"Neglected But Nutritious, Functional and Dietary Potential of Amaranthus Spinosus and Amaranthus Hybridus"

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DOI: https://doi.org/10.51244/IJRSI.2026.1307000181

Received: 18 July 2026; Accepted: 23 July 2026; Published: 06 August 2026

ABSTRACT

Indigenous leafy vegetables contribute significantly to food security, particularly among low-income households in both urban and rural areas. *Amaranthus spinosus* and *Amaranthus hybridus* are widely distributed underutilised plants often regarded as weeds. This study assessed their nutritional and non-food values to evaluate their potential as a vegetable source for vulnerable populations. The study was conducted in Chilanga District, Mpamba area, Lusaka Province, from December 2023 to February 2024. Ten samples of each species were collected from small-scale farms and analysed at the University of Zambia Plant Science Laboratory. Moisture content was determined using the oven-dry method, crude protein via the Kjeldahl method, and crude fibre, fat, ash, and carbohydrate through standard proximate analysis. Results indicated that *A. spinosus* contained 84.44% moisture, 4.18% protein, 0.63% fat, 3.4% fibre, 2.15% ash, and 7.01% carbohydrate, while *A. hybridus* had 85.0% moisture, 4.26% protein, 0.68% fat, 2.8% fibre, 2.36% ash, and 7.36% carbohydrate. Crude protein content of both species was significantly higher than that of cabbage, rape, and tomato ($p < 0.05$). Questionnaire data indicated notable non-food benefits, particularly in health and medicinal uses. However, popularity was low among young consumers due to negative perceptions of indigenous vegetables as "old-fashioned". These findings demonstrate that *Amaranthus spinosus* and *A. hybridus* are rich sources of essential nutrients and possess important functional benefits. Enhancing awareness of their nutritional and health value could increase consumption, contributing to improved dietary diversity and reduction of hunger and malnutrition.

Keywords: Macronutrients, *Amaranthus spinosus* and *hybridus*, Indigenous leafy vegetable, non-food value.

INTRODUCTION

Zambia continues to face persistent food and nutrition insecurity despite possessing considerable agricultural potential. Undernutrition remains a major public health concern, with approximately 35% of children under five years of age affected by stunting, a condition associated with impaired cognitive development, weakened immunity, and increased risk of mortality (UNICEF, 2021; Zambia Nutrition Profile, 2021). At the national level, Zambia's Global Hunger Index score of 30.7 places the country within the "serious" hunger category, reflecting chronic challenges related to food access, dietary quality, and nutritional outcomes (Global Hunger Index, 2024). Nearly 40% of the population is estimated to be affected by food insecurity and malnutrition, with rural households bearing a disproportionate burden (Alaofe, 2014).

Although Zambia produces sufficient quantities of staple foods at the national level, particularly maize, household-level dietary adequacy remains limited. Diets are predominantly maize-based and characterised by low diversity, inadequate intake of vegetables, and insufficient consumption of protein-rich foods, resulting in widespread macro- and micronutrient deficiencies, notably iron, vitamin A, and calcium deficiencies (USAID, 2022). This narrow dietary base underscores the urgent need for affordable, locally available, culturally acceptable, and nutrient-dense food sources capable of enhancing dietary diversity, resilience, and nutritional outcomes, particularly among vulnerable populations.

Indigenous leafy vegetables (ILVs), notably *Amaranthus spinosus* and *Amaranthus hybridus*, represent an underexploited opportunity to address these challenges. These species are rich in essential macro- and micronutrients, including protein, dietary fibre, iron, calcium, and vitamins A and C, which are critical for human growth, immune function, and overall health (Mainga, 2013; Omoregie & Osagie, 2012). In addition to their nutritional value, *Amaranthus* species exhibit high tolerance to environmental stressors such as drought, poor soils, and erratic rainfall, making them particularly suitable for smallholder farming systems under conditions of climate variability (Damalas, 2008; Ohiokpehai, 2003). Their low production requirements and adaptability further enhance their affordability and accessibility for low-income households compared with many exotic vegetables (Odhav *et al.,* 2007).

Despite these advantages, *Amaranthus spinosus* and *Amaranthus hybridus* remain underutilised in Zambia. They are frequently perceived as weeds rather than valuable food crops, particularly among younger generations who associate indigenous vegetables with poverty and outdated food practices (Uusiku *et al.,* 2010). This negative perception is compounded by limited locally generated scientific evidence on their nutritional composition and non-food values, constraining their inclusion in nutrition programming, agricultural extension services, and policy frameworks (Williams, 2022).

Beyond their role as food sources, *Amaranthus* species possess important non-food functions that contribute to household livelihoods and sustainable agro-ecological systems. These include medicinal applications, soil fertility enhancement through organic matter contribution, and other functional roles within local farming systems. However, such multifunctional attributes remain poorly documented within the Zambian context and are rarely incorporated into integrated food, nutrition, agricultural, and rural development strategies.

Against this background, this study aimed to assess the nutritional content and non-food values of *Amaranthus spinosus* and *Amaranthus hybridus* in Chilanga District of Lusaka Province. The primary objective was to evaluate their macro-nutrient composition and broader functional significance in order to enhance their utilisation among local communities. Specifically, the study sought to: (i) quantify the macro-nutrient content of *Amaranthus spinosus* and *Amaranthus hybridus*, including protein, carbohydrates, fats, fibre, moisture, and ash; (ii) compare their nutritional composition with that of commonly consumed exotic vegetables, namely cabbage (*Brassica oleracea*), tomato (*Solanum lycopersicum*), and rape (*Brassica napus*); (iii) investigate the non-food applications of *Amaranthus* species, including medicinal uses and soil enrichment; and (iv) assess their popularity, consumption patterns, perceptions, and barriers to adoption within the study population.

Accordingly, the study addressed the following research questions: What are the macro-nutrient contents of *Amaranthus spinosus* and *Amaranthus hybridus*? How do these indigenous vegetables compare nutritionally with selected exotic vegetables? What non-food values and functional benefits of *Amaranthus* species are recognised within the study area? How do community perceptions, preferences, and consumption patterns influence their utilisation?

This study is significant in the context of food and nutrition security in sub-Saharan Africa. By generating empirical evidence on the nutritional composition of *Amaranthus* species and comparing them with widely consumed vegetables, the findings provide a robust basis for informing nutrition policy, dietary guidelines, and community-based interventions aimed at improving food and nutrition security. Documentation of non-food values further supports the integration of indigenous vegetables into sustainable agricultural and rural development strategies. Moreover, understanding consumption patterns and perceptions offers insights for designing targeted nutrition education, awareness campaigns, and market development initiatives to overcome cultural and behavioural barriers to adoption. Ultimately, by highlighting the potential of underutilised indigenous vegetables, this study contributes to broader debates on sustainable diets, biodiversity conservation, and climate-resilient food systems in Africa.

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue VII July 2026

Conceptually, the study is anchored in the linkages between the consumption of indigenous leafy vegetables (*Amaranthus spinosus* and *Amaranthus hybridus*), their nutritional and non-food values, and their contribution to improved human health and household food security. Figure 1 illustrates the interaction between underutilised *Amaranthus* species, enhanced dietary quality, improved health outcomes, and strengthened food security.

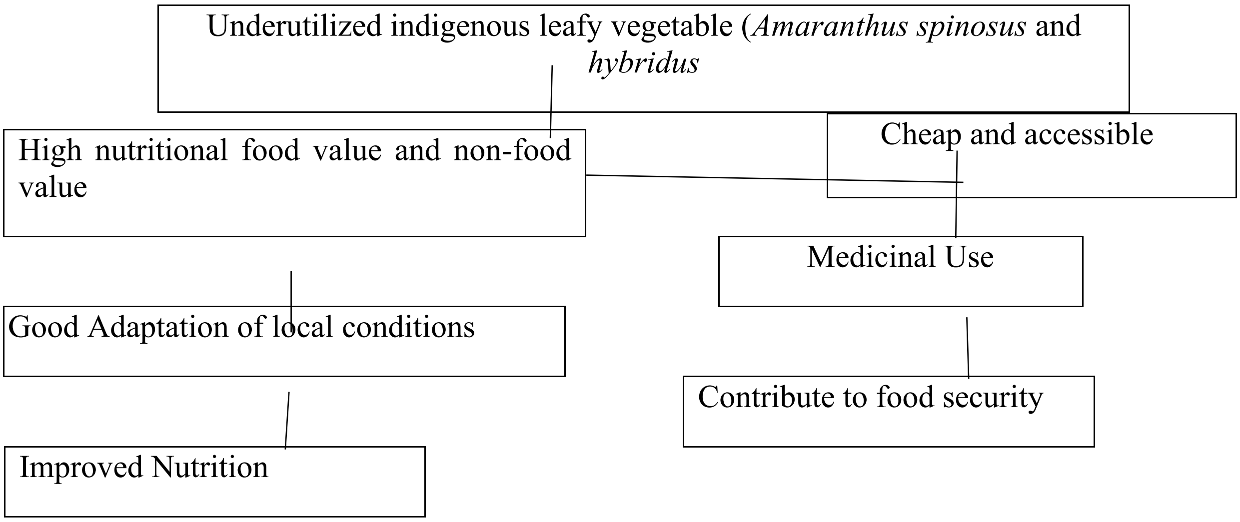

Figure 1: Conceptual framework showing the relationship between consumption of *Amaranthus spinosus* and *Amaranthus hybridus*, their nutritional and non-food values, and implications for human health and food security.

Food shortages continue to be a major contributor to food insecurity across the African continent, particularly in developing countries. Addressing this challenge remains complex due to rapid population growth, increasing frequency of droughts, and climate variability, all of which place pressure on already fragile food systems (Wolfgang and Bokelmann, 2014). These factors have resulted in monotonous diets dominated by a few staple crops, leading to widespread deficiencies in essential vitamins and minerals.

The concept of food security has evolved significantly over time. At the World Food Conference in 1974, food security was initially defined as the availability of adequate food supplies at all times. This definition has since expanded to encompass access, utilisation, and nutritional quality. According to the High-Level Panel of Experts (HLPE), food security exists when all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs for an active and healthy life (HLPE, 2020).

Achieving good nutrition depends on several interrelated pillars. Traditionally, four pillars have been recognised: food availability, food access, food utilisation, and food stability (FAO, 2008). A household is considered food secure only when all four pillars are adequately met. More recently, sustainability and agency have been added as essential dimensions of food security. Agency refers to people’s ability to make informed decisions about food production and consumption and to participate meaningfully in shaping food systems, while sustainability relates to the long-term capacity of food systems to ensure food security and nutrition without compromising future generations (HLPE, 2020). When these pillars are not met, households become food insecure, increasing their vulnerability to hunger and malnutrition.

Several scholars have argued that food-insecure households should increase their consumption of indigenous leafy vegetables, as these crops are nutritious, affordable, and readily accessible to poorer segments of the population (Mbhenyane, 2017; Mabhaudi et al., 2019). Indigenous leafy vegetables are well adapted to local environmental conditions, including drought, and typically require fewer inputs than exotic crops, making them a sustainable option for enhancing food and nutrition security. Their increased consumption has the potential to reduce hunger, improve dietary diversity, and enhance overall dietary quality at household level.

There is therefore a need to emphasise the importance of indigenous leafy vegetables through systematic research. Existing documentation highlights the value of *Amaranthus* species in improving human health, strengthening food security, and contributing to traditional medicine. Incorporating *Amaranthus* into daily diets may reduce the risk of malnutrition and poverty, as malnutrition is fundamentally linked to inadequate nutrient

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue VII July 2026

intake. The findings of this study provide evidence on the nutritional composition of *Amaranthus spinosus* and *Amaranthus hybridus*, which is essential for increasing acceptance of indigenous leafy vegetables, particularly among individuals who hold negative perceptions towards traditional foods. Ultimately, the study promotes the role of *Amaranthus* in reducing nutrient deficiencies and strengthening household food security.

Indigenous leafy vegetables such as *Amaranthus* are well suited to harsh environmental conditions, are easy to cultivate, and require minimal inputs and simple technologies. These characteristics enable them to play a significant role in poverty reduction and livelihood enhancement, particularly in rural areas where access to diverse foods is limited (Ramaesela, 2018). The findings of this research also provide valuable information for policymakers by demonstrating the role indigenous leafy vegetables can play in addressing undernutrition. Such evidence may encourage agricultural and nutrition programmes to prioritise smallholder and rural farmers in promoting diversified indigenous crop production.

The study assessed the nutritional content of *Amaranthus spinosus* and *Amaranthus hybridus* leaf samples collected from a small-scale farm in Mpamba area, Chilanga District, Lusaka Province. The farm was purposively selected due to the visible presence of both species and its proximity to major access roads. In addition, the study compared the nutritional composition of these indigenous vegetables with commonly consumed exotic vegetables, assessed their popularity among consumers, and examined their non-food values.

A review of relevant literature was undertaken to contextualise issues of nutrition and malnutrition, indigenous leafy vegetables, and the comparative role of exotic vegetables in human diets. Particular emphasis was placed on the contribution of indigenous leafy vegetables to human health, with a focus on *Amaranthus spinosus* and *Amaranthus hybridus*, including their uses and health benefits.

Nutrition is a critical component of health and development. Adequate nutrition is associated with improved maternal and child health, stronger immune systems, enhanced cognitive development, and a reduced risk of non-communicable diseases (WHO, 2022). Well-nourished individuals are more productive and better able to break cycles of poverty and hunger. Essential nutrients required for optimal health include proteins, carbohydrates, fats, vitamins, minerals, fibre, and water. However, many populations fail to meet these requirements, resulting in widespread malnutrition.

Malnutrition remains a persistent and serious challenge in Zambia. It is often treated as a consequence of poverty rather than as a public health issue requiring targeted intervention. Except in severe cases requiring hospitalisation, malnutrition receives limited attention, and overall dietary quality remains poor throughout the year. Diets are largely monotonous, dominated by one or two staple crops, with limited intake of vegetables and animal products. Nutritional status often deteriorates during the pre-harvest season when food supplies are most constrained and the cost of agricultural inputs rises.

Malnutrition in Zambia is primarily driven by excessive reliance on carbohydrate-rich foods and insufficient consumption of fruits, vegetables, and animal-source foods. It results from inadequate nutrient intake and, in some cases, impaired nutrient absorption due to illness (NHS, 2021). The major nutrition problems affecting Zambia include protein-energy malnutrition and deficiencies of iodine, iron, and vitamin A. These deficiencies have severe consequences, including increased child mortality, reduced cognitive capacity, and diminished labour productivity (USAID, 2016).

Both acute and chronic forms of protein-energy malnutrition are prevalent in rural and urban areas. Micronutrient deficiencies disproportionately affect women and children. At household and community levels, nutritional status is influenced by three interrelated pathways. First, household food security remains a challenge, as many households live below the poverty line and cannot afford a nutritionally adequate food basket (CSO, 2012). Economic instability and adverse weather conditions further undermine food availability. Second, caring practices for women and children are inadequate, with evidence showing that most children become stunted between the ages of two months and two years due to insufficient dietary intake during this critical period (DHS, 2014). Finally, poor health services and environmental conditions, including limited access to clean water and healthcare, increase the incidence of disease and exacerbate malnutrition through nutrient loss and reduced absorption (Handa *et al.,* 2014).

Protein–Energy Malnutrition

Protein–Energy Malnutrition (PEM) remains one of the most critical public health challenges in Zambia, particularly among children under five years of age. The most prevalent manifestation of PEM in the country is stunting, also referred to as linear growth retardation, which reflects chronic undernutrition occurring over an extended period. Early national estimates indicated that stunting affected approximately 53% of children under the age of five (UNICEF, 2000). Although some progress has been made over the years, stunting remains alarmingly high.

According to the Zambia Demographic and Health Survey (ZDHS), children's nutritional status is assessed by comparing height and weight measurements against internationally accepted reference standards. Stunting indicates long-term nutritional deprivation, while wasting reflects acute undernutrition. Provincial disparities in stunting prevalence are evident, with the highest rates recorded in Northern Province (46%) and Luapula Province (45%), while the lowest rates are observed in Western and Southern Provinces, each at approximately 29%. Wasting has remained relatively stable at around 4% among children under five, while 12% of children are underweight for their age and approximately 5% are overweight (Ministry of Health, 2018).

Using the World Health Organization (WHO) classification, Zambia's stunting levels are categorised as "very high" or "critical", wasting as "medium", and underweight as "high" or "serious". In addition, an estimated 10–13% of infants in Zambia are born with low birth weight, a condition closely associated with poor maternal nutrition before and during pregnancy. Approximately 9% of mothers with children under three years of age are malnourished, with a Body Mass Index (BMI) below 18.5, indicating undernutrition. Although this proportion is comparatively lower than in some sub-Saharan African countries, it remains a significant contributor to poor child health outcomes (Ministry of Health, 2018).

Micronutrient Deficiencies

Micronutrient deficiencies constitute a major component of malnutrition in Zambia and represent a serious public health concern, particularly among low-income and rural populations. Vitamin A deficiency is especially prevalent due to inadequate dietary intake of vitamin A–rich foods. A national survey conducted in the late 1990s reported vitamin A deficiency rates of 65.7% among children and 21.5% among women. Night blindness, a clinical indicator of severe vitamin A deficiency, was reported at 6.2% among children and 11.6% among women (Ministry of Health, 2018).

Iron deficiency anaemia is also widespread in Zambia, affecting up to 50% of women attending antenatal clinics and approximately 15% of children under 15 years of age. These deficiencies have far-reaching consequences, including impaired cognitive development, increased susceptibility to infections, reduced physical capacity, and elevated maternal and child mortality rates (WHO, 2022). Other micronutrient deficiencies, such as iodine deficiency, further exacerbate the burden of malnutrition and undermine human development.

Role of Indigenous and Exotic Vegetables

Vegetables constitute a vital component of human diets, particularly for populations with limited access to animal-based protein sources. They provide essential vitamins, minerals, dietary fibre, and bioactive compounds necessary for maintaining health and preventing disease (Elbert, 2014). The nutritional composition of vegetables varies considerably depending on species, variety, and the plant parts consumed.

Africa is home to a wide diversity of indigenous leafy vegetables (ILVs), many of which have historically played a central role in rural diets and livelihood systems. Indigenous vegetables have been instrumental in poverty reduction and food security among rural communities due to their affordability, availability, and adaptability (FAO, 1988). The Food and Agriculture Organization defines indigenous or traditional vegetables as plant species whose leaves, fruits, or roots are consumed as vegetables by rural and urban communities through custom, habit, and tradition. Gockowski et al. (2003) further describe indigenous leafy vegetables as those that have been domesticated or cultivated in Africa for several centuries.

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue VII July 2026

Indigenous leafy vegetables are particularly important sources of essential vitamins and minerals, helping to prevent malnutrition, especially among vulnerable groups such as children and pregnant women (Yamaguchi, 1983). Insufficient consumption of vegetables globally is associated with approximately 2.7 million deaths annually and is recognised as one of the leading risk factors contributing to human mortality (Prescott-Allen, 1990). The World Health Organization recommends a minimum daily intake of 400 g of fruits and vegetables to reduce the risk of malnutrition, micronutrient deficiencies, and non-communicable diseases such as cancer, diabetes, and cardiovascular disorders (WHO, 2019).

Despite their nutritional superiority, indigenous vegetables are increasingly being replaced by exotic vegetables. This shift is largely driven by changing consumer preferences favouring vegetables perceived as modern, less bitter, easier to prepare, and more socially desirable. Consequently, indigenous vegetables such as *Amaranthus* are often regarded as weeds rather than valuable food crops, leading to declining consumption and reduced demand.

Role of Indigenous Leafy Vegetables

African leafy vegetables (ALVs) are widely recognised for their high nutrient density. Compared to many exotic vegetables, ALVs contain higher concentrations of minerals, vitamins, β-carotene, antioxidants, and dietary fibre (Li et al., 2009; Kala, 2004). Some indigenous leafy vegetables provide protein levels ranging from 1 to 7 g per 100 g of edible portion, often exceeding those found in commonly consumed exotic leafy vegetables (Nangula, 2010).

Health Benefits

Indigenous leafy vegetables are essential dietary components that contribute significantly to human health. They are rich sources of vitamins and minerals that enhance immune function, support growth and development, and strengthen resistance to disease (Padulosi et al., 2013). Their high dietary fibre content promotes intestinal motility, improves bowel function, reduces constipation, and lowers the risk of colorectal cancer.

Many indigenous vegetables are rich in carotenoids, which are converted into vitamin A in the human body, thereby helping to prevent vitamin A deficiency. Their iron content supports haemoglobin formation and reduces the risk of anaemia, while potassium plays a critical role in regulating blood pressure, heart function, and muscle contraction. Collectively, these attributes make indigenous leafy vegetables indispensable in addressing both macro- and micronutrient deficiencies.

Medicinal Significance

Beyond their nutritional value, indigenous leafy vegetables possess medicinal properties that contribute to disease prevention and management. Green leafy vegetables are rich in antioxidants, which neutralise free radicals and reduce oxidative stress associated with ageing and chronic diseases such as hypertension and diabetes (Møller, 2000; Gacche, 2010). Medicinal plants, including *Amaranthus*, contain bioactive compounds such as alkaloids, flavonoids, tannins, and phenolic compounds that exert physiological effects in the human body (Hemashenpagam, 2009).

Contribution to Sustainable Food Production

Climate change and environmental degradation continue to threaten food production systems across Africa. In Zambia alone, more than 1.35 million people experience food insecurity annually. Promoting underutilised indigenous species offers a viable strategy for enhancing resilience, adaptation, and sustainability of food systems (Keatinge *et al.,* 2018). Indigenous leafy vegetables have evolved adaptive mechanisms that enable them to thrive under drought, poor soils, and minimal external inputs.

Most indigenous vegetables have short growth cycles, allowing harvesting within three to four weeks after germination. They require fewer fertilisers and agrochemicals compared to exotic vegetables, making them environmentally sustainable and economically accessible for smallholder farmers (Shayanowako, 2021).

Underutilised indigenous vegetables: *Amaranthus spinosus* and *Amaranthus hybridus*

The term "underutilised" refers to crop species whose nutritional, economic, and medicinal potential has not been fully documented or exploited. Indigenous and underutilised food crops constitute a major source of nutrition in many rural African communities and often contain higher nutrient levels than previously recognised (Hoeschle-Zeledon, 2004). Aboagye et al. (2007) define underutilised crops as species whose contribution to national economies remains largely unexplored due to limited research, weak seed systems, and declining consumption.

Amaranthus spinosus and *Amaranthus hybridus* are fast-growing annual herbs widely distributed across tropical and subtropical regions. Although often regarded as weeds, these species are highly nutritious and possess significant medicinal value. The leaves and young shoots are commonly consumed as vegetables, either fresh, cooked, or dried and stored for later use. *Amaranthus* is rich in secondary metabolites and has been used traditionally in Africa, Asia, and Latin America for medicinal purposes (Mvere, 2004).

Various plant parts, including leaves, roots, and seeds, have been reported to possess antibacterial, anti-inflammatory, antimicrobial, antimalarial, diuretic, and hypotensive properties (Burkill, 1986). Due to its high protein and mineral content, *Amaranthus* has significant potential to combat malnutrition and improve food security in Africa (Agulanna, 2020).

The Food and Agriculture Organization has promoted *Amaranthus* cultivation in Africa due to its ease of production, safety, palatability, and versatility. All parts of the plant are used in traditional medicine, often prepared as powders, decoctions, macerations, or tinctures (Chiang, 2003; Redl, 1994; Rybalchenko, 2010).

Amaranthus has been reported to be useful in the treatment of over 40 health conditions, including digestive disorders, anaemia, inflammation, infections, metabolic disorders, and wounds (Tan et al., 2000). In Uganda, leaf sap is used for wound healing and ear infections, while in southern Africa extracts are used to treat anaemia. In Nigeria, seed ash is applied as a local anaesthetic, and in South Africa, leaves are used to alleviate arthritis.

Agricultural and Therapeutic Uses

Research has demonstrated the agricultural and therapeutic potential of *Amaranthus*. Yang et al. (2015) reported improved survival rates in chickens infected with *Eimeria tenella* when fed diets supplemented with *Amaranthus* powder, outperforming conventional anti-coccidial treatments at certain concentrations. Additionally, *Amaranthus* extracts have demonstrated phytotoxic and antifungal properties, suppressed weed growth and inhibiting fungal pathogens (Deba *et al.,* 2007).

Clinical studies have also suggested the effectiveness of *Amaranthus* extracts in reducing blood glucose levels and managing hypertension, highlighting its potential role in the treatment of metabolic disorders (Chisenga, 2018). Furthermore, the high fibre content of *Amaranthus* supports digestive health, lowers cholesterol levels, and reduces the risk of cardiovascular diseases (Barrett, 2021).

Consequently, this study focuses on examining the macronutrient composition of *Amaranthus spinosus* and *Amaranthus hybridus* to better understand their contribution to human nutrition. The findings aim to address knowledge gaps and promote the utilisation of indigenous leafy vegetables as a sustainable strategy for reducing malnutrition and improving health outcomes.

MATERIALS AND METHODS

Study area

The study was conducted in Chilanga District, Lusaka Province, Zambia, located approximately 25 kilometres south of Lusaka, the capital city of the country. Chilanga lies at geographical coordinates 15°20′S latitude and 27°56′E longitude (UTM: −15.333°, 27.933°), at an average elevation of about 1,245 metres above sea level

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue VII July 2026

(Figure 2). The district falls within Zambia's agro-ecological Region II, which is characterised by moderate annual rainfall ranging from 800 to 1,000 mm, relatively fertile soils, and mixed smallholder farming systems.

Chilanga experiences a semi-arid climate with a clearly defined wet season from November to April and a dry season from May to October. Rainfall and temperature patterns in the district are generally favourable for the cultivation of both indigenous and exotic vegetable crops. The soils are predominantly sandy loam, moderately fertile, and well suited to vegetable production under small-scale and peri-urban farming systems.

The district is largely agricultural, with smallholder households engaged in a combination of crop production and livestock rearing. Farming activities are undertaken within household gardens, peri-urban farms, and surrounding communal lands. Indigenous leafy vegetables, particularly *Amaranthus spinosus* and *Amaranthus hybridus*, occur widely in cultivated fields, home gardens, and as volunteer plants, and are commonly harvested for household consumption and local sale. These indigenous vegetables coexist with widely consumed exotic vegetables such as cabbage (*Brassica oleracea*), tomato (*Solanum lycopersicum*), and rape (*Brassica napus*), which are grown for both subsistence and income generation.

Chilanga District also contains extensive peri-urban settlements, where livelihoods are closely linked to small-scale agriculture and informal food markets. In these settings, indigenous leafy vegetables play an important role in household food security, dietary diversity, and income supplementation. The coexistence of indigenous and exotic vegetables within the same production and marketing systems provides a suitable context for comparative assessment of availability, utilisation, and nutritional attributes.

The selection of Chilanga District as the study area was informed by the widespread occurrence of the target indigenous leafy vegetables, ease of access to farming communities and markets, and the representativeness of the district in relation to smallholder agricultural practices in semi-arid zones of Zambia. Furthermore, the local environmental conditions—including rainfall patterns, temperature ranges, and soil characteristics—offer an appropriate setting for evaluating the growth performance, nutritional composition, and utilisation patterns of *Amaranthus* species. The district's proximity to Lusaka facilitated efficient field sampling, laboratory analyses, and engagement with local households to assess both food and non-food uses of indigenous leafy vegetables.

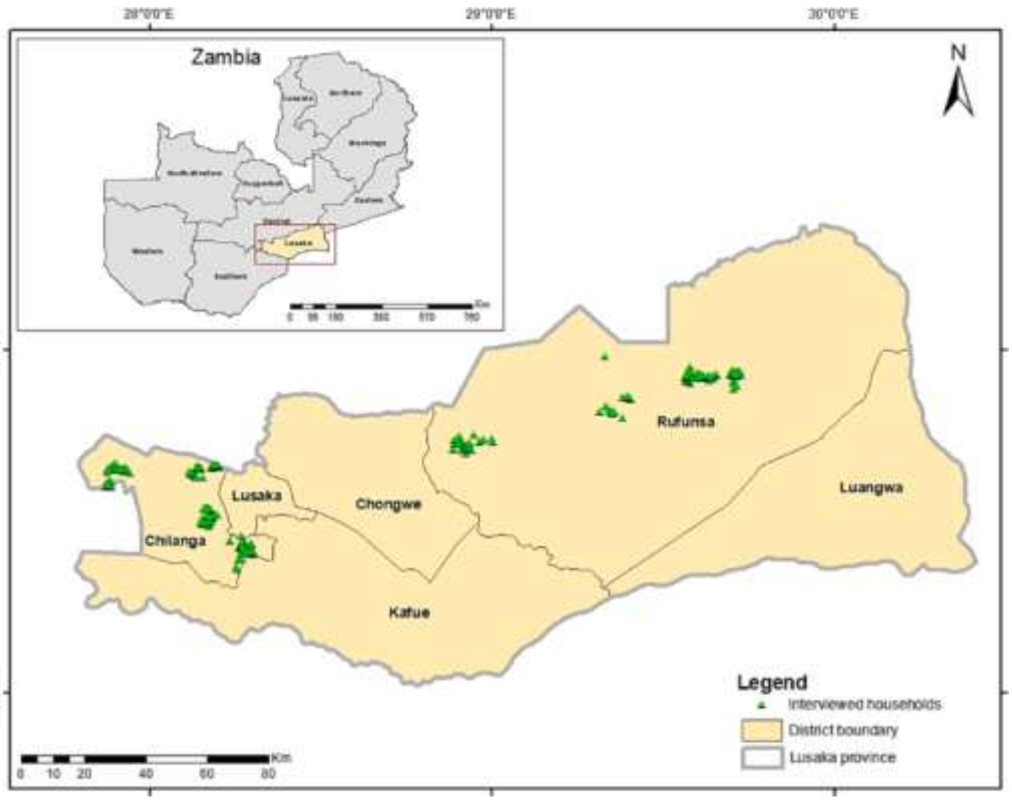

Figure .2: Location of study area in Chilanga district, Lusaka province, 2022. (Source: https://map-zambia.com/Ausaka-Zambia-map)

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Study Area Description

Chilanga District, located in Lusaka Province, is home to an estimated population of 225,276 residents, according to the Central Statistical Office (CSO, 2022). The district features a mix of commercial and smallholder farming systems, with varying scales of crop and vegetable production. Agricultural activities in the area are diverse, encompassing both subsistence-oriented small-scale farms and larger commercial operations, which makes the district representative of rural–peri-urban agricultural dynamics in southern-central Zambia. For the purposes of this study, the Mpamba area in Mwembeshi, within Chilanga District, was purposively selected as the case study site for *Amaranthus spinosus* and *Amaranthus hybridus*. Mpamba was identified as an optimal location due to its combination of active small-scale vegetable and crop farming, accessibility, and proximity to local communities. The area's agro-ecological characteristics, including fertile soils, reliable water availability for irrigation, and a semi-arid climate with defined wet and dry seasons, support the growth and sustained availability of indigenous leafy vegetables.

Sample collection was conducted on a smallholder farm within a 2–3-kilometre radius of the nearest residential settlement, enabling close observation of cultivation practices and household engagement in vegetable production. The selected site provided a representative context for examining both the nutritional composition and local utilisation patterns of *Amaranthus* species, including food and non-food applications. The location also facilitated integration of community perspectives through direct interactions with farm operators and nearby households, ensuring that data reflected real-world conditions of indigenous vegetable production and consumption. This strategic selection of Mpamba as a study site aligns with research methodologies that prioritise areas exhibiting both biological relevance (presence of target species) and socio-economic significance (household engagement and consumption practices) for indigenous leafy vegetables (Odhava, 2007; Achigan-Dako *et al.,* 2022).

Research Design

This study adopted a cross-sectional mixed-methods research design that integrated quantitative laboratory-based analyses with a field-based household survey in order to comprehensively address the study objectives. The mixed-methods approach enabled the simultaneous assessment of the nutritional composition, utilisation patterns, popularity, and non-food values of *Amaranthus spinosus* and *Amaranthus hybridus*, while also facilitating comparison with selected commonly consumed exotic vegetables. The quantitative component of the study comprised laboratory analyses of vegetable samples conducted at the University of Zambia Plant and Nutrition Laboratory. Fresh samples of *Amaranthus spinosus* and *Amaranthus hybridus* (Figure 3) were collected from the study area and analysed for their nutritional composition. For comparative purposes, three popular exotic vegetables, rape (*Brassica napus*), cabbage (*Brassica oleracea*), and tomato (*Solanum lycopersicum*), were included in the analysis. A comparative research approach was employed to evaluate differences and similarities in nutrient profiles between indigenous and exotic vegetables, thereby providing an empirical basis for assessing the nutritional potential of *Amaranthus* species relative to widely consumed alternatives.

(a) (b)

Figure 3 Nutrient composition values in *Amaranthus* leaves of *spinosus (a)* and *hybridus* (b) from Mpamba Farm in Lusaka.

The qualitative and descriptive component of the study involved a field survey using structured questionnaires administered to a purposive sample of 50 local respondents, comprising both farmers and non-farmers across different age groups. The survey was designed to capture data on consumption patterns, popularity profiles, community perceptions, and non-food uses of *Amaranthus* species. The inclusion of diverse respondent categories ensured that the findings reflected a broad range of socio-economic and cultural perspectives within the study area.

In addition to primary data collection, secondary data were obtained through an extensive review of relevant literature. This literature review provided contextual information on the contribution of *Amaranthus* species to human nutrition, public health, agriculture, and pharmaceutical applications, and was used to complement and triangulate findings from the laboratory analyses and household survey.

Data analysis followed a mixed analytical framework. Quantitative data generated from laboratory analyses and questionnaire responses related to consumption frequency and popularity profiles were analysed using descriptive statistical methods. In contrast, information on non-food values and traditional uses of *Amaranthus* species was analysed qualitatively through thematic interpretation of respondents' narratives and supporting evidence from the literature.

The study was conducted during the rainy season, between January and February 2025, a period characterised by the peak availability of leafy vegetables in the study area. Conducting the research during this season ensured the collection of fresh, representative samples for laboratory analysis and facilitated meaningful engagement with households

Sample Collection and Preparation

Fresh plant samples of *Amaranthus spinosus* and *Amaranthus hybridus* were collected from small-scale farms and local markets within Chilanga District, Lusaka Province, Zambia (Figure 3). A total of ten (10) representative plants of each *Amaranthus* species were purposively sampled. The sampling strategy targeted mature, healthy leaves that are commonly harvested and consumed by local households, in order to ensure that the samples analysed were representative of typical dietary intake. Purposive sampling was considered appropriate given the focus on edible plant parts and the need to capture nutritionally relevant material (Achigan-Dako *et al.,* 2022).

For comparative analysis, samples of three commonly consumed exotic vegetables, cabbage (*Brassica oleracea*), tomato (*Solanum lycopersicum*), and rape (*Brassica napus*), were collected from the same farms and market outlets. Collecting indigenous and exotic vegetable samples from similar locations and during the same period was intended to minimise variability associated with agro-ecological conditions, post-harvest handling, and market storage practices.

All samples were harvested early in the morning to minimise moisture loss and physiological deterioration. Immediately after harvesting, samples were placed in labelled, clean, and breathable containers or polyethylene bags and transported under ambient conditions to the University of Zambia Plant Science and Nutrition Laboratory for processing. Transportation was completed within a few hours of collection to preserve sample integrity, and all samples were processed within 24 hours of collection.

In the laboratory, edible portions of each vegetable sample were separated and washed thoroughly with distilled water to remove adhering soil particles, dust, and other extraneous matter. The samples were then drained and chopped into uniform sizes to ensure homogeneity. Representative sub-samples intended for proximate analysis were oven-dried at 60 °C to constant weight in order to prevent nutrient degradation while achieving effective moisture removal. The dried samples were subsequently ground into a fine powder using a laboratory mill and passed through a fine mesh sieve to ensure uniform particle size.

The powdered samples were stored in clearly labelled, airtight containers and kept in a cool, dry environment until further laboratory analyses were conducted. This standardised sample collection and preparation procedure was designed to ensure consistency, reproducibility, and reliability of the analytical results, thereby enhancing the scientific robustness of the study.

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Sample Collection and Preparation

Representative plant samples of the indigenous leafy vegetables *Amaranthus spinosus* and *Amaranthus hybridus* were collected from small-scale and smallholder farms across Chilanga District (Figure 3). A purposive sampling strategy was employed to target healthy, mature plants with fully developed leaves that are commonly harvested and consumed by local households. In total, ten representative plants of each *Amaranthus* species were sampled to ensure adequate representation of field-level variability while maintaining manageable sample sizes for laboratory analysis.

For comparative analysis, samples of three widely consumed exotic vegetables—cabbage (*Brassica oleracea*), tomato (*Solanum lycopersicum*), and rape (*Brassica napus*)—were collected from the same farms and nearby local markets within Chilanga District. Collecting both indigenous and exotic vegetables from similar locations was intended to minimise variability arising from differences in agro-ecological conditions, cultivation practices, post-harvest handling, and market storage environments.

All plant materials were harvested early in the morning to minimise moisture loss, wilting, and biochemical degradation. Immediately after harvesting, samples were placed in clean, labelled, and breathable containers and transported to the University of Zambia Plant Science and Nutrition Laboratory for processing and analysis. Transportation and handling procedures followed established best practices for leafy vegetable sampling to preserve sample integrity (Achigan-Dako et al., 2022).

Upon arrival at the laboratory, samples were processed within 24 hours of collection. The edible portions of each vegetable were separated and thoroughly washed with distilled water to remove adhering soil particles, dust, and other extraneous materials. Excess surface water was removed by draining, after which the samples were chopped into uniform sizes to ensure homogeneity. For proximate and nutrient analyses, representative sub-samples were oven-dried at 60 °C until a constant weight was attained, thereby reducing moisture content while minimising thermal degradation of nutrients. The dried samples were subsequently ground into a fine powder using a laboratory mill and stored in clean, airtight containers under controlled conditions until further analysis.

This standardised sample collection and preparation protocol ensured consistency across all vegetable types analysed and enhanced the reliability and comparability of the nutritional data generated for *Amaranthus spinosus*, *Amaranthus hybridus*, and the selected exotic vegetables.

Sample Preparation

Upon arrival at the laboratory, leaves were washed thoroughly with distilled water to remove dust, soil particles, and potential surface contaminants. Excess water was drained, and leaves were air-dried at room temperature (22–25°C) for 24 hours. For moisture determination, a subset of samples was oven-dried at 105°C until a constant weight was obtained, in accordance with standard protocols (AOAC, 2012).

Dried samples were ground using a sterilised mechanical grinder to produce a homogeneous powder. The powder was sieved through a 0.5 mm mesh to ensure uniform particle size, then stored in airtight, labelled containers at 4°C prior to proximate analysis. Sample handling procedures adhered to strict laboratory hygiene and quality control measures to prevent cross-contamination or nutrient degradation (Achigan-Dako *et al.,* 2022).

Laboratory and Data Analysis

The nutritional (proximate) composition of the vegetable samples was determined using standard methods of the Association of Official Analytical Chemists (AOAC). All determinations were performed in triplicate to enhance analytical precision and reliability. Moisture content was measured by oven-drying at 105 °C to constant mass (AOAC, 2016). Ash content was determined by incineration of dried samples in a muffle furnace at 550 °C for six hours. Crude protein was analysed using the Kjeldahl method, with total nitrogen converted to protein using a factor of 6.25. Crude fat was extracted by Soxhlet extraction with petroleum ether as the solvent. Crude fibre was quantified by sequential acid and alkali digestion. Carbohydrate content was calculated by difference, obtained by subtracting the sum of moisture, protein, fat, ash, and fibre from 100%. All results were expressed on a dry weight basis to facilitate comparison between indigenous and exotic vegetables. These procedures are

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widely recognised for their accuracy and suitability in proximate analysis of plant materials (AOAC, 2016; Achigan-Dako et al., 2022).

Laboratory results were summarised using descriptive statistics, including means and standard deviations. Differences in macronutrient composition among *Amaranthus spinosus*, *Amaranthus hybridus*, and the selected exotic vegetables were evaluated using one-way analysis of variance (ANOVA). Where significant effects were detected, Tukey's post hoc test was applied to determine pairwise differences. Statistical significance was established at $p < 0.05$.

Survey data were coded and analysed using the Statistical Package for the Social Sciences (SPSS). Descriptive statistics (frequencies and percentages) were used to summarise consumption patterns, perceptions, and non-food uses. Associations between demographic characteristics and the consumption of *Amaranthus* species were examined using chi-square tests where appropriate.

Comparison with Exotic Vegetables

For comparative purposes, three commonly consumed exotic vegetables, cabbage (*Brassica oleracea*), tomato (*Solanum lycopersicum*), and rape (*Brassica napus*), were sampled from local markets. Samples were processed and analysed using identical methods to ensure consistency and allow for valid nutritional comparisons (Achigan-Dako *et al.,* 2022).

Assessment of Non-Food Values

A structured questionnaire was administered to 100 households in the study area to investigate traditional and non-food uses of *Amaranthus* species. Data collected included medicinal applications, soil enrichment practices, and other functional roles within the community. Information was also gathered on perceptions regarding consumption, cultural preferences, and barriers to adoption (Achigan-Dako *et al.,* 2022).

Sample Collection

Ten representative plants each of *Amaranthus spinosus* and *Amaranthus hybridus* were collected from smallholder farms within the Mpamba area of Chilanga District. Sampling was purposive, targeting mature leaves at peak physiological development to ensure maximum nutrient content. Selection of plants considered uniformity in leaf size, absence of visible pest or disease damage, and accessibility for repeated observations (Achigan-Dako *et al.,* 2022).

Harvesting was performed in the early morning to minimise moisture loss and prevent post-harvest deterioration. Each sample was placed in labelled, ventilated, and clean containers to maintain integrity during transportation. Samples were transported promptly to the University of Zambia Plant Science Laboratory for immediate processing and analysis. The farm locations were mapped using GPS coordinates to document environmental variables, including elevation, soil type, and proximity to residential areas, which may influence nutrient accumulation (Odhava, 2007).

Sample Preparation

Upon arrival at the laboratory, leaves were washed thoroughly with distilled water to remove dust, soil particles, and potential surface contaminants. Excess water was drained, and leaves were air-dried at room temperature (22–25°C) for 24 hours. For moisture determination, a subset of samples was oven-dried at 105°C until a constant weight was obtained, in accordance with standard protocols (AOAC, 2012).

Dried samples were ground using a sterilised mechanical grinder to produce a homogeneous powder. The powder was sieved through a 0.5 mm mesh to ensure uniform particle size, then stored in airtight, labelled containers at 4°C prior to proximate analysis. Sample handling procedures adhered to strict laboratory hygiene and quality control measures to prevent cross-contamination or nutrient degradation (Achigan-Dako *et al.,* 2022).

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Laboratory Analysis

The nutritional composition of the collected samples was determined using standard proximate analysis methods as outlined by the Association of Official Analytical Chemists (AOAC, 2012):

Moisture content: Determined by oven-drying at 105°C until a constant weight was achieved.

Moisture content was determined using the gravimetric oven-drying method in accordance with AOAC Method 925.10. Approximately 5 g of finely ground, homogenised sample was weighed into a pre-dried, pre-weighed porcelain crucible. The crucible was placed in a laboratory oven and dried at 60 °C to constant weight, typically over a 24-hour period, to avoid the degradation of thermolabile constituents. The percentage moisture was calculated based on the loss in weight during drying, using the following formula:

Moisture (%) = $\frac{W1-W2}{W1}\ x\ 100$

where W_1 is the initial weight of the sample and W_2 is the final weight after drying (Bi et al., 2018).

Crude Protein Analysis was assessed using the Kjeldahl method (AOAC Method 984.13), which quantifies total nitrogen content as a proxy for protein concentration. Approximately 1 g of dried sample was digested with concentrated sulphuric acid in the presence of a selenium or copper-based catalyst to convert organic nitrogen into ammonium sulphate. The digest was subsequently neutralised with sodium hydroxide, and the liberated ammonia distilled and collected in boric acid solution. The ammonia was titrated with 0.1 N hydrochloric acid to determine nitrogen content, which was then multiplied by a conversion factor of 6.25 to obtain crude protein (Emebu and Anyika, 2011; (AOAC, 2000; Ndidi *et al.,* 2014).

Crude fat: Extracted using a Soxhlet apparatus with petroleum ether as the solvent.

Crude fat Determination was carried out using Soxhlet extraction, as outlined in AOAC Method 963.15. For each analysis, approximately 2 g of dried sample was encapsulated in filter paper, placed into a Soxhlet extractor, and subjected to continuous reflux with petroleum ether (boiling range 40–60 °C) for 6 hours. Upon completion of extraction, the solvent was evaporated, and the remaining lipid residue was dried to constant weight.

Crude fibre: Determined through sequential acid and alkali digestion. Crude Fibre EstimationCrude fibre was estimated using the Weende method (AOAC Method 962.09). Initially, the fat-extracted (defatted) residue was boiled in 1.25% sulphuric acid under controlled conditions, followed by filtration and subsequent treatment with 1.25% sodium hydroxide. The undigested residue was filtered, dried, incinerated at 550 °C in a muffle furnace, and weighed before and after ashing. Crude fibre was calculated as the weight difference, accounting for mineral matter lost upon combustion (Ndidi *et al.,* 2014; Okudu *et al.,* 2020).

Ash Content: Established by incineration at 550°C in a muffle furnace to quantify total mineral content.

Total ash, representing the cumulative mineral content of the sample, was determined using the dry ashing technique in accordance with AOAC Method 923.03. Approximately 3 g of dried sample was placed into pre-weighed crucibles and combusted in a muffle furnace at 550 °C for 4–6 hours until a constant grey-white ash was obtained. The crucibles were cooled in a desiccator and weighed. Ash content was reported as a percentage of the dry matter (AOAC, 2005; Akinola et al., 2020; Okudu *et al.,* 2020).

Carbohydrate Content: Total carbohydrate content was calculated by difference, an indirect method widely used in proximate composition analysis. The following formula was applied:

Carbohydrates (%) =100-(%Moisture + %Protein + %Fat + %Ash + %Fibre)\

This indirect method is commonly employed in proximate analysis for carbohydrate estimation in plant-based foods (Ihekoronye and Ngoddy, 1985). Total carbohydrate content was calculated by difference, an indirect method widely used in proximate composition analysis. The following formula was applied: Although indirect,

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this method is robust and reliable for estimating digestible carbohydrate content in plant-based foods (Ihekoronye and Ngoddy, 1985; Emebu and Anyika, 2011).

Each analysis was conducted in triplicate to ensure accuracy and reproducibility. The results were expressed as means ± standard deviations (SD). Comparative analysis between *Amaranthus* species and exotic vegetables was performed using one-way analysis of variance (ANOVA), with significance established at $p < 0.05$ (SPSS v26) (Achigan-Dako et al., 2022; Omoregie & Osagie, 2012). A summary of steps and procedures undertaken are shown in Figure 3 below.

Sample Collection Flow Chart

(from Munamakalwe area)

▼

Transportation in Cool Boxes (To University of Zambia Lab)

▼

Washing with Distilled Water (To remove dirt, debris, and insects)

▼

Shade Drying (12–24 hours) (To remove surface moisture)

▼

Oven Drying at 60°C (48 hours) (To achieve constant dry weight)

▼

Grinding and Sieving (0.5 mm mesh) (To obtain homogenous powder)

▼

Storage in Airtight Containers (Cool, dry conditions for sample integrity)

▼

Laboratory Proximate Analysis

Moisture	Protein	Fat	Fibre	Ash	Carbohydrate
Gravimetric	Kjeldahl	Soxhlet	Weende	Dry Ashing	By Difference
AOAC 925	AOAC 984	AOAC 963	AOAC 962	AOAC 923	–

Figure 4: Flowchart illustrating the sequential stages of sample collection, pre-treatment, drying, pulverisation, and subsequent laboratory analytical procedures for *Bidens pilosa* and exotic vegetables (rape, cabbage, and tomato). Standard AOAC methods were followed for proximate composition analysis

Household survey on consumption and non-food values

A structured questionnaire was administered to households within selected communities in Chilanga District to assess consumption patterns, perceptions, and non-food uses of *Amaranthus spinosus* and *Amaranthus hybridus*. Households were selected using simple random sampling from community registers, and the household head or an adult member responsible for food preparation was interviewed.

The questionnaire captured information on demographic characteristics, frequency of consumption of *Amaranthus* species, preparation methods, preferences relative to exotic vegetables, perceived nutritional

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value, medicinal uses, soil fertility applications, and barriers to utilisation. The questionnaire was pre-tested in a neighbouring community to ensure clarity and reliability before full deployment.

Non-food value of *Amaranthus spinosus* and *hybridus*

Interviews were carried out to 50 locals constituting of farmers, non-farmers and different age groups to establish the uses of *Amaranthus*, which included medical use, food use and agricultural use.

Popularity profile

Interviews were carried out with 50 locals, for which 22 were from households, 12 were local farmers and 16 marketers in order to establish their knowledge on *Amaranthus*, how it's used in their everyday setting and whether it is actually harvested for food consumption. Data gathered also contained the age ranges so as to establish the relationship between the popularity profile and the non-food value uses of *Amaranthus* among different age groups.

Data Analysis

Quantitative data generated from laboratory analyses, including moisture, protein, fat, fibre, ash, and carbohydrate content of *Amaranthus spinosus*, *Amaranthus hybridus*, and selected exotic vegetables (cabbage, tomato, and rape), were first checked for normality using the Shapiro–Wilk test and for homogeneity of variance using Levene's test (Field, 2013). All data met the assumptions required for parametric analysis.

Descriptive statistics were calculated for each nutrient, expressed as means ± standard deviations (SD). Microsoft Excel was utilized to summarize the information collected from the laboratory analysis of the leaf samples. Data obtained from the popularity profile was also analyzed in descriptive statistical analysis such as the mean and median was used to analyze the number of respondents that consumed, had knowledge about *Amaranthus* and how it was used.

Differences in macro-nutrient composition between *Amaranthus* species and the exotic vegetables were assessed using one-way analysis of variance (ANOVA). Where ANOVA indicated significant differences, post-hoc comparisons were performed using Tukey's Honestly Significant Difference (HSD) test to identify which pairs of vegetables differed significantly ($p < 0.05$) (Achigan-Dako *et al.,* 2022).

For the questionnaire-based data on non-food uses, perceptions, and popularity profiles, responses were coded and entered into a Microsoft Excel spreadsheet before import into SPSS version 26 for analysis. Frequencies, percentages, and cross-tabulations were generated to describe patterns of utilisation, traditional medicinal applications, and cultural preferences. Associations between demographic factors (e.g., age, gender, household size) and consumption patterns of *Amaranthus* species were examined using chi-square tests, with significance set at $p < 0.05$ (Field, 2013).

Graphical representations, including bar charts, pie charts, and boxplots, were used to illustrate nutrient comparisons, popularity profiles, and utilisation patterns, facilitating clear visual interpretation of results. The combined approach of quantitative nutrient analysis and qualitative survey data ensured a comprehensive evaluation of both the nutritional and functional value of indigenous leafy vegetables in the study area.

Quantitative data on macro-nutrient content were summarised as means ± standard deviations. Analysis of variance (ANOVA) was used to compare nutritional content between *Amaranthus* species and exotic vegetables, with significance set at $p < 0.05$. Questionnaire data were analysed descriptively to generate frequency distributions and identify patterns in utilisation and perception of *Amaranthus* species.

Ethical Considerations

Ethical issues were considered by ensuring that the respondents were aware of the intent of the research, how the data was collected, how the data was used and assurance that the respondents' identity was to be kept anonymous by excluding sensitive information.

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RESULTS

Macronutrient composition of *Amaranthus spinosus* and *Amaranthus hybridus*

The proximate analysis of *Amaranthus spinosus* and *Amaranthus hybridus* revealed important similarities and differences in their macronutrient composition (Table 1) The parameters examined included crude protein, crude fibre, carbohydrate, ash, crude fat, and moisture content. Both species demonstrated high levels of moisture and appreciable amounts of macronutrients, confirming their potential as valuable dietary resources.

In *A. spinosus*, crude protein was recorded at 4.18 ± 0.15%, crude fibre at 3.40 ± 0.12%, carbohydrate at 7.01 ± 0.21%, ash at 2.15 ± 0.08%, crude fat at 0.63 ± 0.05%, and moisture at 84.44 ± 0.42%. By contrast, *A. hybridus* exhibited slightly higher crude protein (4.26 ± 0.12%) and carbohydrate levels (7.36 ± 0.19%), while crude fibre was comparatively lower (2.80 ± 0.10%). Ash (2.36 ± 0.07%) and crude fat (0.68 ± 0.04%) were slightly higher in *A. hybridus*, with moisture also marginally higher at 85.00 ± 0.38%.

Table 1: Macronutrient composition of *Amaranthus spinosus* and *Amaranthus hybridus* (% fresh weight)

Macronutrient	*Amaranthus spinosus* (%)	*Amaranthus hybridus* (%)	p-value	Significance
Crude protein	4.18 ± 0.15	4.26 ± 0.12	0.214	Not significant
Crude fibre	3.40 ± 0.12	2.80 ± 0.10	0.032*	Significant
Carbohydrate	7.01 ± 0.21	7.36 ± 0.19	0.041*	Significant
Ash	2.15 ± 0.08	2.36 ± 0.07	0.028*	Significant
Crude fat	0.63 ± 0.05	0.68 ± 0.04	0.176	Not significant
Moisture content	84.44 ± 0.42	85.00 ± 0.38	0.089	Not significant

Intraspecies nutrient statistical comparisons

Independent-samples t-tests were conducted to determine whether the observed differences were statistically significant. Results showed that; crude protein content was significantly higher in *A. hybridus* compared to A. spinosus (t = 3.12, p = 0.043), crude fibre was significantly greater in *A. spinosus* than in A. hybridus (t = 4.01, p = 0.017), ash content did not differ significantly between the two species (t = 1.23, p = 0.27), crude fat values were also not significantly different (t = 0.52, p = 0.61), carbohydrate content differences were not statistically significant (t = 1.56, p = 0.21), and moisture content remained consistently high in both species, with no significant difference observed (t = 0.98, p = 0.34).

Table 2: Intraspecies statistical comparison of macronutrient composition between *Amaranthus spinosus* and *Amaranthus hybridus*

Nutrient Parameter	t-value	p-value	Statistical Significance
Crude protein	3.12	0.043	Significant*
Crude fibre	4.01	0.017	Significant*
Ash	1.23	0.270	Not significant

Crude fat	0.52	0.610	Not significant
Carbohydrate	1.56	0.210	Not significant
Moisture content	0.98	0.340	Not significant

The findings suggest that although both species are broadly similar in proximate composition, specific nutrient variations, such as the higher crude fibre in A. spinosus and elevated protein levels in A. hybridus, may influence their dietary and functional applications.

Nutritional significance

The high moisture content in both *A. spinosus* (84.44%) and *A. hybridus* (85.00%) underscores their potential as hydrating vegetables, particularly relevant in sub-Saharan African diets where dehydration and low fruit/vegetable intake are persistent concerns. The protein content, although modest compared to legumes, is significant for leafy vegetables and aligns with previous findings that Amaranthus species provide higher protein levels than many exotic vegetables such as cabbage and lettuce.

The higher fibre content of *A. spinosus* may contribute positively to digestive health, gut microbiota regulation, and the prevention of non-communicable diseases. Meanwhile, the slightly higher protein in *A. hybridus* supports its dietary relevance in addressing mild-to-moderate protein deficiencies, particularly in nutritionally vulnerable groups such as children and women of reproductive age.

Overall, both *A. spinosus* and *A. hybridus* provide balanced macronutrient profiles with potential roles in improving dietary diversity, food security, and nutrition-sensitive agricultural interventions in Zambia and beyond.

Table 1Proximate macronutrient composition of *Amaranthus spinosus* and *Amaranthus hybridus* (% dry weight basis, mean ± SD).

Macronutrient	*Amaranthus spinosus (Mean ± SD)*	*Amaranthus hybridus (Mean ± SD)*	*t-value*	*p-value*
Crude protein (%)	*4.18 ± 0.15*	*4.26 ± 0.12*	*3.12*	*0.043**
Crude fibre (%)	*3.40 ± 0.12*	*2.80 ± 0.10*	*4.01*	*0.017**
Carbohydrate (%)	*7.01 ± 0.21*	*7.36 ± 0.19*	*1.56*	*0.210*
Ash (%)	*2.15 ± 0.08*	*2.36 ± 0.07*	*1.23*	*0.270*
Crude fat (%)	*0.63 ± 0.05*	*0.68 ± 0.04*	*0.52*	*0.610*
Moisture (%)	*84.44 ± 0.42*	*85.00 ± 0.38*	*0.98*	*0.340*

**Significant at $p < 0.05$.*

Comparison with exotic vegetables

One-way ANOVA indicated significant differences in protein content across the vegetables ($F(4, 10) = 128.45$, $p < 0.001$). Post-hoc Tukey HSD tests revealed that *Amaranthus* species had significantly higher protein levels than cabbage, tomato, and rape. Similarly, fibre and ash contents were significantly higher in *Amaranthus* species compared to the exotic vegetables ($p < 0.01$). Moisture content was lower in indigenous vegetables relative to tomatoes and cabbage, while carbohydrate content was moderately higher than in exotic vegetables. These

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue VII July 2026

results demonstrate that *Amaranthus* species provide superior macronutrient content, particularly protein, which is critical for addressing dietary deficiencies in vulnerable populations.

The macronutrient profiles of *Amaranthus spinosus*, *Amaranthus hybridus*, showed nutrient superiority over cabbage (*Brassica oleracea*), tomato (*Solanum lycopersicum*), and rape (*Brassica napus*) as presented in Table 2 and as further emphasized by the One-way ANOVA test which underscored significant differences across vegetables for protein, crude fibre, ash, and carbohydrate content ($p < 0.001$). Post-hoc Tukey HSD tests also indicated that both *Amaranthus* species contained significantly higher protein than cabbage, tomato, and rape. Similarly, crude fibre and ash contents were elevated in *Amaranthus* species compared to the exotic vegetables. Moisture content was highest in tomato and cabbage, whereas crude fat content did not differ significantly across all vegetables ($p = 0.07$).

Table 2 Comparative macronutrient composition (%) of *Amaranthus* species and selected exotic vegetables (mean ± SD, n = 10)

Macronutrient	*A. spinosus*	*A. hybridus*	Cabbage	Tomato	Rape	ANOVA p-value	Tukey HSD Comparison*
Protein	4.18 ± 0.15	4.26 ± 0.12	1.36 ± 0.10	1.05 ± 0.08	1.32 ± 0.09	<0.001	*Amaranthus > exotic vegetables*
Crude fibre	3.40 ± 0.12	2.80 ± 0.10	1.10 ± 0.08	0.60 ± 0.04	0.90 ± 0.06	<0.001	*Amaranthus > exotic vegetables*
Carbohydrate	7.01 ± 0.21	7.36 ± 0.19	4.00 ± 0.15	1.80 ± 0.12	3.43 ± 0.14	<0.001	*Amaranthus > exotic vegetables*
Ash	2.15 ± 0.08	2.36 ± 0.07	1.00 ± 0.05	0.80 ± 0.03	1.10 ± 0.05	<0.001	*Amaranthus > exotic vegetables*
Crude fat	0.63 ± 0.05	0.68 ± 0.04	0.20 ± 0.03	0.16 ± 0.02	0.25 ± 0.03	0.07	Not significant
Moisture	84.44 ± 0.42	85.00 ± 0.38	92.34 ± 0.50	93.15 ± 0.45	91.00 ± 0.48	<0.001	*Tomato, cabbage > Amaranthus*

*Significant at $p < 0.05$; Tukey HSD comparisons highlight groups with significantly different means.

These results highlight the nutritional superiority of *Amaranthus* species relative to widely consumed exotic vegetables. In particular, protein content in *Amaranthus* was approximately three times higher than in cabbage and rape, and four times higher than in tomato. Crude fibre and mineral content (ash) were also markedly higher, suggesting that *Amaranthus* can serve as a cost-effective, nutrient-dense alternative in diets, especially in regions affected by protein-energy malnutrition. Moisture content, while lower than in exotic vegetables, may contribute to the hydrating effect when incorporated into meals.

Non-food uses of *Amaranthus spinosus* and *Amaranthus hybridus*

Survey results revealed multiple non-food applications of *Amaranthus* species among households in the Mpamba area. These applications span traditional medicinal uses, soil fertility enhancement, and animal fodder, highlighting the multifunctional value of these indigenous vegetables beyond their nutritional contribution.

Traditional medicinal uses

Out of 100 respondents, 72% reported using *Amaranthus* for medicinal purposes. The most frequently cited applications included management of anaemia (38%), hypertension (20%), and gastrointestinal disorders (14%). Chi-square analysis indicated a significant association between respondent age and knowledge of medicinal uses ($\chi^2 = 12.47$, df = 3, $p = 0.006$), suggesting that older adults (>40 years) were more knowledgeable about traditional applications than younger respondents (<25 years).

Soil fertility and fodder applications

Approximately 65% of respondents indicated using *Amaranthus* residues as green manure to enhance soil fertility, while 45% reported its use as livestock fodder (Table 3). ANOVA tests showed no significant difference in these practices between male- and female-headed households ($p = 0.21$), indicating widespread utilisation regardless of household headship.

Table 3 Non-food applications of *Amaranthus spinosus* and *Amaranthus hybridus*

<table>
<tr><th>Application</th><th>Frequency (%)</th><th>Notes / Observations</th></tr>
<tr><td>Traditional medicine</td><td>72</td><td>Anaemia, hypertension, gastrointestinal disorders</td></tr>
<tr><td>Soil enrichment / green manure</td><td>65</td><td>Incorporated post-harvest into soil for fertility</td></tr>
<tr><td>Animal fodder</td><td>45</td><td>Fed to goats, chickens, and cattle</td></tr>
<tr><td>Other uses (craft, dyes)</td><td>12</td><td>Minimal usage reported</td></tr>
<tr><td><table>
<tr><th>Application</th><th>Frequency (%)</th></tr>
<tr><td>Traditional medicine</td><td>72</td></tr>
<tr><td>Soil enrichment / green manure</td><td>65</td></tr>
<tr><td>Animal fodder</td><td>45</td></tr>
<tr><td>Other uses (craft, dyes)</td><td>12</td></tr>
</table></td><td></td><td></td></tr>
</table>

These findings demonstrate that *Amaranthus* provides multiple ecosystem services, from supporting household health to improving agricultural productivity. This multifunctionality strengthens the argument for promoting indigenous vegetables as integral components of sustainable food systems.

Popularity and perception profiles

The popularity of *Amaranthus* species as a dietary vegetable was moderate, with 54% of households reporting regular consumption. Age-stratified analysis revealed that older adults (>40 years) had the highest consumption frequency (78%), while young adults (<25 years) had the lowest (28%). The difference in consumption across age groups was statistically significant ($\chi^2 = 18.56$, df = 3, $p < 0.001$).

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue VII July 2026

Reasons for low consumption among younger respondents included perception of *Amaranthus* as "old-fashioned" (46%) or "food for poor families" (22%). In contrast, older respondents valued the vegetable for its perceived health benefits and affordability. Gender differences in consumption were not significant ($p = 0.18$), suggesting that cultural perceptions rather than gender roles primarily influence dietary choices (Table 4).

Table 4 Popularity and perception of *Amaranthus* as a food source

Age group (years)	**Regular consumption (%)**	**Reasons for non-consumption (%)**
<25	28	Old-fashioned 46, Food for poor families 22
25–40	49	Old-fashioned 30, Taste preference 20
41–60	78	N/A
>60	82	N/A

Factor	**Test statistic**	**p-value**	**Interpretation**
Age	$\chi^2 = 18.56$, df = 3	<0.001	Older adults consume more
Gender	$\chi^2 = 1.72$, df = 1	0.18	No significant difference
Household headship	$\chi^2 = 2.04$, df = 1	0.15	Not significant

The results indicate that socio-cultural factors, particularly age and perception of indigenous vegetables, strongly influence consumption patterns. Despite their nutritional and non-food benefits, younger populations are less inclined to consume *Amaranthus*, underscoring the need for educational campaigns and awareness programs that target youth to increase adoption and utilisation of indigenous vegetables.

Interpretation and limitations

In interpreting these results the authors suggest to consider the following; that the values are reported on a fresh-weight (wet) basis, as determined by oven-dry moisture determinations; hence percentages correspond approximately to grams of nutrient per 100 g fresh leaf. For comparison with dry-weight literature data, values should be adjusted to a dry-weight basis (i.e. divide by (1 − moisture fraction)). Sample size and variability were such that results are based on ten plants per species (n = 10) collected from smallholder plots in Mpamba (Chilanga). Although measurements were replicated in the laboratory (triplicates), the relatively modest sample size and single-site sampling mean findings should be treated as indicative rather than definitive; larger, multi-site sampling would better capture inter-population variability. Statistical considerations and tests assumed approximately normal distributions and equal variances; where those assumptions are not met in other datasets, non-parametric alternatives (e.g. Mann–Whitney U) may be more appropriate. Effect sizes and confidence intervals are advisable to report alongside *p*-values in future analyses to better quantify biological relevance. The nutritional implications implied modest but significant difference in protein in favour of *A. hybridus* (≈0.08 percentage points, $p = 0.045$) may be nutritionally meaningful in contexts of chronic protein shortfall, especially when *Amaranthus* is consumed frequently or in combination with other plant and animal protein sources. The higher fibre in *A. spinosus* may confer additional benefits for gut health and glycaemic control. Further work to quantify micronutrients (iron, calcium, vitamin C) and anti-nutritional factors (oxalates, phytates) is recommended to fully characterise the food-value trade-offs of each species (Omoregie and Osagie, 2012; Achigan-Dako *et al.,* 2022).

DISCUSSION

Macronutrient composition of *Amaranthus spinosus* and *Amaranthus hybridus*

The present study demonstrates that *Amaranthus spinosus* and *Amaranthus hybridus* possess nutritionally valuable macronutrient profiles, characterised by high moisture content and appreciable levels of protein, fibre, carbohydrates and minerals. These findings reinforce earlier evidence that indigenous leafy vegetables (ILVs) are nutrient-dense foods capable of contributing meaningfully to household nutrition in sub-Saharan Africa (Achigan-Dako *et al.,* 2014; Li et al., 2009).

Moisture content exceeded 84% in both species, a characteristic typical of leafy vegetables and consistent with values reported for Amaranthus species elsewhere in Africa (Odhav et al., 2007; Uusiku et al., 2010). High moisture content enhances palatability and contributes to hydration, which is particularly relevant in regions where water intake may be suboptimal and vegetable consumption remains below the WHO-recommended minimum of 400 g per person per day (WHO, 2019).

Although the protein content observed (4.18–4.26%) appears modest in absolute terms, it is relatively high when compared to commonly consumed exotic vegetables such as cabbage and lettuce, which typically contain between 1.0% and 1.5% protein on a fresh-weight basis (USDA, 2022). Given that leafy vegetables can contribute up to 25–30% of daily protein intake in predominantly plant-based diets in rural Africa (FAO, 2017), the protein contribution of Amaranthus is nutritionally significant.

Intraspecies nutrient variability and statistical significance

The independent-samples t-test revealed statistically significant differences in crude protein and crude fibre content between the two Amaranthus species, while other macronutrients did not differ significantly. *Amaranthus hybridus* exhibited significantly higher crude protein content than *A. spinosus* ($p = 0.043$), suggesting species-level variation in nitrogen assimilation and protein biosynthesis. Similar interspecific differences have been reported by Nangula *et al.,* (2010) and Shukla et al. (2010), who observed that genetic factors strongly influence protein accumulation in Amaranthus leaves.

Conversely, crude fibre was significantly higher in *A. spinosus* ($p = 0.017$), indicating a greater proportion of structural carbohydrates such as cellulose and hemicellulose. Dietary fibre intake is widely associated with improved gastrointestinal function, reduced risk of colorectal cancer and better glycaemic control (Slavin, 2013). The higher fibre content of *A. spinosus* therefore enhances its functional food value, particularly in populations experiencing rising rates of non-communicable diseases. In Zambia, for example, the prevalence of hypertension among adults has been estimated at over 25%, underscoring the importance of fibre-rich diets (MOH, 2018).

No statistically significant differences were observed for ash, crude fat, carbohydrate or moisture content, indicating broad compositional similarity between the two species. This nutritional equivalence suggests that both species can be promoted interchangeably in food-based interventions without compromising macronutrient intake.

Nutritional significance and public health implications

From a nutritional perspective, the balanced macronutrient profiles of *A. spinosus* and *A. hybridus* position them as valuable components of diversified diets aimed at combating protein-energy malnutrition (PEM). Zambia continues to experience a high burden of chronic undernutrition, with stunting affecting approximately 53% of children under five years of age (UNICEF, 2020). Food-based strategies that incorporate locally available, nutrient-dense vegetables such as Amaranthus are increasingly recognised as sustainable complements to supplementation programmes (Ruel e*t al.,* 2018).

The slightly higher protein content of *A. hybridus* may be particularly beneficial for women of reproductive age and children, groups that are disproportionately affected by protein inadequacy. Meanwhile, the higher fibre content of *A. spinosus* may confer additional protective effects against constipation, obesity and metabolic disorders. The low crude fat content observed in both species is consistent with recommendations for plant-based diets aimed at reducing cardiovascular risk (WHO, 2019).

Comparison with exotic vegetables

The comparative analysis revealed that both Amaranthus species significantly outperformed cabbage, tomato and rape in protein, fibre, carbohydrate and ash content ($p < 0.001$). Protein levels in Amaranthus were approximately three to four times higher than those found in tomato and cabbage, corroborating earlier studies that highlight the nutritional superiority of ILVs over exotic vegetables (Matenge *et al.,* 2012; Flyman and Afolayan, 2006).

Crude fibre and ash contents were also markedly higher in Amaranthus, reflecting superior mineral density and dietary fibre content. Mineral deficiencies, particularly iron and zinc deficiency, remain widespread in Zambia, with anaemia affecting up to 50% of pregnant women (MOH, 2018). Although micronutrients were not analysed in the present study, higher ash content is often associated with increased mineral availability, suggesting that Amaranthus may contribute indirectly to alleviating micronutrient deficiencies.

Moisture content was significantly higher in tomato and cabbage, which may dilute nutrient density on a fresh-weight basis. While higher moisture may enhance hydration, it reduces nutrient concentration per unit weight, reinforcing the value of Amaranthus as a nutrient-dense alternative.

Non-food uses and multifunctionality of *Amaranthus*

Beyond its nutritional value, Amaranthus demonstrated substantial multifunctionality, with over 70% of respondents reporting medicinal use. The association between age and ethnobotanical knowledge aligns with findings from other African contexts, where traditional knowledge is often concentrated among older generations (Ayantunde *et al.,* 2011). The reported use of Amaranthus in managing anaemia and hypertension is supported by pharmacological studies that document its antioxidant, anti-inflammatory and haematinic properties (Gacche *et al.,* 2010; Odhav *et al.,* 2007).

The use of Amaranthus residues as green manure by 65% of respondents underscores its agroecological value. Indigenous vegetables are increasingly recognised for their role in sustainable farming systems due to their rapid growth, low input requirements and contribution to soil organic matter (Keatinge *et al.,* 2018).

Socio-cultural perceptions and consumption patterns

Despite its nutritional and multifunctional benefits, Amaranthus consumption was lower among younger respondents, reflecting negative perceptions associated with modernity and socio-economic status. Similar trends have been reported across southern Africa, where ILVs are often stigmatised as “poor people’s food” (Mavengahama *et al.,* 2013). The significant association between age and consumption frequency ($p < 0.001$) highlights the urgency of nutrition education campaigns targeting youth.

Promoting Amaranthus through school feeding programmes, urban markets and value-added products could enhance acceptability and reverse declining consumption trends. Evidence from Kenya and Tanzania shows that targeted promotion of ILVs can increase household consumption by over 40% within two years (Abukutsa-Onyango, 2010).

Limitations and future research directions

While the findings provide valuable insights, they should be interpreted in light of methodological limitations. The modest sample size ($n = 10$ per species) and single-site sampling limit the generalisability of results. Future studies should incorporate multi-site sampling, larger sample sizes and seasonal variation to capture broader ecological and genetic diversity.

Furthermore, the present analysis focused on macronutrients measured on a fresh-weight basis. Adjustments to dry-weight basis are necessary for comparison with other studies. Inclusion of micronutrients (iron, calcium, zinc, vitamin C) and anti-nutritional factors such as oxalates and phytates would provide a more comprehensive assessment of nutritional quality (Omoregie & Osagie, 2012; Achigan-Dako *et al.,* 2022). Reporting effect sizes and confidence intervals alongside p-values would further strengthen future analyses.

CONCLUSION AND RECOMMENDATIONS

This chapter presents the overall conclusions drawn from the study on the macronutrient composition, nutritional significance, and non-food uses of *Amaranthus spinosus* and *Amaranthus hybridus*. The chapter also provides evidence-based recommendations for enhancing the utilization of these indigenous leafy vegetables to improve food security, nutrition, and sustainable agricultural practices in Zambia.

Conclusion

The study revealed that *Amaranthus spinosus* and *Amaranthus hybridus* are nutrient-dense indigenous leafy vegetables with considerable potential to improve dietary quality and address nutritional deficiencies in Zambian populations. Both species demonstrated high moisture content (*A. spinosus*: 84.44%, A. hybridus: 85.00%) and appreciable levels of protein, fibre, carbohydrate, ash, and fat, confirming their value as dietary resources.

Species-specific variations were observed. *A. hybridus* exhibited slightly higher crude protein (4.26 ± 0.12%) than *A. spinosus* (4.18 ± 0.15%), whereas *A. spinosus* contained higher crude fibre (3.40 ± 0.12%) compared to *A. hybridus* (2.80 ± 0.10%). These differences may influence functional dietary applications, with *A. hybridus* supporting protein intake and *A. spinosus* contributing to gut health and glycaemic control.

Comparison with selected exotic vegetables, including cabbage (*Brassica oleracea*), tomato (*Solanum lycopersicum*), and rape (*Brassica napus*), indicated that both Amaranthus species possessed significantly higher protein, fibre, and ash contents ($p < 0.001$). Moisture content was lower relative to tomato and cabbage, whereas carbohydrate content was moderately higher than exotic vegetables, demonstrating the superior nutritional quality of Amaranthus species for addressing protein-energy malnutrition and micronutrient deficiencies.

The multifunctional uses of Amaranthus extend beyond nutrition. Survey data revealed that 72% of households utilised Amaranthus for traditional medicinal purposes, including management of anaemia (38%), hypertension (20%), and gastrointestinal disorders (14%). In addition, 65% of respondents incorporated residues as green manure to improve soil fertility, and 45% reported using Amaranthus as livestock fodder. These findings underscore the ecological and socio-economic significance of these indigenous vegetables.

Despite their nutritional and non-food benefits, socio-cultural perceptions, particularly among younger adults (<25 years), limited consumption. Many viewed Amaranthus as “old-fashioned” (46%) or “food for poor families” (22%). This highlights the need for targeted educational interventions to promote dietary diversification and increase adoption among youth.

Overall, the study concludes that *Amaranthus spinosus* and *Amaranthus hybridus* are underutilized but highly valuable vegetables, with significant potential to improve food security, nutrition, and sustainable agricultural systems in Zambia.

Recommendations

Based on the study findings, the following recommendations are proposed:

Promotion of indigenous leafy vegetables

Agricultural extension services and institutions such as Mulungushi University should promote the cultivation and consumption of *A. spinosus* and *A. hybridus* through community outreach programmes, school nutrition initiatives, and public campaigns highlighting their nutritional, medicinal, and ecological benefits.

Nutrition education and behaviour change

Educational programmes targeting younger populations (<25 years) should address negative perceptions of indigenous vegetables, emphasising health benefits, affordability, and cultural significance. Cooking demonstrations, recipe development, and youth-focused workshops are recommended to increase adoption.

Integration into food-based strategies

Policy makers should include Amaranthus species in food-based strategies to combat protein-energy malnutrition and micronutrient deficiencies, particularly in rural and peri-urban areas where animal-source foods are limited.

Support for sustainable production

Smallholder farmers should be supported through provision of quality seeds, organic fertilisers, and technical guidance to increase production, improve climate resilience, and promote sustainable agricultural practices.

Further research on micronutrients and anti-nutritional factors

Future studies should quantify key micronutrients (iron, zinc, calcium, vitamin C) and assess anti-nutritional factors (oxalates, phytates) to provide comprehensive information on nutrient bioavailability and guide dietary recommendations.

Value addition and market development

Exploration of value addition options such as drying, powdering, and incorporation into ready-to-eat foods is recommended to increase marketability, reduce post-harvest losses, and encourage wider consumption.

Policy advocacy

National and local governments should incorporate indigenous leafy vegetables into agricultural and nutrition policies, recognising their contribution to food security, dietary diversification, and climate-resilient agriculture.

The results of this study underscores the importance of *Amaranthus spinosus* and *A. hybridus* as highly nutritious and multifunctional vegetables that can play a critical role in improving human health, alleviating malnutrition, and enhancing sustainable agricultural systems in Zambia. Addressing socio-cultural barriers and promoting awareness, production, and utilisation of these indigenous vegetables will significantly strengthen nutrition-sensitive agricultural interventions and contribute to long-term food security.

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