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REVIEW

Overview on Nutritional Value and Anti-nutritional Factors in Green Leafy Vegetables Grown in Sri Lanka

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ABSTRACT

Purpose: *Green leafy vegetables (GLVs) are loaded with essential vitamins, minerals, and phenolic compounds. In Sri Lanka, a diverse array of GLVs are cultivated and found in the wild making them readily available and affordable for the local diet. This paper presents a thorough review of the nutritional value and anti-nutritional factors of GLVs consumed in Sri Lanka.*

Research Method: *Many studies were reviewed for a holistic understanding of the overall nutritional value, anti-nutritional factors, and potential health implications of consuming GLV.*

Findings and Values: *The review highlights the high nutritional potential of commonly consumed GLVs. Several studies have delved deeply into understanding the details of the nutritional composition and anti-nutrients inherent in leafy greens. While existing literature highlights the nutritional significance of GLVs, this review identifies the substantial gaps in Sri Lankan studies, concerning anti-nutrient properties. Furthermore, there are several underutilized indigenous GLVs yet to be studied for their nutritional profiles. Insights from this review may illuminate future agricultural research, influence cultivation practices, and dietary recommendations, and contribute to improved food and nutrient security in Sri Lanka and beyond.*

Keywords: *Anti-nutrients, Essential nutrient, Green leafy vegetables.*

INTRODUCTION

Food is a fundamental part of human life (Popova & Mihaylova 2019). Food systems are highly susceptible to significant vulnerabilities stemming from conflicts, climate fluctuations, and economic contraction clinging to the persistent global challenge of hunger. It is estimated that between 691 and 783 million people in the world will face hunger in 2022. This is 122 million more people than before the COVID-19 pandemic (FAO *et al.* 2023). In a situation where food insecurity and inflation have become global trends, middle-income countries like Sri Lanka have a greater impact since a larger share of income is spent on food than high-income countries. According to the World Food Program (WFP) situation report for Sri Lanka, 32% of households are food-insecure while 73% of households are adopting negative food and livelihood-based coping strategies (WFP 2022).

Currently, millions of Sri Lankans suffer extreme poverty magnifying food insecurity and leading to malnutrition due to the unaffordability of sufficient amounts of nutritious food (OCHA 2023). When considering the malnutrition problem, a higher prevalence of micronutrient deficiencies like iron, zinc, calcium, and

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vitamin A were recognized within Sri Lankan society (Abeywickrama *et al.* 2018). Consequently, promoting the consumption of locally available, nutrient-rich, and cost-effective crops is vital for sustainable agricultural and nutritional outcomes (Keatinge *et al.* 2011). When considering local food, underutilized fruits (Abeysuriya *et al.* 2020), underutilized vegetables, and especially commonly available GLVs (Nadeeshani *et al.* 2018) contain huge amounts of nutrient components, including macronutrients. The World Health Organization (WHO) recommends at least 400 g of fruits and non-starchy vegetables should be consumed to meet the daily allowance of nutrition (WHO 2003). Based on an intake of 2000 calories, the Dietary Guidelines of Americans (2015-2020) recommends five servings of vegetables per day and one of those servings should be GLVs. Therefore, GLVs are under the spotlight for nutritional studies (U.S. Department of Health and Human Services & U.S. Department of Agriculture 2015).

Leafy greens, which are the vegetative part of a plant consumed as a vegetable, are recognized for their abundance of bioactive compounds with nutritional and anti-nutritional properties (Deyalage *et al.* 2021). Nutritional studies reveal dark GLVs are considered rich sources of vitamins like A and C, and minerals including calcium, iron, and phosphorus (Nadeeshani *et al.* 2018). Sri Lanka, with its tropical climate, nests a diverse range of GLVs (Nadeeshani *et al.* 2018). The traditional Sri Lankan diet also mainly consisted of leafy greens (Weerasekara *et al.* 2020). Material evidence reveals that the ancestral history of Sri Lankan GLV consumption dates to 2700 BCE (Mihiranie *et al.* 2020). After colonization, dietary diversity, practices, and food patterns were changed in the local food culture (Weerasekara *et al.* 2020), specifically reducing the consumption of GLVs.

There are many studies carried out regarding the nutritional and anti-nutritional properties of Sri Lankan GLVs. Table 1 elaborates a tabulated summary of studies carried out regarding the above-mentioned properties of GLVs. This paper aims to review thoroughly the nutritional content and anti-nutrient factors of GLVs, highlighting their potential in addressing nutritional deficiencies within the context of Sri Lanka's agricultural landscape.

Additionally, this review seeks to guide future agricultural research, influence cultivation practices, and inform dietary recommendations, ultimately enhancing food and nutrient security in Sri Lanka and beyond.

NUTRITIONAL FACTORS IN GREEN LEAFY VEGETABLES

The nutrient component available in GLVs can be divided into two groups; macronutrients and micronutrients. Leafy vegetables are known for their availability of major macronutrients; protein, carbohydrate, lipid, fiber, and rich sources of micronutrients; vitamins, and minerals (Nadeeshani *et al.* 2018).

Protein, carbohydrate, and lipid

Upon reviewing previous studies, it becomes evident that in most GLVs, protein constitutes a greater proportion of macronutrients compared to fat and carbohydrate, although the absolute levels vary across species. Nadeeshani *et al.* (2018) showed a high protein content in *Sesbania grandiflora* (Kathurumurunga) (7.17%) from several GLVs (*Alternanthera sessilis* – 3%, *Amaranthus viridis* – 4%) commonly consumed in Sri Lanka. The protein content in *S. grandiflora* is higher when compared with non-meat products such as green peas (5.42%) (Bohrer 2017). The crude fat contents were lower when compared with the other macronutrients (Nadeeshani *et al.* 2018) manifesting, GLVs are poor sources of lipids. The total carbohydrate content of studied leafy vegetables showed the lowest amounts in *Trianthema portulacastrum* (Heen Sarana) (4.41%) while *A. sessilis* (Mukunuwenna) (10.76%) showed the highest carbohydrate content. Other components of proximate constituents such as ash content varied in each GLV with the lowest and highest ash contents observed in *Dregea volubilis* (Aguna kola/Thiththaaguna) (1.28%) and *A. viridis* (Thampala) (3.86%) respectively (Nadeeshani *et al.* 2018). Jayasinghe *et al.* (2019) reported

Table 1. Summary of nutritional, phytochemical and antioxidant properties of Sri Lankan green leafy vegetables.

Green Leafy Vegetable	Vernacular Name	Macro-nutrients	Micronutrients	Anti-nutrients	Reference
Acalypha indica	Kuppameniya	Protein, lipid, carbohydrate, fiber	C; Ca, Cr, Cu, Fe, P, Zn, etc.	Phytic acid	Begum *et al.* (2020), Refilda *et al.* (2021)
Alternanthera sessilis	Mukunuwenna	Protein, lipid, carbohydrate, dietary fiber	NI; Ca, Cr, Cu, Fe, K, Mg, Mn, Mo, Se, Zn	Nitrates	Nadeeshani *et al.* (2018), Deraniyagala *et al.* (1994), Arasaretnam *et al.* (2018), Nifras *et al.* (2017)
Amaranthus caudatus	Thampala	Protein, lipid, carbohydrate, dietary fiber	A, C, E; Ca, Mg, Na, P, K, Zn, Mn, Cu, Fe	Phytate, oxalate, saponins, alkaloids	Jimoh *et al.* (2020)
Amaranthus tricolor	Sudu Thampala/Thampala	NI	A, C, B1, B2; Fe, Zn, Mg, P	NI	Schönfeldt & Pretorius (2011)
Amaranthus viridis	Red and green Thampala	Protein, lipid, carbohydrate	NI; Ca, Cr, Cu, Fe, K, Mg, Mn, Mo, Se, Zn	Oxalate, saponins, tannins	Nadeeshani *et al.* (2018), Olawoye & Gbadamosi (2017)
Argyreia pomacea	Maha Dumbada	Protein, lipid, carbohydrate	C; Na, K, Ca, Mg	NI	Arasaretnam *et al.* (2018), Mahendraraj *et al.* (2020)
Asparagus racemosus	Hathawariya	Dietary fiber	A, B1, B2, B9, C, E; Mg, P, Ca, Cu, Fe, K, Mn, Zn	NI	Deraniyagala *et al.* (1994)
Asteracantha longifolia	Neeramulliya	NI	NI; Al, Ca, Co, Fe, Mm, Mg, Zn	NI	Saple *et al.* (2020)
Bacopa monnieri	Lunuwila/water hyssop	NI	A, D, E, B, C; Zn, Se, Cu, Mg, Ca, Fe	NI	Mitra-Ganguli *et al.* (2017)
Basella alba	Ceylon spinach	Dietary fiber	A, B9; NI	Phytate, oxalate	Deraniyagala *et al.* (1994), Srivarathan *et al.* (2023), Wen Lee *et al.* (2022), Singh (2022)

Green Leafy Vegetable	Vernacular Name	Macro-nutrients	Micronutrients	Anti-nutrients	Reference
Boerhavia diffusa	Pita sudu/ beheth sarana	Dietary fiber	A, C, B1; NI	Phytate, oxalate, tannins	Chandrika *et al.* (2010), Deraniyagala *et al.* (1994), Gupta *et al.* (2005)
Cardiospermum halicacabum	Welpenela	Protein, lipid, carbohydrate	C; Na, K, Ca, Mg	NI	Arasaretnam *et al.* (2018)
Celosia argentea	Kirihanda	Protein, lipid, carbohydrate, fiber	A, C, E, B1; Ca, Na, K, Mg, Fe, Zn, Mn	Phytate, oxalate, saponin, alkaloid	Chandrika *et al.* (2010), Adegbaju *et al.* (2019), Fayaz *et al.* (2019)
Centella asiatica	Gotukola	Protein, lipid, carbohydrate, dietary fiber	A, C, B1; NI	Phytate, oxalate, tannins, nitrates	Chandrika *et al.* (2010), Deraniyagala *et al.* (1994), Gupta *et al.* (2005), Nifras *et al.* (2017), Arasaretnam *et al.* (2018)
Coccinia grandis	Kowakka	Protein, lipid, carbohydrate	NI; Ca, Cr, Cu, Fe, K, Mg, Mn, Mo, Se, Zn	Oxalate	Nadeeshani *et al.* (2018), Getachew *et al.* (2013)
Commelina benghalensis	Gira pala	Protein, lipid, carbohydrate	A, C, B1; Ca, Mg, P, Na, K, Fe, Zn, Cu, Co	Phytate, oxalate, tannins	Chandrika *et al.* (2010), Gupta *et al.* (2005), Peduruhewa *et al.* (2021), Kagale *et al.* (2023)
Costus speciosus	Thebu kola	Protein, lipid, carbohydrate	NI; Ca, Cr, Cu, Fe, K, Mg, Mn, Mo, Se, Zn	NI	Nadeeshani *et al.* (2018)
Cucurbita maxima	Pumpkin leaves	Protein, lipid, carbohydrate, fiber, calorie	A, C, B1; Fe, Zn, Mg, P, Ca	Phytate, oxalate, tannins, cyanogenic glycoside	Chandrika *et al.* (2010), Schönfeldt & Pretorius (2011), Gupta *et al.* (2005), Oruma *et al.* (2022), Okon (2014)

Green Leafy Vegetable	Vernacular Name	Macro-nutrients	Micronutrients	Anti-nutrients	Reference
Delonix elata	NI	Protein, lipid, carbohydrate	A, C, B1; Na, K, Ca, Mg	Phytate, oxalate, tannins	Chandrika *et al.* (2010), Arasaretnam *et al.* (2018), Gupta *et al.* (2005)
Dregea volubilis	Kiri aguna/ Anguna	Protein, lipid, carbohydrate	NI; Ca, Cr, Cu, Fe, K, Mg, Mn, Mo, Se, Zn	NI	Nadeeshani *et al.* (2018)
Eichhornia crassipes	Water hyacinth/ Japan jabara	Protein, lipid, carbohydrate, fiber	NI; Ca, Mg, Na, K, P, Zn, Fe	Tannin, cyanide, oxalate, phytate	Rufchaei *et al.* (2022), Suleiman *et al.* (2020)
Gymnema lactiferum	Kurignan/ Ceylon cow tree	Protein, lipid, carbohydrate, fiber	NI; Na, Ca, Fe, K	NI	Deyalage *et al.* (2021)
Hemidesmus indicus	Iramusu	Protein, lipid, carbohydrate, fiber	C, B3; Na, K, Ca, Mg, Zn, Mn, Fe, Cu	NI	Mohan & Kalidass (2010)
Ipomoea aquatica	Kankung	Protein, lipid, carbohydrate, fiber	NI; Na, K, Ca, Mg, Fe, Zn, Mn, Cu	Oxalate, tannin, saponin, alkaloid, flavonoid, phytate	Ndamitso *et al.* (2015)
Ipomoea batatas	Sweet potato	Protein, lipid, carbohydrate, fiber	A; Fe, Mn, Cu, Zn	Oxalate, tannin, saponin, phytate	Wen Lee *et al.* (2022), Deraniyagala *et al.* (1994), Mobeen *et al.* (2021), Lawal & Adeniyi (2013)
Lasia spinosa	Kohila	Fat	NI; NI	Phytic acid	Begum *et al.* (2020), Mobeen *et al.* (2021)
Manihot esculenta	Bitter /sweet cassava	Protein, lipid, carbohydrate, fiber	B1, B2, C; Ca, Cu, K, Mg, Mn, Zn	Phytate, cyanogenic glycoside, saponins, tannin	Ogbuji & David-Chukwu (2016), Begum *et al.* (2020), De Silva Santos (2020)
Mollugo pentaphylla	Hinipala	Protein, lipid, carbohydrate	C; Na, K, Ca, Mg	NI	Arasaretnam *et al.* (2018)

Green Leafy Vegetable	Vernacular Name	Macro-nutrients	Micronutrients	Anti-nutrients	Reference
Moringa oleifera	Murunga	Protein, lipid, carbohydrate, fiber	NI; Ca, Fe, Mg, Na, Mn, Cu, Zn, K	Nitrates	Nifras *et al.* (2017), Abdulkadir *et al.* (2016)
Murraya koenigii	Curry leaves/ Karapincha	Protein, lipid, carbohydrate	A, C, E, B1, B2, B3; Ca, Fe, Mg, Na, Zn, K	Cardiac glycoside, Phenol, Alkaloid, Phytate, Oxalate, tannin	Abeysinghe *et al.* (2021), Igara *et al.* (2016), Ifemeje *et al.* (2014)
Passiflora edulis	Passion fruit leaves	NI	NI; P, K, Zn, Mn, Ca, Mg	NI	He *et al.* (2020)
Pisonia grandis	Wathabanga	Protein, lipid, carbohydrate	C; Na, K, Ca, Mg	NI	Arasaretnam *et al.* (2018)
Premna latifolia	Mahamidi	Protein, lipid, carbohydrate	C; Na, K, Ca, Mg	NI	Arasaretnam *et al.* (2018)
Sesbania grandiflora	Kathurumurun-ga	Protein, lipid, carbohydrate, dietary fiber	NI; Ca, Cr, Cu, Fe, K, Mg, Mn, Mo, Se, Zn	Phenol	Nadeeshani *et al.* (2018), Deraniyagala *et al.* (1994)
Solanum nigrum	Black nightshade	Protein, lipid, carbohydrate, dietary fiber	A, C, E; Fe, Ca, Zn	Cyanogenic glycoside	Essack *et al.* (2017), Sangija (2021)
Spinacia oleraceae	Spinach	Protein, lipid, carbohydrate	E; Na, Cl, K, Ca, Mg	Nitrates, Oxalates	Nifras *et al.* (2017), Santamaria (2006), Pereira *et al.* (2019)
Trianthema portulacastrum	Heen Sarana	Protein, carbohydrate, lipid	A, C, B1; Ca, Cr, Cu, Fe, K, Mg, Mn, Mo, Se, Zn	Phytic acid, Oxalic acid, Tannins	Chandrika *et al.* (2010), Gupta *et al.* (2005), Nadeeshani *et al.* (2018)
Triathema monogyna	Sarana/giant pigweed	Protein, lipid, carbohydrate, fiber	C; Ca, Fe	NI	Sinha (2018)
Vigna unguiculata	Cowpea leaves	Protein, lipid, carbohydrate, fiber	A (β-carotene), B2; Fe, Zn, Mg, P, Na, Ca	Phytate, oxalate	Schönfeldt & Pretorius (2011), Enyiukwu *et al.* (2020)
Watakaka volubilis	Anguna/milkweed climber	NI	B1, B3, B6, B9, C; Ca, Zn, Mg, Cu, K	NI	Deyalage *et al.* (2021), Sharma *et al.* (2014)

NI: Not Identified. Antioxidant activity is detected via the assays; FRAP, PFRAP, ABTS, and DPPH.

comparatively higher fat contents in several GLVs, including *Ipomea aquatica* (Kankun) (12.6%) and *Lasia spinosa* (Kohila) (6.5%), which are commonly consumed in the Sri Lankan diet, compared to the values reported in other studies. Several studies are reporting the proximate composition and macronutrients of either common or underutilized GLVs such as *Premna latifolia* (Mahamidi) and *Pisonia grandis* (Wathabanga) etc. and are summarized in Table 1.

Dietary fiber

Dietary fibers, which are structural components of plant cell walls, are generally classified based on solubility into two groups: soluble and insoluble fibers. They are carbohydrate polymers with a degree of polymerization greater than three, and they are neither digested nor absorbed in the small intestine (Ötles & Ozgoz 2014). High intake of dietary fiber can improve lower blood sugar to control diabetes, and reduce body weight, blood pressure, and body cholesterol to prevent cardiovascular diseases (Ötles & Ozgoz 2014). According to Arasaretnam *et al.* (2018), some GLVs show higher fiber content than the other macronutrients. *Asparagus racemosusy* (Hathawariya) showed the highest fiber content; 5.61%, out of 7 leafy vegetable species; *Centella asiatica*, *I. aquatica*, *S. grandiflora*, *Alternanthera sessilis*, *Basella alba* (Ceylon/Indian/Malabar spinach), *Boerhaavia diffusa* (Pita sudu/beheth sarana) and *A. racemosusy* (Deraniyagala *et al.* 1994).

Vitamins

Vitamins are bioactive organic compounds, classified according to their solubility as fat-soluble vitamins (A, D, E, K) and water-soluble vitamins (B and C), which are essential for human body functioning (Santos *et al.* 2012). Green leaves can produce vitamins A, B, C, and E (Gupta *et al.* 2005), where vitamin A is present in two different forms, provitamin A carotenoids and non-provitamin A carotenoids. Lutein, a non-provitamin A carotenoid, is highly prevalent in *Cucurbita maxima* (Pumpkin leaves) (655 μgg^{-1} DW) (Chandrika *et al.* 2010). Chandrika *et al.* (2010), Gupta *et al.* (2005), and Adegbaju *et al.* (2019) report the presence of β-carotene (a type of provitamin A), vitamin C, and thiamin (vitamin E) in several GLVs consumed by Sri Lankans, including *Celosia argentea* (Kirihanda) (Vitamin A – 28.6 μgg^{-1} DW, Vitamin C – 7.70 μgg^{-1} DW, Vitamin E – 8.06 μgg^{-1} DW), *Commelina benghalensis* (Gira pala) (Vitamin C – 46 mg/100g), and *Syngonium angustatum* (Wel Kohila) (β-carotene 263.4 μgg^{-1} DW), etc. Wen Lee *et al.* (2022) report high amounts of vitamin A carotenoid in *Ipomoea batatas* (sweet potato leaves) and Ceylon spinach. According to Schönfeldt & Pretorius (2011), *Amaranthus tricolor*, *C. maxima*, and *Vigna unguiculata* (cowpea leaves) harbor the vitamins beta-carotene (A. tricolor – 1.6 mg/100 g, *C. maxima* – 1.695 mg/100 g, *V. unguiculata* – 2.249 mg/100 g) and vitamin B2 (A. tricolor – 0.03 mg/100 g, *C. maxima* – 0.12 mg/100 g, *V. unguiculata* – 0.05 mg/100 g). GLVs are also major sources of folic acid (vitamin B9), which can cause severe consequences in deficiency (Randhawa *et al.* 2015). Singh (2022) reports the highest folate content in spinach (194 μgg^{-1}) among tested vegetables and cereals. Arasaretnam *et al.* (2018) reported vitamin C in GLVs, including some wild-type species. However, a substantial void exists in quantitative data regarding vitamin E and B complex in Sri Lankan GLVs.

Minerals

Minerals have a wide array of functionalities in metabolism and homeostasis, serving as co-factors for enzymes and upholding protein structure. GLVs are rich in minerals compared to staple foods like grains (Thakur *et al.* 2022). Nadeeshani *et al.* (2018) reported 10 GLV species, including varieties of *A. sessilis* and *A. viridis*, contained Ca, Cr, Cu, Fe, K, Mg, Mn, Mo, Se, and Zn. Notably, *A. viridis* (Red Thampala) had the highest Ca (11.17 mg g^{-1}), Cr (0.54 μg g^{-1}), Cu (0.39 μg g^{-1}), Fe (156.04 μg g^{-1}), K (9.98 mg g^{-1}), and Mg (1.57 mg g^{-1}), while *A. sessilis* (Weda

Mukunuwenna) showed the highest Co (0.51 μg g^{-1}), Mn (247.72 μg g^{-1}), and Zn (34.69 μg g^{-1}). The study highlights significant differences in mineral content among GLV varieties. Schönfeldt & Pretorius (2011) revealed Fe, Zn, Mg, P, and Ca in *A. tricolor*, *C. maxima*, and *V. unguiculata*, with *A. tricolor* showing highest Fe (16.2 mg/100 g) and *C. maxima* high Zn (0.9 mg/100 g), Ca (383 mg/100 g), Mg (142 mg/100 g), and P (119 mg/100 g).

According to the insights of the studies reviewed, the nutritional diversity among Sri Lankan GLVs can inform cultivation strategies by identifying nutrient-rich species as well as varieties, suitable for wider promotion, while also supporting dietary guidelines aimed at improving public health. Furthermore, it shows, there are gaps in current research on comparisons of nutritional contents between GLV variety, which is highly important as Sri Lankan GLVs harbors a wide variety within species.

ANTI-NUTRITIONAL FACTORS

The undesirable phytochemical constituents present in plants are known as anti-nutrients or anti-nutritional substances (Dagostin 2017). These undesirable substances, endogenous or occurring through external sources, can exist within a plant's chemical composition, such as pesticide contaminants (Dagostin 2017). Anti-nutrients are also referred to as allelochemicals due to their ability to exert different adverse effects as well as benefits to their consumers (Salim *et al.* 2023). Anti-nutrients are one of the defense chemical compounds that plants use for protection from herbivores, insects, and microorganisms (Dagostin 2017, Sharma 2020). Dagostin (2017) reports that the plant defense system releases anti-nutrients as toxins when plant tissues are damaged.

Anti-nutrients can cause deleterious effects such as reduction of nutrient utilization and food intake, which are referred to as anti-nutritional factors (Salim *et al.* 2023). They decrease the nutritive value by reducing the optimal utilization of nutrients, proteins, vitamins, and minerals via binding them to the anti-nutrient and making the nutrient biologically unavailable (Salim *et al.* 2023). However, research evidence shows that the ingestion of appropriate amounts of anti-nutrients can be advantageous to humans (Salim *et al.* 2023). Anti-nutrients like phytic acid, lectins, phenolic compounds, amylase inhibitors, and saponins can reduce blood glucose levels and insulin response to starchy foods, plasma cholesterol, and triglycerides. Furthermore, lectins, phytic acid, phenolics, saponins, protease inhibitors, phytoestrogens, and lignans have shown potential in reducing cancer risk (Natesh *et al.* 2017, Qadir & Cheema 2017, Moyo *et al.* 2020, Salim *et al.* 2023). Reports show that nitrates, another potentially beneficial anti-nutrient, can improve vascular function in conditions like exercise-induced hypoxia in muscles and low oxygen availability, such as living at high altitudes (Ranasinghe & Marapana 2018). Nitric oxide, a free radical gas and a derivative of nitrite, functions as an essential signaling molecule in endothelial function and metabolic regulation. With high consumption of dietary nitrate, plasma nitrite concentration is increased. Through this mechanism, resting blood pressure is reduced, improving vascular function (Hord *et al.* 2009).

Among the number of anti-nutrients, phytic acid, oxalic acid, nitrates, nitrites, and cyanogenic glycosides are commonly found in GLVs (Natesh *et al.* 2017). Phytic acid is an inherent chemical compound that acts as a vital phosphorus source for seed germination in plants. It interacts with potassium, calcium, or magnesium ions, but can affect digestive enzymes through chelation of mineral cofactors in the gastrointestinal tract, reducing bioavailability of dietary minerals (Salim *et al.* 2023). A similar phenomenon occurs with oxalates.

Oxalates are anti-nutrients formed when minerals or salts react with oxalic acid. Oxalic acid can be found in the plant cell sap as soluble salts like potassium and sodium salts, or insoluble salts like calcium, magnesium, and iron, or as a mixture of both, depending on the plant species (Morita *et al.* 2008). Insoluble oxalate salts are excreted via feces, while soluble oxalates form strong chelates with minerals like calcium, making them unavailable for absorption (Verma *et al.* 2019).

Dietary nitrates are mainly found in GLVs and root vegetables, with the highest concentrations typically in GLVs (Spinach – 4259 mg kg^{-1}, Lettuce – 2430 mg kg^{-1}), while other vegetables (radish – 1878 mg kg^{-1}, cucumber – 212 mg kg^{-1}, onions – 23 mg kg^{-1}) showed comparatively lower nitrate amounts (Ranasinghe & Marapana 2018). Nitrate and nitrite content vary depending on geographical location, cultivar type, growth density, harvesting time, and nitrogen fertilizer use (Ranasinghe & Marapana 2018).

Even though any amount of nitrate present per serving of green leaves is non-toxic, its by-products, such as nitrites, nitric oxide, and N-nitrous compounds, can adversely affect human health. The production of nitrosamines is reduced by vitamin C and flavonoids; therefore, consumption of vegetables high in vitamin C and flavonoids can mitigate nitrosamine formation (Inoue-Choi *et al.* 2016, Griesenbeck *et al.* 2009). According to Ranasinghe & Marapana (2018), high nitrate intake can increase the risk of cancers in the thyroid, esophagus, and urinary bladder.

Cyanogenic glycosides are a group of antinutritive secondary metabolites found in plants, which are derived from plant amino acids (Sun *et al.* 2018). The potential toxicity of cyanogenic glycosides arises from enzymatic degradation to produce hydrogen cyanide (Cressey & Reeve 2019). The infamous *Cassava esculenta* (Cassava) poisoning occurs due to the presence of cyanogenic glycosides, which are precursors to cyanide toxins (Sun *et al.* 2018). Cassava tuber is a commonly used staple food in many countries, and the leaves are used as a leafy vegetable (Bayata 2019). Despite the cyanide-mediated toxicity, several diseases are related to chronic dietary intake of cyanogenic glycosides. Konzo (a motor neuron disease characterized by irreversible weakness in the legs), Tropical ataxic neuropathy (several neurological symptoms affecting the mouth, eyesight, hearing, or gait of mostly older males and females), and Goitre and cretinism (occurring due to iodine deficiency) are some of the diseases resulting from high and sustained intake of Cassava (Cressey & Reeve 2019). Furthermore, malnutrition can increase susceptibility to the effects of cyanogenic glycosides.

Different studies evidence the availability of anti-nutrients, including phytic acid, oxalic acid, tannins, nitrates, and cyanogenic glycosides in several widely consumed Sri Lankan GLVs (Begum *et al.* 2020, Essack *et al.* 2017, Gupta *et al.* 2005, Srivarathan *et al.* 2023). The study of Nifras *et al.* (2017) compared the nitrate content in organic and conventionally grown *C. asiatica* (18.3 $\mu g\ g^{-1}$, 108.8 $\mu g\ g^{-1}$), *Spinacia oleraceae* (13.5 $\mu g\ g^{-1}$, 26.2 $\mu g\ g^{-1}$), *Moringa oleifera* (16.2 $\mu g\ g^{-1}$, 73.4 $\mu g\ g^{-1}$), and *A. sessilis* (16.2 $\mu g\ g^{-1}$, 77.3 $\mu g\ g^{-1}$), manifesting higher nitrate content in conventionally grown GLVs. Furthermore, conventionally grown *C. asiatica* showed a remarkably higher amount of nitrates compared to organic. According to Santamaria (2006), *S. oleracea* is classified under "very high" nitrate content (> 2500 mg kg^{-1}). The study of Oruma *et al.* (2022) compared the cyanogenic glycoside content of cooked and raw *C. maxima* (1.71 mg kg^{-1}), a commonly consumed GLV in Sri Lanka, revealing the reduction of cyanogenic anti-nutrients during cooking (0.008 mg kg^{-1}). It also shows the presence of cyanogenic glycosides in spinach (0.76 mg kg^{-1}), which is significantly lower compared with Cassava leaves (750–790 mg kg^{-1}) as shown by Ndubuisi & Chidiebere (2018). Ogbuji & David-Chukwu (2016) report comparative cyanogenic glycoside amounts in several varieties of Cassava. However, evidence on anti-nutrient content in Sri Lankan GLVs is scarce or outdated compared with nutritional studies. A comprehensive study of anti-nutrients and their effect on the bioavailability of nutrients could help address this knowledge gap, as well as inform crop selection and cultivation practices in agriculture.

CONCLUSION

The critical role of food in sustaining human life emphasizes the vulnerabilities within global food systems exacerbated by conflicts, climate fluctuations, and economic downturns.

The COVID-19 pandemic and its economic aftermath have intensified food insecurity, driving millions into extreme poverty. The surge in food inflation has further hindered access to nutritious food, resulting in widespread malnutrition. Promotion of locally available, nutrient-rich food, with a specific focus on underutilized GLVs, can address nutritional deficiencies. Dark GLVs are particularly highlighted for their nutritional value and therapeutic properties, offering a sustainable approach to addressing health issues. The frequency of GLV consumption and their potential can enhance food and nutrient security during current challenges.

By studying previous research, a thorough understanding of the nutritional benefits and anti-nutrient factors of GLVs in Sri Lanka can be gained and used to guide further research, develop novel agricultural practices, and shape dietary recommendations for achieving sustainable food security. Leafy vegetables are recognized as rich sources of essential macronutrients, including proteins, carbohydrates, lipids, and fibers.

Moreover, vital micronutrients including vitamins such as A, B, C, and E, specifically lutein and β-carotene, are highly available in various GLVs, contributing significantly to vitamin A intake. Folic acid, a crucial component of vitamin B9, is abundant in GLVs and plays a vital role in preventing folate deficiencies. The mineral-rich nature of GLVs is emphasized, with different varieties exhibiting varying mineral content. Fiber and protein contents in GLVs are reported to surpass fat and carbohydrates.

This paper reviews the biochemistry of GLVs, revealing the presence of phytochemical constituents termed anti-nutrients. These anti-nutrients function as defense mechanisms for plants against herbivores, insects, and microorganisms and are undesirable due to their potential adverse effects on nutrient utilization and food intake. The insights of this review identify knowledge gaps and the need for comprehensive research on the impact of anti-nutrients in Sri Lankan GLVs. Furthermore, studies on underutilized and rare species of GLVs, which are not commonly cultivated, are required. Overall, this review highlights the need for a holistic approach to address global food insecurity by promoting locally available nutrient-rich GLVs.

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