres, cultivating food for one person consumes a staggering 2000-5000 litres of water (FAO, 2017). Even more startling are the water requirements for particular crops: 1 kilogram of wheat requires about 1000–3000 litres, but 1 kg of cattle fed grain requires an astounding 13000–15000 litres (Pimentel *et al.*, 1997). The importance of this resource is demonstrated by the steadily increasing demand for irrigation water worldwide (Shiklomanov *et al.*, 2007). Notably, in 2000, irrigation was used on around 274 million hectares of agricultural land, or roughly 16% of all cultivated land on Earth (Siebert *et al.,* 2006). To illustrate, in Sweden alone, nearly 53,000 hectares were irrigated in 2003 (Wriedt *et al.,* 2009).

On several occasions, water for irrigation is accumulated at a point, natural or artificial. The water bodies available for irrigation purposes are less than 1% of the land (Zia *et al.,* 2013). Irrigation water comes from different sources such as well water, pond/groundwater, rainwater, tap water, or wastewater. Rainwater for irrigation is seen as the easiest method in the production of crops (Khamidov and Muratov, 2021). The term used for the collection, storage and processing of water in water tanks or reservoirs is called rainwater harvesting (Makoto, 1999; Prinz, 1999). This water collected is used for the irrigation of crops for some time. A pond is a natural or artificial water-filled area that is smaller than a larger body of water, such as a lake. It may form part of groundwater, stated to be safer and hygienic than tap water used for irrigation purposes (Drechsel *et al.,* 2023). It is common to see Tap water used for irrigating crops (Winter *et al.*, 1999). Due to the scarcity of freshwater resources for irrigation, farmers have resorted to utilizing any available water, including wastewater or polluted water, for irrigation purposes. It is worth mentioning that approximately 20 million hectares of farmland, which accounts for 7% of the total irrigated land worldwide, rely on various forms of wastewater for irrigation (Danso *et al.*, 2014). Despite being wastewater, the demand for its use in developing countries has risen due to its nutrient content and its reliability as a water source for vegetable production (Mayilla *et al.*, 2016). To access liquid resources, usually water, a well is a structure or excavation made in the ground through digging or drilling. The most common type of well is a water well, which provides access to groundwater stored in underground aquifers. To retrieve the well water, various methods are used, such as pumps or manual lifting with containers like buckets. In some cases, water can also be returned to the aquifer through the well. Wells have a long history, with different construction methods employed over time, ranging from simple sediment scoops in dry watercourses to complex systems like qanats in Iran, stepwells in India, and sakiehs (Hussain *et al.*, 2001).

Different methods are available for irrigating plants, including tap irrigation and localized irrigation. Tap irrigation is the simpler method, relying on gravity flow without the need for pumps. This can be accomplished through bordered strip, flooding, or furrow irrigation; in contrast to other irrigation techniques, water is not sprayed directly onto the plant surface. This reduces the risk of contamination from unclean water (Solomon *et al.*, 2002). Localized irrigation, on the other hand, involves delivering water to each plant through interconnected pipes (Vermeiren and Jobling, 1983). Drip irrigation, micro-sprinkler irrigation, and bubbler irrigation are common techniques used in localized irrigation (FAO, 2020). Micro-irrigation, in particular, allows precise application of water to the canopy or areas of the root, resulting in improved crop quality and yield. Sprinkler irrigation systems will be utilized in this research for leafy vegetables. With capillary force promoting water flow to the plant zone, sub-irrigation may be used in regions with high groundwater levels by elevating water using pumps and pipes to open ditches or subterranean channels (Smajstrla *et al.*, 1991).

Despite their effectiveness, open irrigation systems can result in significant water losses because of evaporation and problems with the distribution routes (Rivas *et al.*, 2007). For instance, evaporation causes a 50% water loss in Zimbabwe's traditional irrigated gardens during tap irrigation (Batchelor *et al.*, 1996). Implementing a water circuit is crucial to enhance efficiency in irrigation water distribution systems and save water, with potential savings ranging from 10% to 50% (Postel, 1992). The quality of irrigation water distribution systems can be affected by several factors, including the water source's microbiological condition, environmental complexity, nutrient availability, microbial interactions, and sediment accumulation, which may contain a range of microbial communities crucial to food safety (Pachepsky *et al.*, 2011. The use of partially treated or untreated wastewater for farm irrigation poses a risk of microbial contamination to irrigated crops. Microorganisms can persist within the water circuit, including biofilms (Yan *et al.*, 2009). Environmental variables, soil nutrient availability, microbial interactions, pipe materials, system hydraulics, disinfectant usage, residual presence, sediment buildup, and carbon accumulation are limiting factors that impact pathogen survival and development in the water system (Pachepsky *et al.*, 2011). Pathogenic microorganisms have been detected in irrigation water within pipes during irrigation events (Pachepsky *et al.*, 2011). Water circuit irrigation systems are being used for a variety of crops, including vegetables, as a result of technological advancements. However, the usage of alternative irrigation water sources, such as wastewater, has increased due to growing urbanization and the shortage of freshwater resources. While wastewater offers nutritional benefits due to its inherent mineral content, its use raises significant food safety concerns. This study investigates the impact of these irrigation sources on the proximate and mineral composition of cabbage, lettuce, and amaranthus cultivated in the Offinso Municipality, Ghana.

Fig. 1. Pond used for the irrigation of vegetables (Photo Credit: Peter Nsiah)

Figure 2: Well, used for irrigation (Photo Credit: Peter Nsiah)

Figure 3: Tap water used for irrigation (Photo Credit: Peter Nsiah)

Fig. 4. Wastewater used for irrigation (Photo Credit: Peter Nsiah)

Fig. 5. Harvesting rainwater for irrigation (Photo Credit: Peter Nsiah)

Materials and Methods

Study area

The Offinso Municipality, one of the administrative regions under the jurisdiction of Ghana's Municipal and District Assemblies, served as the study's site. Located in the Ashanti Region, Offinso serves as the municipal capital. Geographically, the municipality lies in the northwestern part of the Ashanti Region, positioned between longitudes 1°50'W and 1°45'E, and latitudes 7°20'N and 6°50'S. Covering about 585.7 square kilometres, it makes up roughly 2.4% of the region's total land area. For this research, three towns were chosen: Abofour, Ayensua, and Namong. These communities are well known for their vegetable farming, particularly lettuce, cabbage, and amaranthus, along with other vegetable varieties and cash crops.

Experimental design and procedure

The study employed a 5x3 factorial completely randomized design with three replications. The first factor is water sources at five levels (wastewater, pond water, tap water, well water, and rainwater), and the second factor is vegetables at three levels (cabbage, lettuce and amaranthus). Samples of the three vegetables were prepared for various analyses. 10 heads of cabbage were taken from the farmers who used the different water sources. For lettuce and Amaranthus, 500g of each was taken from farmers using the five water sources. The selected vegetables were based on the type of water used to irrigate each, that is, they were put into groups.

The quantitative and experimental research designs were used for the study. Specifically, a causal design was used by the researcher to undertake this study. In investigating the causes and effects between variables, a causal design is appropriate. Also, as stated by Sone (2017), causal design is appropriate when a study aims to investigate a proportion of a population and generalize the findings for the entire population. Examining the link between variables is made easier by the causal design. This study, for example, employed the causal design to ascertain the effect of varying irrigation water on the nutritional components of a selected green vegetable.

Sampling

The study targeted vegetable crop farmers who cultivate lettuce, cabbage and amaranthus in the selected communities, that is Abofour, Namong and Ayensua. The total number of registered farmers was one hundred and thirty-one (131) out of which sixty-seven (67) were sampled. Which breaks down to forty (40) from Abofour, eighteen (18) from Namong and nine (9) from Ayensua. Out of these farmers selected from the larger population, each of them was using at least three (3) of the sources of water for the study, that is, wastewater, pond /groundwater, well water, rainwater, and tap water. Also, each of the farmers selected cultivates the three vegetable crops.

According to data from the Vegetable farmers' associations from the selected areas, the study areas have a farmer population of one hundred and thirty-one (131), excluding those whose farms are not registered with the associations. These three communities were selected based on their active involvement in the vegetable crops production in the municipality and in the region at large (Amass information, 2019). The study used probability and non-probability sampling techniques. This was used by the researcher to select the required sample size; in that respect, a fair representation of the study population is obtained. This research also employed a multistage selection approach that included purposive and basic random sampling processes to choose localities and study participants. This technique helped to identify selected farmers who used all five sources of water in the three selected communities, who are intended to be representatives of the general population of all farmers.

Initially, the three villages for the research were chosen using purposive sampling, a non-probability selection approach. Lastly, simple random sampling was adopted to choose farmers for the subsequent selection of the vegetables for laboratory analysis.

Sample analysis

Proximate analysis of the leafy vegetable

Moisture Content

The oven-drying technique was used to determine the moisture content. A pre-weighed crucible was filled with around 2 g of each sample. After being dried for 24 hours at 60 °C in a hot-air oven, the samples were moved to a desiccator to cool before being weighed again. Until a consistent weight was achieved, drying was repeated.

The following formula was used to get the % moisture content:

Moisture percentage = (D / B) × 100

Where,
Crucible weight (A)
B is the weight of the new sample.
C is the weight of the dry sample.
D is loss of moisture (B − C)

Crude protein content

The Micro-Kjeldahl technique, as outlined by the AOAC (1990), was used to evaluate the protein content. Ten milliliters of concentrated H_2SO_4 were combined with roughly two grams of the material in a digestion tube. The mixture was then digested in a fume hood until it became transparent after adding one tablespoon of selenium catalyst. Following digestion, the material was neutralized using an equivalent volume of 10 millilitres of 45% NaOH solution and diluted with distilled water. After utilizing a Kjeldahl apparatus to distill the combination, the distillate was collected and placed in a 4% boric acid solution with three drops of methyl red indicator. The distillate was titrated from a 50 ml sample. Three duplicates of the process were carried out, and the average value was determined.

The following formula was used to get the percentage of nitrogen:

% N = [50(S - B) × 0.019057 × 0.0140 × 100] / (10 × Sample Weight)

The nitrogen value was multiplied by 6.25 to determine the percentage protein:
% P = % N × 6.25

Where,
S = Titre value
B = 0.20 Blank
% N is the nitrogen percentage.
Protein Percentage (% P)

Crude fat

The Soxhlet extraction technique was used to ascertain the samples' fat content. A thimble was filled with around 2 g of each sample, which was then loosely wrapped in filter paper. A round-bottom flask that had been previously weighed was filled with the thimble and its contents. After that, the flask was filled with around 120 milliliters of petroleum ether. The Soxhlet apparatus, fitted with a condenser and connected to a heating mantle, was assembled, and the extraction process was allowed to reflux continuously for 3 hours. During this period, the fat was extracted from the sample into the solvent. The petroleum ether was extracted by heating the flask that contained the solvent and fat at the conclusion of the extraction. The flask was subsequently dried for ten minutes at 100 °C in an oven to guarantee total evaporation. The weight of the removed fat was then determined by cooling it and weighing it again.

(A - B) / C × 100 = % Fat

Where,
A is the flask weight plus the fat that has been removed, and B is the flask's empty weight.
C is the sample weight.

Carbohydrate content

By adding together all of the proximate metrics and subtracting from 100, the carbohydrate was determined to be the nitrogen-free extract as defined by AOAC (1990). (m + p + f1 + A + f2) - 100 is the nitrogen-free extract (NFE).

In this case, A = ash and f2 = crude fiber m is for moisture, p is for protein, and f1 is for fat.

Ash content

A known-weight porcelain crucible was filled with around 2 g of each sample. The crucibles were ashed for three hours at 550 °C in a muffle furnace. The samples were kept ashing until they became white, signifying full combustion and the lack of carbon. The crucibles were ashed, then moved to a desiccator, allowed to cool to room temperature, and weighed again. The following formula was used to determine the amount of ash:

(A + B) - A = B (A + C) - A = C % Ash = C/B x 100

Where,
A is the weight of the crucible,
B is the weight of the sample, and
C is the weight of the ash.

Crude fibre content

In the presence of one gram of asbestos, two grams (2 g) of each sample were boiled for 30 minutes with 200 milliliters of a 1.25% H_2SO_4 solution. A Buchner funnel was set over a muslin cloth, and the mixture was filtered through it. The residue was then carefully cleaned with boiling water to remove any remaining acid. 200 ml of 1.25% NaOH solution was used to repeat the process, and 10 ml of 95% ethanol was then used to wash the residue.

After being cleaned and dried, the residue was put into a porcelain crucible and dried at 100 °C in an oven until its weight remained constant. After cooling in a desiccator, it was weighed again. After the crucible and its contents were burned, the weight of the ash was measured.

The crude fiber % was computed as follows:

$$\% \text{ Crude Fibre} = \frac{(A-B)}{C} \times 100$$

Where:
A = dry crucible weight + dried residual
B = crucible weight + post-incineration ash weight
C = sample weight

Vitamin C Content

The techniques outlined by Xinmei *et al.* (2013) were used to determine the vitamin C content. Five grams of the material were weighed and dissolved in one hundred milliliters of distilled water to create a sample solution. After that, a 10-milliliter aliquot of the sample solution was put into a conical flask. A 0.5% starch indicator was added to this mixture. Iodine solution (0.005M) was used to titrate the solution until a little pink tint was seen. Ascorbic acid has previously been used to standardize the iodine solution. As advised by Xinmei *et al.* (2013), the experiment was carried out in triplicate, and the average titre value was noted for further computations.

$$C1V1 = C2V2$$

Where,
C1 is the iodine solution's known molarity.
V1 = initial iodine volume
C2 = unknown ascorbic acid solution molarity
V2 is the ascorbic acid volume.

Mineral Content (Iron, Calcium, Phosphorus, Potassium, Magnesium, Zinc)

A porcelain crucible containing one gram (1 g) of powdered vegetable material was heated to 500°C for four hours. Ten millilitres of a 1:5 HCl-water solution were used to digest the ash, and it was heated for two minutes.After filtering the digest into a 100 ml volumetric flask, it was carefully washed and diluted with distilled water to the appropriate level. To lessen cation interference, lanthanum and cesium oxide solutions were used to provide a further dilution (1:50). Mineral concentrations (K, Mg, Mn, Zn, Na, Fe, Ca, Cu) were determined using Atomic Absorption Spectrophotometry (AAS) at respective wavelengths after calibration. Finally, the specific elements present in the sample would be calculated based on the measured concentrations.

The (Fe, Mn, Cu, Zn) ppm = concentration x coefficient factor, and the dilution factor 50 (Ca, Mg, P, K) % = concentration x df (Ca, Mg, P, K) % = concentration x 50/100 = concentration /2

Statistical analysis

The impact of therapy on the different parameters was ascertained using analysis of variance (ANOVA). Means were compared using the least significant difference (LSD) at the 5% level.

Result and Discussion

Proximate analysis of the vegetables

Moisture content

Table 1. Moisture content (%) of three leafy vegetables as affected by various sources of irrigation water.

Water sources	Vegetables			
	Cabbage	Lettuce	Amaranthus	Means
Well	91.44a	92.42a	83.08bc	88.98bc
Rain	92..12a	94.08a	88.05a	92.44a
Tap	93.08a	91.96a	78.19c	87.74c
Pond	92.90a	92.10a	89.31ab	91.44ab
Waste	94.04a	94.52a	80.98c	89.18bc
Means	92.33a	93.02a	84.52b	
HSD (0.01):				

The leafy vegetables and the interaction for various water sources for moisture content showed significant ($P \leq 0.01$) variations (Table 1). The highest moisture content was observed by all three vegetables irrigated under the various water sources, except for amaranthus irrigated using tap and wastewater. In terms of the type of vegetables, cabbage had the highest moisture content (92.33%), which was similar to lettuce and the least was amaranthus (84.52%). For the different sources of irrigation, moisture content for rainwater was the highest (92.44%) and the least was tap water (87.74%). The highest moisture content was recorded by both cabbage and lettuce irrigated under the various water sources, while amaranthus irrigated using the various water sources recorded the least. This could be due to the fact that cabbage and lettuce are genetically similar and have a higher surface area and size and therefore their moisture content is higher as compared to amaranthus. This study supports Zhao *et al.* (2013), who stated that cabbage has to be processed the right way by removing a lot of moisture since it has a greater moisture content and this prolongs its shelf life. For the different sources of irrigation, the moisture content for wastewater was the highest and the lowest was rainwater. The possible reason could be the availability of wastewater to the farmers, so watering with wastewater was more frequent than watering with rainwater.

Crude protein content

Table 2. Protein (%) content of three leafy vegetables as affected by various sources of irrigation water.

Water sources	Vegetables			
	Cabbage	Lettuce	Amaranthus	Means
Well	20.99a	16.64bcde	12.58f	16.74a
Rain	13.65def	14.48cdef	11.03f	13.06b
Tap	17.57abcd	13.45ef	10.60f	13.87b
Pond	21.39a	20.37ab	11.82f	17.86a
Waste	20.22ab	18.18abc	13.68def	17.38a
Means	18.77a	16.26b	11.96c	
HSD (0.01):				

There were significant variations between the interaction of leafy vegetables and different Water Sources for protein content in Table 2. The highest protein content was obtained by cabbage, which was irrigated using pond water (21.39%), which was similar to cabbage irrigated using well water (20.99%) while the least was amaranthus irrigated with tap water (10.60%). In terms of the type of vegetables, cabbage had the highest protein (18.77%) and the least was amaranthus (11.96%). For the different sources of irrigation, protein content for well water was (16.74%) and for pond water (17.86%) and for both rain and tap water (13.06%).

The variation in the genetic makeup of the three leafy vegetables could account for the differences in the protein content. The study's findings showed that amaranthus watered with tap water had the lowest protein level, whereas cabbage irrigated with pond water had the greatest protein content, comparable to cabbage irrigated with well water.

Crude fat content

Table 3. Fat (%) content of three leafy vegetables as affected by different sources of irrigation water.

Water sources	Vegetables			
	Cabbage	Lettuce	Amaranthus	Means
Well	5.95a	4.95b	4.94b	5.28a
Rain	3.77d	4.96b	2.96e	3.89c
Tap	3.70d	3.94c	4.95b	4.19b
Pond	1.95f	4.94b	2.94e	3.28d
Waste	4.95b	5.97a	4.95b	5.29a
Means	4.06c	4.96a	4.15b	
HSD (0.01):				

In Table 3, the interaction of leafy vegetables and various water sources for fat content varied significantly ($P \leq 0.01$). The highest content of fat was obtained by lettuce, which was irrigated using wastewater (5.97), which was similar to cabbage irrigated using well water (5.95) while the least was in cabbage irrigated with pond water (1.95). In terms of the type of vegetables, lettuce had the highest fat (4.96) and the least was in cabbage (4.06). For the different sources of irrigation, the fat content for well water was the highest (5.28) and the least was in pond water (3.28). The variations in crude fat content among the leafy vegetables may be attributed to their inherent genetic differences, with lettuce exhibiting a naturally higher tendency to accumulate fats. This observation aligns with findings by Neelesh and Arya (2018), who noted that leafy vegetables such as lettuce generally have greater lipid accumulation compared to others like cabbage or amaranthus due to differences in their metabolic profiles. The high fat content seen in vegetables that are irrigated with wastewater and well water may be caused by dissolved organic and inorganic elements in these sources, which may promote the manufacture of fat in plant tissues (Moazma *et al.*, 2024). Conversely, pond water may lack sufficient nutrient concentration or may contain competing factors that limit lipid formation, accounting for its association with lower fat content.

Carbohydrate content

Table 4. Carbohydrate (%) content of three leafy vegetables as affected by various sources of irrigation water

Water sources	Vegetables			
	Cabbage	Lettuce	Amaranthus	Means
Well	26.84i	40.05de	44.24bc	37.04b
Rain	37.85ef	39.70de	48.38a	41.98a
Tap	32.88gh	42.31cd	46.31abc	40.49a
Pond	33.31g	34.83fg	46.77ab	38.30b
Waste	28.88hi	33.65g	47.95ab	36.82b
Means	31.95c	38.11b	46.73a	
HSD (0.01):				

In Table 4, the relationship between the carbohydrate content of various water sources and leafy vegetables varied significantly (P≤ 0.01). The highest carbohydrate content was obtained by amaranthus, which was irrigated using rainwater (48.38%), while the least was cabbage irrigated with well water (26.84%). In terms of the type of vegetables, amaranthus had the highest carbohydrate (46.73%) and the least was cabbage (31.95%). For the different sources of irrigation water, carbohydrate content for rainwater (41.98%) and tap water (40.49%) was the highest, and the least was wastewater (36.82%). The present study's findings showed that amaranthus, which was irrigated with rainwater, had the greatest carbohydrate content, while cabbage, which was irrigated with well water, had the lowest. The observed variations can result from genotypic variations among the several green vegetables included in this investigation.

Ash content

Table 5. Ash (%) of three leafy vegetables as affected by various sources of irrigation water.

Water sources	Vegetables			
	Cabbage	Lettuce	Amaranthus	Means
Well	7.23f	12.60bc	11.80cd	10.54ab
Rain	7.07f	13.41ab	11.32d	10.60a
Tap	7.34f	13.62a	11.60cd	10.86a
Pond	6.43f	11.30d	11.78cd	9.83c
Waste	7.23f	14.22a	8.95e	10.13bc
Means	7.06c	13.03a	11.09b	
HSD (0.01):				

There were significant (P≤ 0.01) variations between the interaction of the leafy vegetables and different water sources for ash concentration (Table 5). The lettuce that was irrigated with wastewater had the highest ash level (14.22%), which was comparable to lettuce that was irrigated with tap water (13.62%). The cabbage that was irrigated with all of the water sources had the lowest ash content. For the vegetables only, lettuce recorded the highest content of ash (13.03%) and the least was in cabbage

(7.06%). For the sources of irrigation, both tap water (10.86%) and rainwater (10.60%) recorded the highest ash content, and the least was recorded by pond water (9.83%). The results obtained indicated that the highest ash content was recorded by lettuce, which was irrigated using wastewater, which was similar to lettuce irrigated using tap water, while cabbage irrigated by the various water sources recorded the least ash content. This current result is in agreement with the assertion made by Scheller *et al.* (2010) that differences in ash content in vegetables could be differences in the genetic makeup of the leafy vegetables. Furthermore, ash is one of the inorganic mineral components that are provided in food to enhance the bioavailability of free minerals (Gbadegesin *et al.*, 2017). Additionally, Muzzama *et al.* (2024) clarified that ash increases with increasing dry matter concentration and vice versa. This could also explain why there were no significant differences in terms of the various types of water used.

Crude fibre content

Table 6. Fibre (%) of three leafy vegetables as affected by various sources of irrigation water

Water sources	Vegetables			
	Cabbage	Lettuce	Amaranthus	Means
Well	38.99a	24.76g	26.43fg	30.39ab
Rain	37.66b	27.45e	26.31fg	30.47ab
Tap	38.51a	26.67f	26.54f	30.57ab
Pond	36.91c	28.55d	26.70f	30.72a
Waste	38.72a	27.97de	24.41h	30.37b
Means	38.16a	27.28b	26.08c	
HSD (0.01):				

The interaction between the various water sources and the leafy vegetables for crude fiber showed significant (P≤ 0.01) variations (Table 6). Amaranthus watered with wastewater produced the least amount of crude fiber (24.41%), whereas cabbage irrigated with tap water produced the most (38.99%). Wastewater generated the least amount of crude fiber (30.37%) among the water sources, whereas pond water produced the most (30.72%). Amaranthus provided the least amount of crude fiber (26.08%) among the vegetables, whereas cabbage produced the most (38.16%). Cabbage irrigated with tap water recorded high crude fibre content, followed by lettuce, while amaranthus recorded the least crude fibre. This result was further explained by Neelesh and Arya (2018) that high crude fibre recorded by cabbage as compared to the low crude fibre content of amaranthus may be due to differences in the lignin and the hemicellulose content in both crops. Lignin is found in the outer cell wall of biomass in terms of physical structure. Schelleriu *et al.* (2010) states that cellulose is typically found inside a lignin shell, but hemicellulose, which has an amorphous and random structure, is found inside cellulose and in between cellulose and lignin. Also, Tarasov *et al.* (2018) explain that deposition of cellulose helps in strengthening the walls of the cells. This could also be the reason while there were no significant differences between the various water sources.

Vitamin C content

Table 7. Vitamin C content (mg/kg) of three leafy vegetables as affected by different sources of irrigation water.

Leafy vegetable	Water Sources					
	Waste	Tap	Well	Rain	Pond	Means
Cabbage	4.31^{de*}	5.16^{cd}	5.36^{c}	6.56^{b}	8.61^{a}	6.00^{a}
Lettuce	2.30^{f}	5.41^{c}	5.43^{c}	6.74^{b}	4.15^{e}	4.81^{b}
Amaranth	1.67^{f}	4.83^{cde}	5.53^{c}	7.11^{b}	5.57^{c}	4.94^{b}
Mean	2.76^{d}	5.13^{c}	5.44^{c}	6.80^{a}	6.11b	
HSD (0.01):						

There were some significant variations between the various leafy vegetables and different water sources interaction for Vitamin C content (Table 7). The highest Vitamin C was recorded by cabbage, which was irrigated using pond water (8.61 mg/kg) and the least was in lettuce and amaranthus irrigated with wastewater (1.67 mg/kg). In terms of the type of vegetables, cabbage had the highest Vitamin C content (6.00 mg/kg) and the least was lettuce (4.81 mg/kg), similar to amaranthus (4.94 mg/kg). For the various sources of water for irrigation, the amount of Vitamin C for rainwater was the highest (6.80 mg/kg) and the least was wastewater (2.76 mg/kg). The highest Vitamin C was recorded by cabbage, which was irrigated using pond water and the least was in lettuce and amaranthus irrigated with wastewater. This could be due to the different genetic makeup of the three leafy vegetables used in the study. This study was further discussed by Miedzianka *et al.* (2006), who stated that because cabbage has a variety of vitamins C and E, it is a vegetable that is important in everyday living. For the various irrigation water sources, Vitamin C for rainwater recorded the highest and the least was wastewater. The possible reason could be that other minerals were washed into the rainwater during rain or during harvesting of the rain.

Mineral Content (Iron, Calcium, Phosphorus, Potassium, Magnesium, Zinc)

Calcium content (mg/kg)

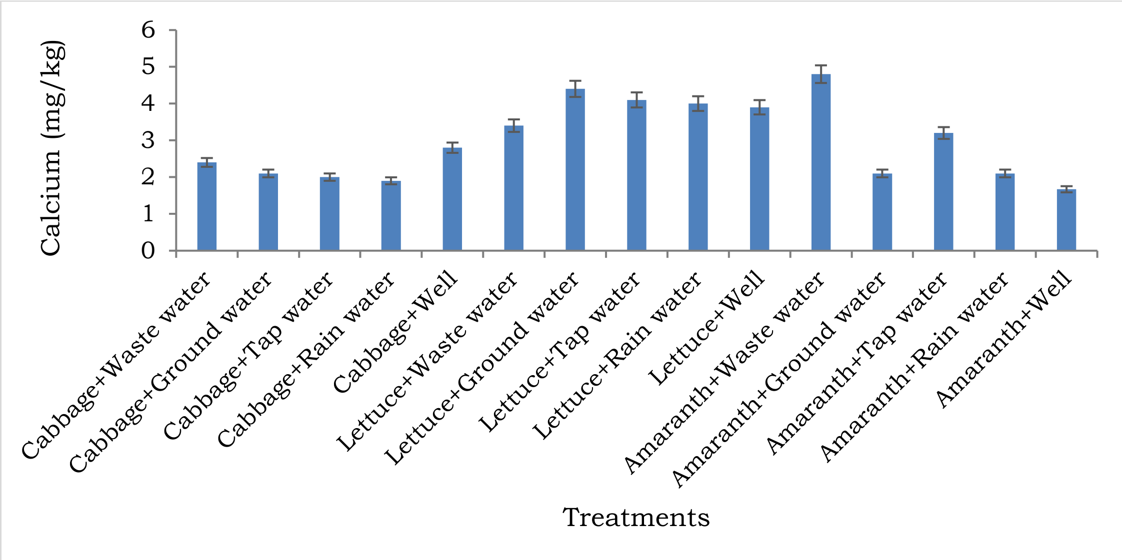

Fig. 6. Calcium content (mg/kg) of the three vegetables irrigated with different water.

Figure 6 shows the different significant variations that existed in the various treatments for the calcium content of the leafy vegetables. Amaranthus, which was irrigated with wastewater, had the highest calcium (48 mg/kg) while amaranthus irrigated with well water had the least in calcium (1.67 mg/kg). The highest calcium content was recorded by amaranthus irrigated with wastewater, while the least was amaranthus, which was irrigated using well water, followed by cabbage, which was irrigated using rainwater. Differences noticed could be due to minerals or chemicals present in the wastewater. According to Moazma *et al.* (2024), the observed variations in calcium may be due to the natural makeup of the vegetables used in the study.

Iron content (mg/kg)

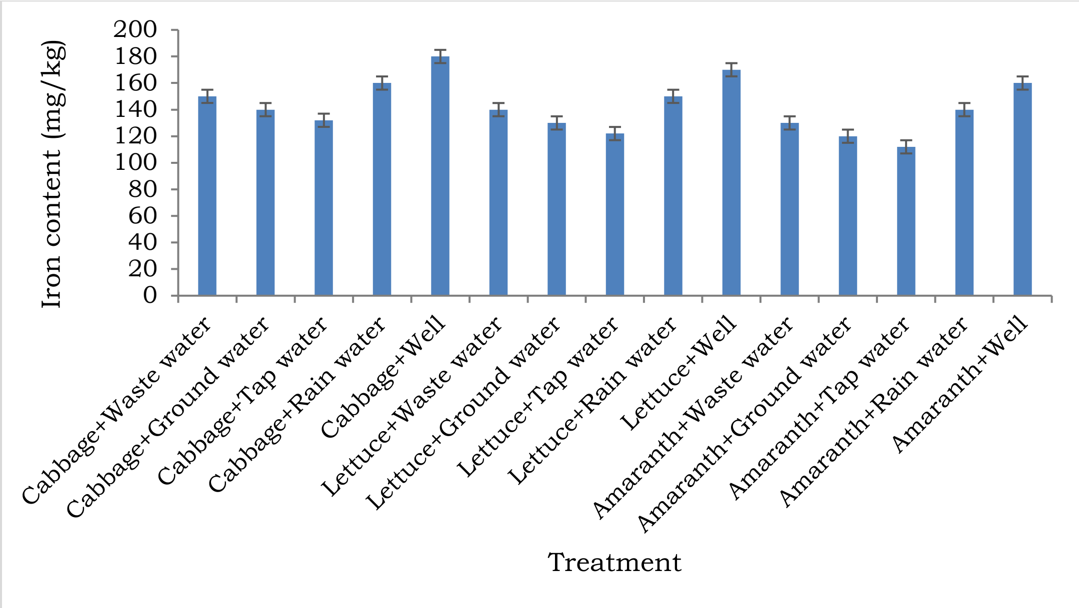

Fig. 7. Iron content (mg/kg) of the three vegetables irrigated with different water.

Figure 7 shows the different significant variations that existed in the various treatments for the Iron content of the leafy vegetables. Cabbage irrigated with well water recorded the highest Iron (180 mg/kg), followed by lettuce, which was also irrigated with well water (170 mg/kg), while amaranthus irrigated with tap water had the least (112 mg/kg). There were significant variations in the various treatments for the iron content of the leafy vegetables. Amaranthus, cabbage and lettuce, which were irrigated with well water, had the highest Iron, while amaranthus irrigated with pond/groundwater had the least. The possible reason could be some chemicals present in well water, as well as the genetic makeup of the vegetables.

Phosphorus content

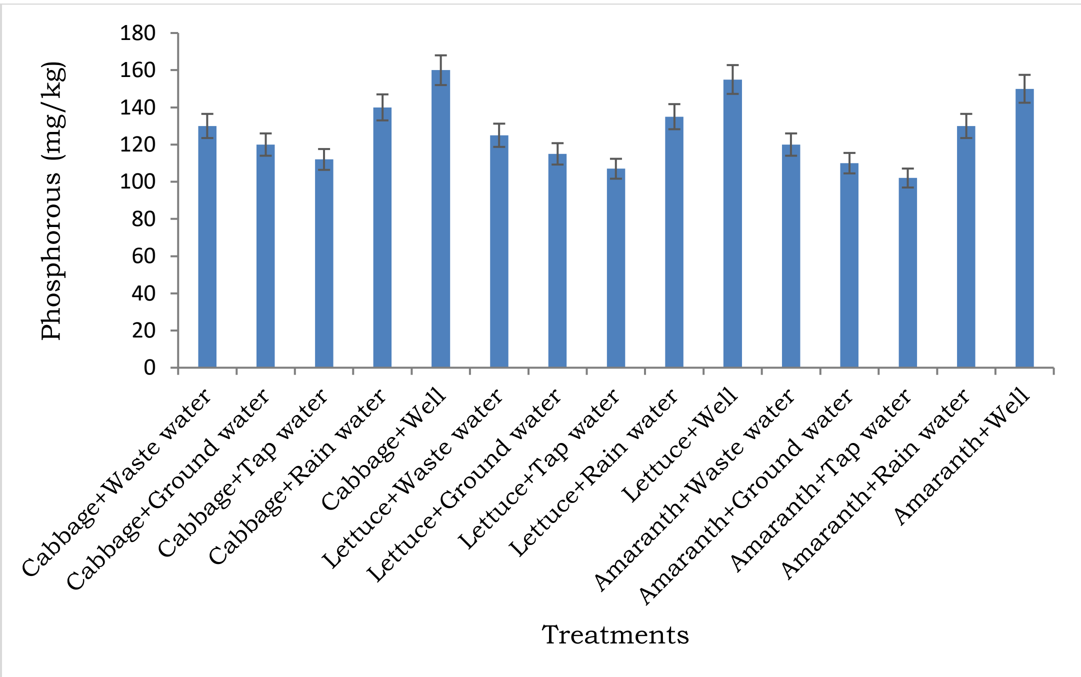

Fig. 8. Phosphorous content (mg/kg) of the three vegetables irrigated with different water sources.

Figure 8 shows the different significant variations that existed in various treatments for the phosphorus content of the leafy vegetables. Cabbage irrigated with well water recorded the highest phosphorus(160 mg/kg) followed by lettuce, which was irrigated with well water (158 mg/kg) and then amaranthus also irrigated with well water (150 mg/kg). The least phosphorus content was recorded by amaranthus irrigated with tap water (102 mg/kg). Cabbage, amaranthus and lettuce, which were irrigated with well water had the highest phosphorus, while amaranthus irrigated with pond water had the least. Phosphorus is essential for metabolic functions and aids in ATP synthesis (Nath, 2024). According to the study, variations in the genetic composition of the plants may account for variations in the phosphorus concentration found. Phosphorus consumption aids in keeping calcium and phosphorus in balance for healthy bones and teeth.

Potassium content (mg/kg)

Table 8. Potassium content (mg/kg) of three leafy vegetables as affected by different sources of irrigation water sources.

Water sources	Vegetables			
	Cabbage	Lettuce	Amaranthus	Means
Well	3.11j	3.36h	4.49e	3.66e
Rain	4.02g	4.90d	7.28a	5.40a
Tap	4.23f	4.45e	3.34h	4.01d
Pond	3.32hi	4.03g	6.41b	4.59b
Waste	3.22i	5.71c	4.28f	4.40c
Means	3.58c	4.49b	5.16a	
HSD (0.01):				

There were significant (P≤ 0.0) variations between the interaction of leafy vegetables and different Water Sources for potassium content (Table 8). Amaranthus, which was irrigated with rainwater, had the greatest potassium content (7.28 mg/kg), whereas cabbage, which was irrigated with well water, had the lowest (3.11 mg/kg). Regarding vegetable kind, amaranthus had the greatest potassium content (5.16%), while cabbage had the lowest (3.58 mg/kg). For the different sources of irrigation, the potassium content for rainwater (5.40 mg/kg) and well water (3.66 mg/kg) recorded the least potassium content. The observed differences in potassium content can be attributed to both the genetic characteristics of the leafy vegetables and the mineral composition of the various water sources. The consistently higher potassium content found in amaranthus aligns with previous findings by Nath (2024), who reported that amaranthus species are naturally richer in potassium due to their efficient uptake and accumulation mechanisms. The superior performance of rainwater as an irrigation source in enhancing potassium content may be explained by its relative purity and the potential presence of dissolved nutrients from atmospheric deposition during precipitation events. Additionally, the slightly acidic nature of rainwater may improve nutrient availability and uptake by plants (Miedzianka *et al.,* 2006). In contrast, well water may contain higher levels of competing ions such as calcium and magnesium, which could potentially limit potassium absorption by the plants.

Magnesium content (mg/kg)

Table 9. Magnesium content (mg/kg) of three leafy vegetables as affected by different sources of irrigation water.

	Vegetables			
Water sources	Cabbage	Lettuce	Amaranthus	Means
Well	0.31e	0.21gh	0.72b	0.41a
Rain	0.21g	0.31e	0.64c	0.39b
Tap	0.21g	0.18h	0.77a	0.39b
Pond	0.22g	0.31e	0.62c	0.38b
Waste	0.26f	0.32e	0.56d	0.38b
Means	0.24c	0.26b	0.66a	
HSD (0.01):				

There were significant (P≤ 0.01) variations between the interaction of leafy vegetables and different Water Sources for magnesium content (Table 9). The highest magnesium content was recorded by amaranthus, which was irrigated using tap water (0.77 mg/kg), while the least was lettuce irrigated with tap water (0.18 mg/kg). In terms of the type of vegetables, amaranthus had the highest magnesium content (0.66%) and the least was cabbage (0.24 mg/kg). For the different sources of irrigation, magnesium content for well water was the highest (0.41 mg/kg) and the least was for all the other water sources. The variation in magnesium content observed among the vegetables is likely a reflection of species-specific nutrient absorption and accumulation capacities. Amaranthus, known for its high mineral uptake efficiency, demonstrated superior magnesium content, corroborating earlier reports by Moazma *et al.* (2024) that highlight its high mineral density relative to other leafy greens.The elevated magnesium content in amaranthus irrigated with tap water could be attributed to localized differences in water mineral composition, especially if the tap water in the study area contained moderate levels of dissolved magnesium salts. Conversely, the low magnesium content in lettuce irrigated with tap water may reflect genotypic limitations in magnesium uptake by lettuce, as well as possible antagonistic interactions with other ions in the water. Magnesium is a vital nutrient in plant physiology, playing key roles in chlorophyll synthesis and enzymatic functions (Gerendás and Führs, 2013). Its presence in vegetables is essential for human bone health, metabolic activity, and cardiovascular function (Watson and Garcia-Casal, 2018; FAO, 2017). These findings suggest that while well water generally supported better magnesium content in vegetables overall, specific vegetable species like amaranthus can benefit from even moderate magnesium concentrations in other water sources, such as tap water. However, consistent monitoring of water quality is essential, especially when using non-traditional sources such as wastewater or pond water, to mitigate potential risks of contamination.

Zinc content (mg/kg)

Table 10. Zinc content (mg/kg) of three leafy vegetables as affected by different sources of irrigation water.

Water sources	Vegetables			
	Cabbage	Lettuce	Amaranthus	Means
Well	62.89ef	30.51g	74.67c	56.03d
Rain	75.69c	54.97f	127.53a	86.06a
Tap	74.03cd	60.10ef	67.85cde	67.32c
Pond	64.42def	58.77ef	106.87b	76.69b
Waste	64.29ef	66.88cde	62.20ef	64.46c
Means	68.26b	54.25c	87.82a	
HSD (0.01):				

There were significant (P≤ 0.01) variations between the interaction of leafy vegetables and different Water Sources for zinc content (Table 10). The highest zinc content was recorded by amaranthus, which was irrigated using rainwater (127.53 mg/kg), while the least was lettuce irrigated with well water (30.51 mg/kg). In terms of the type of vegetables, amaranthus had the highest zinc content (87.82 mg/kg) and the least was lettuce (54.25 mg/kg). For the different sources of irrigation, zinc content for rainwater (86.06 mg/kg) was the highest, and the least was well water (56.03 mg/kg). The higher zinc content observed in amaranthus aligns with its well-documented ability to accumulate essential micronutrients more efficiently than other leafy vegetables (Nath, 2024). The superior performance of rainwater as an irrigation source for enhancing zinc content may be attributed to the potential deposition of atmospheric particulates rich in zinc during rainfall events, as well as the relative purity of rainwater, facilitating nutrient uptake.

Conversely, the lower zinc content recorded in lettuce irrigated with well water may result from mineral competition in the soil solution or possibly lower bioavailability of zinc in that water source due to interactions with other ions such as calcium and magnesium, which are often present in well water (FAO, 2017). Zinc is a vital micronutrient essential for enzymatic functions, immune support, and growth in humans. Its high concentration in amaranthus irrigated with rainwater makes this vegetable a valuable dietary source of zinc, particularly in regions vulnerable to micronutrient deficiencies. However, while rainwater irrigation enhanced zinc accumulation, considerations for possible contamination during rainwater harvesting should be addressed to prevent the introduction of pollutants or pathogens (Pachepsky *et al.*, 2011). These results emphasize that selecting appropriate irrigation sources can substantially influence the mineral composition of vegetables, thereby impacting their nutritional value for human consumption.

Conclusion

The study demonstrates significant variations in nutritional quality among leafy vegetables irrigated with different water sources. Although wastewater contributed to higher calcium in amaranthus, it compromised the Vitamin C content. Rainwater emerged as a preferable source, supporting superior carbohydrate and mineral profiles with lower health risks. Future research should assess microbial contamination levels and propose practical mitigation strategies for farmers relying on wastewater for irrigation.

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