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African nightshades (*Solanum nigrum* complex): The potential contribution to human nutrition and livelihoods in sub-Saharan Africa

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Abstract

Achieving zero hunger in sub-Saharan Africa (SSA) without minimizing postharvest losses of agricultural products is impossible. Therefore, a holistic approach is vital to end hunger, simultaneously improving food security, diversity, and livelihoods. This review focuses on the African nightshades (ANS) *Solanum* spp. contribution to improving food and nutrition security in SSA. Different parts of ANS are utilized as food and medicine; however, pests and diseases hinder ANS utilization. African nightshade is rich in micronutrients such as β-carotene, vitamins C and E, minerals (iron, calcium, and zinc), and dietary fiber. The leaves contain a high amount of nutrients than the berries. Proper utilization of ANS can contribute to ending hidden hunger, mainly in children and pregnant women. Literature shows that ANS contains antinutritional factors such as oxalate, phytate, nitrate, and alkaloids; however, their quantities are low to cause potential health effects. Several improved varieties with high yields, rich in nutrients, and low alkaloids have been developed in SSA. Various processing and preservation techniques such as cooking, drying, and fermentation are feasible techniques for value addition on ANS in SSA; moreover, most societies are yet to adopt them effectively. Furthermore, promoting value addition and commercialization of ANS is of importance and can create more jobs. Therefore, this review provides an overview of ANS production and challenges that hinder their utilization, possible solutions, and future research suggestions. This review concludes that ANS is an essential nutritious leafy vegetable for improving nutrition and livelihoods in SSA.

KEYWORDS

African nightshade, diversity, nutritional, postharvest losses, preservation, utilization

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Abbreviations: AIV, African indigenous vegetable; ANS, African nightshade; BNS, Black nightshade; BW, body weight; CF, Controlled fermentation; DW, Dry weight basis; EFSA, European Food Safety Authority; FAO, Food and Agriculture Organization of the United Nations; FW, Fresh weight basis; HCN, hydrogen cyanide; KSH, Kenyan Shilling; LAB, Lactic acid bacteria; PaP, Processing and preservation; PHH, Postharvest handling; PHL, Postharvest losses; RDA, Recommended daily allowance; SF, Spontaneous fermentation; SGA, Steroidal glycoalkaloid; SSA, sub-Saharan Africa; TGA, Total glycoalkaloids; TM, Traditional medicine; TZS, Tanzanian shilling; UA, Urban agriculture; WHO, World Health Organization; WVC, World Vegetable Center.

1 | INTRODUCTION

African nightshades (ANSs) are among many underutilized and neglected African indigenous vegetables (AIVs) species; if adequately exploited, they could improve food, nutrition, and income among the rural population (Abukutsa, 2003; Abukutsa-Onyango, 2007; Dinssa et al., 2016). However, Weinberger and Msuya (2004) argued that AIVs are not underutilized as usually thought but somewhat are undervalued. ANS belongs to many species in the genus *Solanum* in the family *Solanaceae* found in temperate and tropical regions of the world, and it consists of about 90 genera and 2000 to 3000 species (Edmonds & Chweya, 1997; Yang & Ojiewo, 2013). Within this family, *Solanum* forms the largest and most complex genus composed of more than 1500 species (Edmonds & Chweya, 1997).

ANS is among the known AIVs rich in nutrients to promote food and nutrition security in sub-Saharan Africa (SSA) (Yang & Ojiewo, 2013). The AIVs are considered a new cash crop in most SSA regions because they contribute to income generation to individuals and households (Shackleton et al., 2009). AIVs have been part of SSA's food systems for generations, and their leaves, young shoots, and flowers are consumed for various purposes (Abukutsa-Onyango, 2010; Ambrose-Oji, 2009; Yang & Ojiewo, 2013). ANSs are among high-priority AIVs with the potential for health, nutrition, and economic benefits (Edmonds & Chweya, 1997; Yang & Ojiewo, 2013). They are rich in macro- and micronutrients, including thiamine, ascorbic acid, iron, calcium, zinc, protein, and dietary fiber (Kirigia et al., 2019; Ontita et al., 2017; Ronoh et al., 2017; Yuan et al., 2018). Furthermore, they are rich in bioactive compounds, particularly lutein, zeaxanthin, polyphenol, flavonoids, and chlorophylls, which possess antioxidant activity, anti-genotoxicants, and anticancer properties (Odongo et al., 2018). In SSA, ANS is exploited for food, medicines, animal feed, and spiritual uses, but less exploited for socioeconomic benefits (Abukutsa-Onyango, 2007; Ontita et al., 2017). However, AIVs are wasted (Global Panel, 2018; Stevens et al., 2015) despite the favorable climatic conditions and high production; they account for 50% of postharvest losses (PHL) of all food produced in SSA (Global Panel, 2018; Weinberger & Msuya, 2004).

This review focuses on harnessing the ANS potential in SSA. It explores the ANS diversity, cultivation, nutritional and functional benefits, antinutritional factors, and safety. Further, it summarizes and discusses the impact of PHL, postharvest handling (PHH) and processing, and traditional recipes for ANS. Importantly, the ANS roles in health promotion, trends in utilization and possible constraints, and possible solutions are summarized.

2 | DIVERSITY OF ANS

The commonly available ANS species in SSA include *S. americanum*, *S. scabrum*, *S. nigrum*, and *S. villosum* (Table 1) (Edmonds & Chweya, 1997; Keller, 2004; Yang & Ojiewo, 2013; Yuan et al., 2018). Eight species belong to the *S. nigrum* complex or the black nightshades (BNSs) complex, namely, *S. nigrum* L., *S. americanum*, *S. scabrum* Mill., *S. sarrachoides* Sendtn., *S. villosum* Mill., *S. grossedentatum* A. Rich., *S. florulentum* Bitter, and *S. tarderemotum* Bitter, which are distinguished based on characteristic morphological traits (Dehmer & Hammer, 2004; Edmonds & Chweya, 1997; Ojiewo, Mwai et al., 2013; Ronoh et al., 2017). *Solanum scabrum* and *S. villosum* are most prevalent in East Africa (Table 1) (Ambrose-Oji, 2009) but are produced in other regions of Africa (Table 1 and Figure 1). Nonetheless, they are still considered a wild weedy crop in most SSA (Dinssa et al., 2016; Edmonds & Chweya, 1997). They can be grown in various places such as roadsides, hedgerows, around building and houses, under trees, as garden weeds, riverbanks and in gullies, on forest and grassland margins, quaysides and rubbish tips, on shingle beaches, on railway cuttings, and the edges of cultivated fields and plantations (Edmonds & Chweya, 1997). About 45% of farmers in Mbale, Uganda, collect ANSs from the wild for selling in the urban markets (Ambrose-Oji, 2009; Kasambula et al., 2007). Approximately 90% of vegetable supplies in big cities in SSA, including the Central Africa Republic, Guinea-Bissau, Madagascar, and Tanzania, are predicted to come from urban and peri-urban agriculture (UA) (Ambrose-Oji, 2009). Most of these vegetables are exotic and highly consumed in urban and peri-urban regions (Ambrose-Oji, 2009). However, many fresh AIVs leaves available in urban markets come from rural areas due to seasonal production (Gido et al., 2017).

Solanum nigrum, commonly known to be native to Eurasia, was introduced in the Americas, South Africa, and Australasia (Kuete et al., 2017). Whereby, *S. americanum* (American BNS) is native to the Americas (Dehmer & Hammer, 2004) and is the most unrelated species within the *S. nigrum* complex with only about 43% of genetic similarity (Gilbert, 2006). Within the *S. nigrum* complex, *S. scabrum* and *S. nigrum* are near related species (about 68%), with the *S. villosum* being close to them by 62% (Dehmer & Hammer, 2004; Gilbert, 2006). American BNSs are native to the Americas, particularly Cuba and South America (Dehmer & Hammer, 2004;

TABLE 1 Edible ANS species diversity and distribution in SSA

African nightshades	Description	Distribution	References
Solanum scabrum Mil	Broad leaves Ripe berries (1000 to 2000 berries); 1000 seeds weight of 1.0 to 1.3 g Black or purple leaves of greater than 14 mm in size Differ in growth habits, bitterness, and leaf color Taller up to 1.5 m in height Low rainfall and temperature (18 to 30 °C) Good sources of carotenoid, vitamin C, E and A, C, calcium, iron, zinc, and protein Used as food and medicine	East Africa, West Africa, Central Africa	Abukutsa-Onyango, 2015; Edmonds and Chweya, 1997; Maundu et al., 1999; Wafula, 2017; Yang and Ojiewo, 2013
Solanum nigrum Miller	Black nightshades, leafy green vegetables (*S. eldorettii*, S. *tarderemotum*, and *S. florilegium*) Berries about 3000 to 4000; 1000 seeds weight of 0.4-0.6 g Good sources of carotenoid, vitamin C, E and A, C, calcium, iron, zinc, and protein Used as food and medicine	North Africa, Kenyan Highlands, Northern Tanzania	Edmonds and Chweya, 1997; Jacoby et al., 2003; Maundu et al., 1999; Shackleton et al., 2009; Wafula, 2017; Yang and Ojiewo, 2013
Solanum americanum Miller	Black nightshades; *Mnavu*, *Msogo*, and *Mhaki* (Tanzania) and *Wsuggaenzirugavu* (Uganda) Berries are shiny dark purple, and the barriers are small than 12 mm Small berries about 4500; 1000 seeds weigh 0.3 to 0.4 g Moderately thin branches than other species Good sources of carotenoid, vitamin C, E and A, C, calcium, iron, zinc, and protein Used as food and medicine	East Africa, West Africa, Central Africa, Southern Africa	Edmonds and Chweya, 1997; Maundu et al., 1999; Shackleton et al., 2009; Wafula, 2017; Yang and Ojiewo, 2013
Solanum villosum Miller	Black nightshades or garden huckleberry; *Mnavu* (Tanzania and Kenya) Berries about 3000 to 4000 (orange to yellow); 1000 seeds weight of 0.4 to 0.6 g Wild and cultivatedUsed as food and medicine	East Africa, West Africa, Central Africa, Southern Africa, Egypt	Edmonds and Chweya, 1997; Maundu et al., 1999; Shackleton et al., 2009; Wafula, 2017; Yang and Ojiewo, 2013

Gilbert, 2006). In the Americas, this species is found in California, Mexico, Central America, and South America. The nomenclature and taxonomy are associated with toxic BNS (*Atropa belladonna*) of temperate Eurasian origin; this species has many phenotypic similarities with many nightshades (Gilbert, 2006). ANS has been consumed for centuries by native peoples in Central America, Mexico, and Africa and is essential in these regions (Lotter et al., 2014). In SSA, Bennin, Cameroon, Burkina Fasso, Tanzania, and Kenya highly consume ANS (Keller, 2004; Weinberger & Msuya, 2004; World Vegetable Center [WVC], 2017), and it is also well promoted in the Southern African Development Community (SADC) region (Ojiewo, Mbwambo, et al., 2013). Table 1 shows the diversity and distribution of ANS in SSA. In Tanzania, the northern (Arusha and Kilimanjaro), central (Dodoma), eastern (Morogoro and Tanga), and southern (Iringa and Mbeya) zones are well-known for ANS production (Keller, 2004; Weinberger & Msuya, 2004). Both traditional and exotic vegetables cover 9% of all cultivated land (Weinberger & Msuya, 2004; Dinssa et al., 2016). In East Africa, some improved cultivars of *S. scabrum* and *S. villosum* were released based on their superior yield and acceptability. Thirteen cultivars of *S. scabrum* (ACC.15B, ACC.16A, ACC.16B, ACC.18, ACC.20, ACC.21, ACC.3, ACC.4, ACC.6, ACC.7, and ACC.8B) and *S. villosum* (ACC.25 and ACC.29) were released in Kenya (Ronoh et al., 2019). In Tanzania, cultivars of *S. scabrum* (BG16-Nduruma and

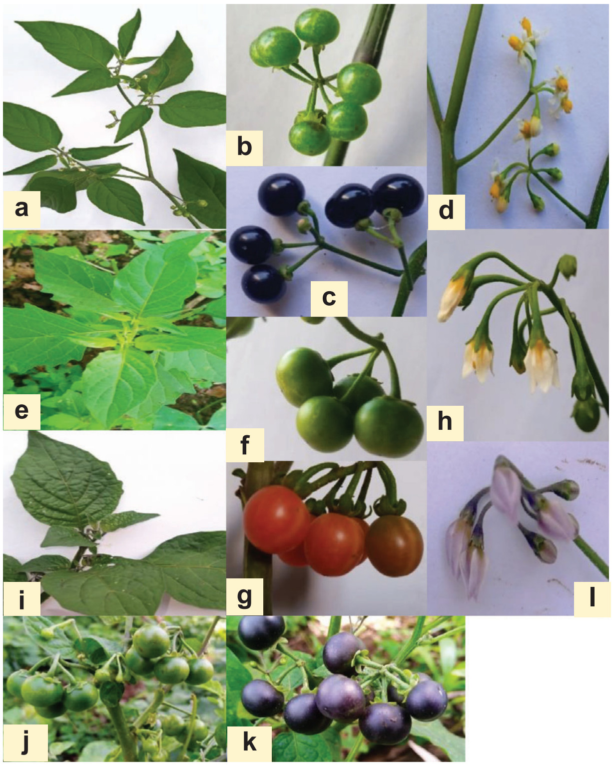

FIGURE 1 Leaves, flowers, and berries of *S. nigrum*, *S. villosum*, and *S. scabrum*: a, e, and i, respectively. Unripe berries, ripe berries, and flower of *S. nigrum*: b, c, and d, respectively. Unripe berries, ripe berries, and flowers of *S. villosum*: f, g, and h, respectively. Unripe berries, ripe berries, and flower of *S. scabrum*: j, k, and l, respectively
Source: Authors.

SS49-Olevolosi), and RC18-ES13-3-Ambureni (*S. villosum*) and RC10-ES13-3-Malala (*S. scabrum*) were released in 2011 and 2018, respectively (https://www.tosci.go.tz/publications/22; Ojiewo, Mbwambo, et al., 2013; Mbwambo et al., 2021). Also, about five advanced lines of *S. scabrum* (SS52, SS40, SS042, ABUK1, and ABUK2) and one of *S. villosum* (ABUK3) are available in Kenya and Tanzania (Ronoh et al., 2019).

3 | CULTIVATION OF ANS

ANS are a popular and cash-generating vegetable in Africa (Yang et al., 2013). The production of ANS requires a small portion of land, and it does not require extensive external inputs and production experts. Therefore, it encourages the majority of farmers to engage in its production (Abukutsa-Onyango, 2007). Demands for AIVs have surged in Africa due to rising market requirements for AIVs varieties (Yang et al., 2013). Small-scale production of ANS is common in Kenya; about 80% of farmers use less than 0.25 acres on production (Abukutsa-Onyango, 2007; Ambrose-Oji, 2009), characterized by low leaf yields of 1.5 to 3 tons/ha specifically for *S. scabrum*, *S. villosum*, and *S. americanum* (Ojiewo, Mbwambo, et al., 2013). A low level of production of ANS hinders the availability and consequently results in low consumption. Onyango et al. (2016) indicated that about 75% to 80% of ANS growers in Kenya are women cultivating small plots of less than 0.25 acres. About 59% of all farmers produce less than 50 kg of ANS per season (Abukutsa-Onyango, 2007; Ambrose-Oji, 2009; Gebru, 2015). AIVs are grown mainly in home gardens within the homestead (Abukutsa-Onyango, 2007), as a source of food and small income generation for their family; it also helps them become financially independent (Onyango et al., 2016).

3.1 | Cropping system of ANS

Mono-cropping, intercropping, and crop rotation are cropping systems used in the growing of ANS. However, most farmers practice mono-cropping, followed by intercropping, and few farmers practice crop rotations. There are several benefits of intercropping that include a diversity of crops in a given season and optimal utilization of resources such as nutrients, water, and light (Gebru, 2015; Onyango et al., 2016). ANS can be intercropped with maize, millet, sweet potatoes, kale, beans, avocado, cassava, groundnuts, and bananas (Abukutsa-Onyango, 2007). The current global trend is encouraging organic farming by avoiding using harmful chemicals to the environment and consumers (Abukutsa-Onyango, 2007). The planting of ANS is carried out twice in Kenya during the long rains (March to July) and the short rains (September to December) (Abukutsa-Onyango, 2007). About 69% of Kenya's farmers depend on rainfall, and only 20% to 31% are practicing irrigation using watering cans (Abukutsa-Onyango, 2007; Gebru, 2015).

3.2 | Yields of ANS

ANS edible leaves give the highest yield between 12 and 50 tons/ha per season (Abukutsa-Onyango, 2015; Edmonds & Chweya, 1997; Ojiewo, Mbwambo, et al., 2013). However, Ojiewo, Mbwambo, et al. (2013) and Molina et al. (2020) reported an annual yield of 1.5–3.0 and 3.85 tons/ha, respectively. The average share of cultivated ANS varies across locations, and the most substantial proportion is the Arumeru district in Arusha, Tanzania, which covers 20% of all cultivated land (Dinssa et al., 2016; Weinberger & Msuya, 2004). Arumeru district produces about 71.8% of all cultivated ANS in Tanzania (Weinberger &

Msuya, 2004). The presence of national and international research centers, including the World Vegetable Center, Eastern and Southern Africa (WVC-ESA), International Institute of Tropical Agriculture (IITA), and Nelson Mandela African Institution of Science and Technology (NM-AIST), positively promotes cultivation and consumption of AIVs, including ANS around these regions (Dinssa et al., 2016).

ANS is tolerant to abiotic stress under low soil moisture and heat. Luoh et al. (2014) reported that ANS *S. scabrum* retains vitamins and minerals and undergoes less weight loss at water deficit. Thus, ANS suffers less in water deficiency and becomes a choice of crops under drought conditions in SSA. ANS can take 3 to 4 weeks for the first harvest; therefore, it is an essential crop to feed the world's large population (Dinssa et al., 2016; Lobell & Gourdji, 2012).

Rapid urbanization has increased the demand for ANS in SSA (Ambrose-Oji, 2009; Shackleton et al., 2009). There is considerable scope to increase ANS yield; therefore, variation between yield obtained in farms and research has been reported (Dinssa et al., 2016). This variation further suggests the importance of technological application for the intense production of ANS in the farms.

3.3 | Factors affecting cultivation of ANS

3.3.1 | Pests and diseases

Pests and diseases are the main challenges during ANS production in SSA, resulting in low yields. Fungi, bacteria, and viruses are the main causative agents for ANS diseases. The major fungi diseases include damping-off (*Rhizoctonia* spp.), early blight (*Alternaria solani*), late blight (*Pychrithium infestans*), fusarium wilt (*Fusarium oxysporum* and *Fusarium solani*), and verticillium wilt (*Verticillium dahliae*). The bacteria diseases are bacterial wilt (*Ralstonia solanacearum*), leaf mold (*Cladosporium oxysporum*), eyespot, and southern blight (Abukutsa-Onyango, 2007; Ambrose-Oji, 2009; Dinssa et al., 2016; Edmonds & Chweya, 1997; MoALF/SHEP PLUS, 2019; Nono-Womdim et al., 2012; Onyango et al., 2016; Shackleton et al., 2009; Yang & Ojiewo, 2013).

Pests and diseases damage the leafy structure and reduce the quality of vegetables, leading to customers' rejection (Abukutsa-Onyango, 2007). *Enterobacter mori* isolated from ANS pickle (Wafula, 2017) cause plant bacterial wilt (Zhu et al., 2011); perhaps they also cause wilt in ANS. The pest and diseases of ANS are the same as of other Solanaceae families. Pests and diseases are a significant problem in Tanzania; however, it becomes more intense when vegetables are grown for multiple harvests over a long time or used for seed production (Keller, 2004).

On the other hand, viruses control insects (aphids, whiteflies) and inadvertently bruising young leaves by touching them (Nono-Womdim et al., 2012; Ojiewo, Mbwambo, et al. 2013). The viral diseases include leaf curl viruses, leaf mosaic viruses, yellow viruses, and tomato mosaic viruses (Nono-Womdim et al., 2012; Wafula et al., 2017). Tomato mosaic virus (ToMV) is a common virus found in ANS in SSA (Nono-Womdim et al., 2012). The control measures for pathogenic microorganisms include use of fungicides, disease free seeds, minimizing injury, avoiding dense planting, using furrow or drip irrigation, and crop rotation. Further, removing infected plants and destroying them immediately after harvest, avoiding overfertilization, adequate sanitation, and using healthy seedlings can control pests and diseases (Nono-Womdim et al., 2012).

The most common pests of ANS include aphids (*Aphis* sp.), spider mite (*Tetranychus evansi* Baker), red and black ants, cutworms, caterpillars (larvae), grasshoppers (*Zonocerus variegatus*), whiteflies (*Bemisia tabaci*), beetles (*Epilachna hirta*, *Lagria* spp., and *Podagrica* spp.), and Nematodes (*Melodigyne* spp.) (MoALF/SHEP PLUS, 2019; Nono-Womdim et al., 2012).

The short shelf life of ANS reduces the market supply and bargaining power of small-scale farmers and local open market sellers (Dinssa et al., 2016; Muhanji et al., 2011). Therefore, a multidisciplinary approach is needed between breeders and postharvest specialists to improve vegetables' shelf life and storage conditions. Interventions through affordable preservation techniques can increase small-scale farmers' income and the vegetables' marketing (Dinssa et al., 2016; Muhanji et al., 2011).

3.3.2 | Lack of improved cultivars

Lack of improved cultivars limits the high production of ANS in SSA, resulting in low-yielding cultivars (Dinssa et al., 2016). Seed manufacturing companies do not consider the production and marketing of ANS seeds as a profit-generating business because most AIVs are open-pollinated, forcing most farmers to produce their seeds (Dinssa et al., 2016). Nevertheless, the seeds of improved ANS cultivars are not available in seed stores of many regions in SSA, particularly in remote areas (Dinssa et al., 2016; Muhanji et al., 2011). As of recently, some improved cultivars of *S. scabrum* and *S. villosum* are available to farmers in Tanzania and Kenya for commercial use (Ronoh et al., 2019; https://www.tosci.go.tz/publications/22). Besides, several advanced lines of *S. villosum* and *S. scabrum* are available to advance the breeding research of the crop for improved characteristics such as yield, pests, and disease resistance (Ronoh et al., 2019).

3.3.3 | Other factors

Other factors that hinder the production and consumption of ANS include inadequate rainfall, lack of knowledge, lack of appropriate storage facilities, low-quality seeds, drought, fragmented marketing channels, poor transport infrastructure, agronomic challenges, and lack of appropriate packaging (Abukutsa-Onyango, 2007; Ambrose-Oji, 2009). For better-improving ANS production, researchers should involve farmers as they are key producers. Improved cultivars are essential because they require fewer inputs, tolerate pests and diseases, and tolerate different climate conditions (Muhanji et al., 2011).

4 | NUTRITIONAL AND FUNCTIONAL BENEFITS OF ANS

4.1 | Macro and micronutrients

ANS' leaves and berries contain a high amount of protein, carbohydrates, minerals, and vitamins (A, C, E, and B complex) and could contribute to a healthy diet (Tables 2 and 3; Ambrose-Oji, 2009; Stoll et al., 2021; Wafula, et al., 2017). The high content of micronutrients is sufficient to contribute to the recommended daily allowance (RDA) (Table 4). According to Food and Agriculture Organization of the United Nations (FAO) and World Health Organization (WHO) (FAO & WHO, 2004) and Agudo & Joint FAO/WHO (2004), the RDA of vegetables and fruits is 400 g, indicating that ANS consumption alone can meet the RDA of vitamins C, E, and A, iron, and manganese. ANSs contain β-carotene (2.8 to 13.8 mg/100 g fresh weight basis [FW]) higher than the average level of various vegetables reported by the USDA National Nutrient Database (Table 2; Yuan et al., 2018). For instance, 100 g of leaves of ANS can provide over 100% of the vitamin A needs of pregnant women (Schreinemachers et al., 2018; WVC, 2017). ANS contains a significant amount of B vitamins including thiamine (0.08 to 0.35 mg/100 g FW), riboflavin (0.17 to 0.19 mg/100 g FW), and folate (12 to 56 μg/100 g FW) (Table 2). The B vitamins function as co-enzymes and help in energy production from carbohydrates, synthesis of neurotransmitters, fatty acids, and hormones (Blake, 2008). Also, ANS contains a high content of vitamin C (140 mg/100 g FW) and vitamin E (1.21 to 5.94 mg/100 g FW), which are natural antioxidants (FAO, 2004 (FAO & WHO, 2004; Blake, 2008). Young leaves of ANS have low vitamin C content than matured leaves (Cheptoo et al., 2019). Vitamin C prevents scurvy, reduces gastric cancer, and stabilizes folate in food and plasma. The dietary intake of 25 mg of vitamin C improves iron absorption and prevents anemia (FAO & WHO, 2004). The ANS leaves are rich in iron (1.3 to 7.2 mg/100 g FW), zinc (0.1 to 0.56 mg/100 g FW), and calcium (173 to 199 mg/100 g FW) (Table 2). *Solanum retroflexum* leaves contain 7.2 mg/100 g of iron (Sivakumar et al., 2020). Calcium content at a concentration of 300-600 mg inhibited 60% iron absorption (FAO & WHO, 2004). Increasing iron intake and avoiding foods rich in calcium and iron at the same time can improve iron absorption (FAO & WHO, 2004). Calcium contributes to bone development; the deficiency led to the development of osteoporosis. Zinc contributes to the improvement of the immune system and repairing of cell and organ integrity. Deficiency of zinc in humans results in growth retardation, bone maturation, delayed sexual maturity, diarrhea, skin lesions, reduced appetite, and increased vulnerability to infections (FAO & WHO, 2004).

Solanum nigrum leaves contain a high amount of protein, fiber, and total ash than the same species' berries. However, the berries contain more fat and carbohydrates (Tables 2 and 3). In comparison, *S. nigrum* leaves contain a high amount of calcium, iron, magnesium, phosphorous, potassium, sodium, and zinc than the berries (Tables 2 and 3). Also, the leaves of *S. nigrum* contain a high amount of vitamins A, C, and B9 than the berries; besides, the berries contain a high amount of vitamin B1. The high contents of the macro- and micronutrients present in ANS leaves suggest that leaves are more nutritious than the berries despite some nutrients being high in the berries. Therefore, researches are needed to assess the nutrients contents of berries in other species of ANS. Notably, the ANSs' dense and diverse nutrients can improve essential nutrients for better health if sufficiently eaten (Table 4).

4.2 | Phytochemicals

Phytochemicals are secondary metabolites present in abundance in various parts of ANS. Total phenols, carotenoids, glycoalkaloids, and chlorophylls are phytochemicals in ANS (Table 5) (Neugart et al., 2017; Nyaga et al., 2019; Nyaga, 2020; Yuan et al., 2018). *Solanum nigrum* var. *sarrachoides* leaves contain flavonoids, alkaloids, tannins, saponin phenols, phytosterols, coumarins, and glycosides. In contrast, *S. villosum* leaves showed all the phytochemicals, except phytosterols and coumarins (Nyaga et al., 2019; Nyaga, 2020). These phytochemicals are also bioactive compounds in ANS with potential health benefits. *Solanum scabrum* contains many carotenoids such as β-carotenoid, zeaxanthin, and lutein (Odongo et al., 2018). Carotenoid content in foods contributes to

TABLE 2 Nutrient content of the raw and processed ANS species

	Raw[a,e,f,g,j,m]	Solar drying[g,j]	Blanched[j]	Fermented	Raw[e,h,i,k,l,m]	Dried[h]	Blanched[h]	Fermented[n]	Raw[e,m]	Blanched	Dried	Fermented
Nutrients	***S. nigrum* Mill.**				***S. scabrum* Mill.**			***S. villosum* Mill.**				
Moisture (%)	87.7	6.5 to 12.3	91.5	–	85.8	–	89.3	–	–	–	–	–
Protein (g)	39.8 DW/3.4 FW	36.1 to 38.2 DW	40.6 DW	–	3 to 6 FW	–	–	14 to 16 DM	4.2 FW	–	–	–
Energy (KJ)	162	–	162	–	–	–	–	–	–	–	–	–
Fat (g)	7.6 DW	4.14 DW	7.28 DW	–	3.1 FW	–	–	–	1.9 FW	–	–	–
Fiber (g)	2.5 FW/14.07 DW	–	–	–	12.8 DW	11.6 DW	12.05 DW	–	1.3 FW	–	–	–
Dry matter (g)	8 FW	–	–	–	10.5 to 22 DW	–	–	21.7 to 22.4 DW	11.1	–	–	–
Carbohydrate (g)	29.04 DW/3.78 FW	14 to 17.1 DW	60.7 DW	–	0.3 DW	–	–	–	–	–	–	–
Total ash (%)	10.6 to 14.6 DW/1.38 to 1.9 FW	11.5 to 12.3 DW	8.8 DW	–	–	–	–	25.1 DW	–	–	–	–
Ca (mg)	173 to 199 FW	–	–	–	1460 to 2430 DW	–	–	–	175 FW	–	–	–
Fe (mg)	1.3 to 7.2 FW	–	6.9 FW	–	70 to 130 DW	–	–	–	3.3 FW	–	–	–
Mg (mg)	25 to 92 FW	–	87 FW	–	330 to 410 DW	–	–	–	NA	–	–	–
P (mg)	36 to 75 FW	–	33 FW	–	270 to 320 DW	–	–	–	–	–	–	–
K (mg)	257 to 430 FW	–	232 FW	–	100 FW	–	–	–	–	–	–	–
Na (mg)	3 to 8 FW	–	8 FW	–	74.22 FW	–	–	–	–	–	–	–
Zn (mg)	0.1 to 0.56 FW	–	0.53 FW	–	4.0 to 6.2 DW	–	–	–	0.8 FW	–	–	–
Cu (mg)	0.16 FW	–	0.15 FW	–	2.6 to 4.2 DW	–	–	–	–	–	–	–
Mn (μg)	2.1 FW	–	2.1 FW	–	25.7 to 28.8 DW	–	–	–	–	–	–	–
β-Carotene (mg)	2.8 to 14.2 FW/102 DW	1.7 to 69.4 DW	11.9 DW	–	5.5 to 10 FW/71.22 DW	47.64 DW	54.8 DW	–	13.8 FW	–	–	–
Vitamin A (μg)	5 FW	–	3	–	8.8 FW	–	–	–	–	–	–	–
Vitamin C (mg)	35 FW/622.9 to 757.2 DW	–	–	–	40 to 140 FW/63 to 177.97 DW	2.4 to 103.7 DW	10.89.4 DW	256.8 DW	2.9 FW	–	–	–
Vitamin B1 (mg)	0.08 FW/0.71 DW	–	0.07 FW	–	–	–	–	0.21 to 1.5 DW	–	–	–	–
Vitamin B2 (mg)	0.17 to 0.19 FW/1.5 DW	–	0.16 FW	–	–	–	–	0.98 to 1.1 DW	–	–	–	–
Vitamin B9 (μg)	12 to 56 FW	–	0.037 FW	–	–	–	–	–	–	–	–	–
Vitamin E (mg)	9.3 to 45.7 DW/1.21 to 5.94 FW	–	–	–	6.4 to 14.2 DW	–	–	44.5 to 48 DM	11.4 DW	–	–	–

Note: The nutrients are expressed per 100 g.

Abbreviations: DW, dry weight basis; FW, fresh weight basis.

Sources: [e]Gogo et al. (2016); [a]Ronoh et al. (2017); [e]Yuan et al. (2018); [f]Van Jaarsveld et al. (2014); [g]Nyambaka et al. (2012); [h]Cheptoo et al. (2019); [i]Mibei et al. (2011); [j]Traoré et al. (2017); [k]Habwe et al. (2008); [l]Kirigia et al. (2019); [m]Yang and Ojiewo (2013); [n]Wafula (2017).

TABLE 3 Nutrient content of ANS berry

Nutrients	*S. nigrum* Mill.
Moisture (%)	76.86
Protein (%)	17.63 DW/4.08 FW
Fat (%)	12.18 DW/2.82 FW
Energy KJ	43.54 DW/ 10.08 FW
Fiber (%)	6.29 DW/ 1.46 FW
Carbohydrate (%)	55.85 DW/ 12.92 FW
Total ash (%)	8.05 DW/1.86 FW
Ca (mg)	11.82 DW/2.74 FW
Fe (mg)	12.91 DW/2.99 FW
Mg (mg)	201.36 DW/46.59 FW
P (mg)	62.50 DW/14.46 FW
K (mg)	37.19 DW/8.60 FW
Na (mg)	2.11 DW/0.49 FW
Zn (mg)	0.05 DW/0.01 FW
Sulfur (mg)	14.48 DW/3.35 FW
Vitamin A (mg)	1.71 DW/0.4 FW
Vitamin C (mg)	23.38 DW/5.4 FW
Vitamin B1 (mg)	10.91 DW/2.52 FW
Vitamin B9 (μg)	8.13 DW/1.88 FW
Vitamin E (mg)	5.71 DW/1.3 FW

Note: The nutrients are expressed per 100 g.
Abbreviations: DW, dry weight basis; FW, fresh weight basis.
Source: Akubugwo et al. (2007).

TABLE 4 The estimated quantity of fresh ANS to meet the RDA

Micro-nutrients	RDA (mg/day)	EQ of ANS per day (g)	Quantity of ANS per 100 g
Thiamine	1 to 1.7	1375 to 2125	0.08 mg
Riboflavin	1 to 1.5	647 to 882	0.17 mg
Folate	400 μgDFE/day	1739	23 μgDFE
Vitamin C	73 to 90	209 to 257	35 mg
Vitamin E	15	154	9.7 mg
Vitamin A	700 to 900 μRAE/day	165 to 213	422 μRAE
Calcium	1000	503	199 mg
Iron	18	250	7.2 mg
Magnesium	400	435	92 mg
Phosphorous	1000	1333	75 mg
Potassium	3500	814	430 mg
Sodium	2400	3243	74 mg
Zinc	15	2500	0.6 mg
Copper	2	1333	0.15 mg
Manganese	2	95	2.1 mg

Note: EQ represents estimated amount of ANS in grams of fresh weight required to be eaten to meet the recommended daily allowance. RDA represents recommended daily allowance. μgDFE represents micro gram of dietary folate equivalent. μRAE retinal activity equivalency. The vitamins and minerals are recommended for a person above 17 and 4 years, respectively. However, this quantity can vary depending on health status, sex, age, pregnant, and lactating women.
Source: http://www.fda.gov/nutritioneducation; FAO & WHO (2004); Zempleni et al. (2007); Van Jaarsveld et al. (2014); Ronoh et al. (2017).

health maintenance and risk reduction of various diseases (Neugart et al., 2017; Oluoch et al., 2012). The high content of β-carotene in ANS contributes to vitamin A production, with health benefits in reproduction, vision, immune function, tissue differentiation, and embryonic development (Blake, 2008; Zempleni et al., 2007). Younger leaves of ANS have low β-carotene than matured leaves; however, matured leaves are rich in carotenoids (Cheptoo et al., 2019). Carotenoids help to reduce reactive oxygen species and prevent some types of cancers. However, they display a pro-oxidative effect under high concentration, high oxygen tension (lung of smokers), low levels of endogenous enzymes, and higher levels of metal ions (Fe^{3+} and Cu^{2+}) (Park et al., 2013; Shin et al., 2020). Usually, β-carotene acts as a pro-oxidant at higher oxygen partial pressure in cells and thermally oxidized bulk oil systems (Ha et al., 2012; Park et al., 2013; Shin et al., 2020). Lutein and zeaxanthin are carotenoids pigments imparting yellow or orange color to various foods such as carrots, peppers, fish, and eggs (Abdel et al., 2013). Carotenoids protect age-related eye disease and filter specific wavelengths of light, thus providing the visual performance and offering photoreceptors protection from light damage (Abdel et al., 2013; Eggersdorfer & Wyss, 2018; Raman et al., 2019). Similarly, they reduced the risk of cataracts and early age-related macular degeneration (Eggersdorfer & Wyss, 2018; Raman et al., 2019). Lutein and zeaxanthin can inactivate free radicals and oxygen triplicates caused by light-induced cellular activity (Raman et al., 2019). Lutein-rich diets improved learning performance in mice and memory in old men and women (Eggersdorfer & Wyss, 2018) and also helped in developing the infant brain (Perrone et al., 2016). Still, there are no established dietary guidelines for lutein required to reach optimal macular pigment density in healthy people's eyes (Eggersdorfer & Wyss, 2018; Raman et al., 2019; Ranard et al., 2017).

Phenolic compounds concentration in ANS is about 16,387- 16,677 μg/g dry weight basis (DW) whereas flavonoids, phenolic acids, saponins, and tannins are widely occurring phenolic compounds in ANS. They act as antioxidative compounds by scavenging free radicals that delay or inhibit the initiation step (Amalraj & Pius, 2015; Degrain et al., 2020; Shahidi & Ambigaipalan, 2015; Yang

TABLE 5 Phytochemicals and antinutritional factors of the leaves of ANS species

Compounds	*S. nigrum*	*S. scabrum*	*S. villosum*	References
TPP per 100 g of GAE FW	725 to 1307 mg	775 to 1247 mg	1026 mg	Yang and Ojiewo, 2013; Yuan et al., 2018
Quercetin glycosides (quercetin-3-rutinoside)	NI	1400 to 3300 μg/g DW	NI	Neugart et al., 2017
Carotenoids	7.9 to 20.0 mg/100 g FW	10,100 mg/100 g DW	1790 μg/g DW	Adebooye et al., 2008; Odongo et al., 2018
Flavonoids	4.7 mg/100 g FW	25.5 mg/100 g FW	19.9 mg/100 g FW	Yang and Ojiewo, 2013
Glycoalkaloids	1722 mg/100 g DW	NI	1448 mg/100 g DW	Mohy-Ud-Din et al., 2010
Chlorophyll	69.8 to 155.8 mg/100 g FW	25,000 to 60,000 mg/100 g DW	19,600 mg/100 g DW	Adebooye et al., 2008; Odongo et al., 2018
Tannins	355.5 mg/100 g DW	NI	NI	Amalraj and Pius, 2015
Phytate	58.8 mg/100 g DW/7.64 mg/100 g FW	NI	0.04 to 0.2 mg/100 g DW/0.0052 mg/100 g FW	Amalraj and Pius, 2015; Mwanri et al., 2018
Oxalate	776.2 mg/100 g DW	33 mg/100 g DW	28.7 to 68 mg/100 g DW	Amalraj and Pius, 2015; Mwanri et al., 2018; Yang and Ojiewo, 2013
Cyanogenic glycosidase	320 mg/100 g FW	NI	NI	Essack et al., 2017
Nitrates	NI	NI	63.0 to 85.6 mg/100 g DW	Mwanri et al., 2018

Note: The total glycoalkaloids content was calculated by the sum of (Solasonine, α-Solamargine, β-Solamargine, and α-Solanine).
Abbreviations: DW, dry weight basis; FW, fresh weight basis; NI, not indicated; TPP, total polyphenol; GAE, gallic acid equivalent

& Ojiewo, 2013; Yuan et al., 2018). Phenolic compounds possess a wide range of physiological properties, mainly antiallergenic, antiatherogenic, anti-inflammatory, antimicrobial, antioxidant, antithrombotic, cardioprotective, and vasodilatory (Boudet, 2007; Manach et al., 2005; Shahidi & Ambigaipalan, 2015). The average daily intake of dietary polyphenols is approximately 1 g per person (Shahidi & Ambigaipalan, 2015). The total polyphenol content of ANS ranges from 725 to 1307 mg/100 g FW (Table 5). This amount is sufficient to meet the RDA for the consumption of 100 g of FW ANS. However, high consumption of polyphenols causes low iron absorption (Zijp et al., 2000). Blanching of ANS at 95 °C or steaming using water or lemon juice solution significantly increases the total phenolic content (Yuan, Dinssa, et al., 2020).

Chlorophylls are natural pigments present in ANS. They act as a natural antioxidant with the ability to scavenge free radical and prevent several oxidative stress-related diseases such as cancer, neurological disorders, inflammatory diseases, dermatitis, tissue damage, sepsis, cardiovascular disorders, decreased immune function, and aging (Lanfer-Marquez et al., 2005; Mishra et al., 2011; Sangija & Wu, 2020; Wang & Wink, 2016). Chlorophyll can inhibit calcium oxalate dihydrate formation, which are the primary sources of kidney stones (İnanç, 2011). Besides, it stimulates the immune system, helps in detoxification, combats foul odors, and helps combat anemia and eliminate molds and toxins in the body (İnanç, 2011). Despite health benefits, chlorophyll can act as a pro-oxidant for oil oxidation when subjected to light (İnanç, 2011; Wang & Wink, 2016). Steaming and water blanching of ANS significantly increase chlorophyll content of 2.82 to 8.87 and 1.19 to 5.54 mg/100 g FW, respectively (Managa et al., 2020).

Glycoalkaloids are plant-derived bioactive compounds capable of interacting with living tissue components with a wide range of likely effects (Huang et al., 2016). ANS berries are a rich source of alkaloids. Solamargine and solasonine are glycoalkaloids in *S. scabrum* and solasodine glycosides in *S. americanum*. *Solanum scabrum* and *S. villosum* methanol leaves extracts lack glycoalkaloids but are present in *S. villosum* Grif 16939 and *S. nigrum* PI 381290 accessions in a very low concentration of 50 μg/g DW or 1 mg/100 g FW (Yuan et al., 2018). Alkaloids have therapeutic effects such as cytotoxic against human carcinoma cells and anti-inflammatory against psoriasis (Al-Ashaal, 2019; Kumar et al., 2012). It prevented cervical carcinoma and showed schistosomicidal effect against *S. mansoni*, and fasciolicidal effect against *Fasciola hepatica*. Additionally, it has an inhibitory effect against HSV-1 (Al-Ashaal, 2019). Steroidal alkaloid solanine A from *S.*

scabrum demonstrated anti-inflammatory activity on Institute of Cancer Research mice (ICR) or albino mice and suppressed the production of nitric oxide in lipopolysaccharide/interferon γ-activated RAW264.7 cells (Zhao et al., 2018).

For a long time, phytate is considered an antinutrient, but recent studies have proven its antioxidant properties (Bhowmik et al., 2017; Mora-Boza et al., 2019; Silva & Bracarense, 2016; Wang & Guo, 2021). Phytate exhibits therapeutic properties on various diseases such as Alzheimer's (Abe & Taniguichi, 2014), Parkinson (Xu et al., 2011), and management of blood glucose for type 2 diabetes (Lee et al., 2006). Similarly, phytate exhibits anticancer properties against the prostate (Raina et al., 2008), hepatocarcinoma (Al-Fatlawi et al., 2014), colorectal (Navarro et al., 2016), rhabdomyosarcoma (Vucenik, 1998), skin (Wawszczyk, 2015), and breast (Hussein et al., 2006) cancers. Besides, it acts as an antibacterial against *Enterococcus faecalis* (Nassar & Nassar, 2016), anti-HIV (Tateishi et al., 2017), and hypolipidemic (Dilworth et al., 2005). Also, it inhibits lipid peroxidation due to its high affinity to multivalent cations (Mora-Boza et al., 2019). Phytate is used in food industries as a molecular binder and functional ingredient, that is, it aggregates proteins and increases precipitation or turbid (Wang & Guo, 2021). The daily intake of 1–2 and 8–12 g of phytate possess a prevention effect on cancer and antitumor therapies (Vucenik & Shamsuddin, 2006). Further studies should explore the benefits of phytate, such as health and functional benefits, instead of addressing the general concept of phytate as an anti-nutrient.

Tannins are a group of phytochemicals (polyphenols) with an astringent taste and are present in various concentrations in vegetables and herbs (Amalraj & Pius, 2015; Khanbabaee & van Ree, 2001). Tannins are water-soluble polyphenols present in many plant foods. Tannins have various health benefits such as antioxidants, cardioprotective, anti-inflammatory, antiviral, antibacterial, anticarcinogenic, antimutagenic, and antidiabetic (Chung, 1998; Delimont et al., 2017; Khanbabaee & van Ree, 2001; Sharma et al., 2019). They also help heal wounds, cures dysentery, and help in hardening arteries (Sharma et al., 2019); nevertheless, it is an antinutrient.

5 | ANTINUTRITIONAL FACTORS OF ANS

ANS contains antinutritional factors such as oxalates, tannins, cyanogenic glycosidase, phytate, glycoalkaloids, and nitrates (Table 5) (Amalraj & Pius, 2015; Essack et al., 2017; Mwanri et al., 2018; Wakhanu et al., 2015). Some of them, for example, tannin, phytate, and glycoalkaloids, exhibit functional properties, for example, anticancer, antibacterial, antivirus, and anti-inflammatory properties (Delimont et al., 2017; Silva & Bracarense, 2016), also elaborated in Section 4.2. The oxalate and phytate contents vary with the maturity stage in *S. villosum* (Silva & Bracarense, 2016). *Solanum villosum* (Nduruma BG 16 and Olevolosi SS 49) had the highest oxalate and phytates content, with a nonsignificant decrease in nitrate content at 35 days (Mwanri et al., 2018). Most of the Solanaceae family species are poisonous to humans and livestock (Jain et al., 2011). For instance, the deadly nightshade (*Atropa belladonna* L.) contains tropane alkaloids. Solanine glycoalkaloids in *S. nigrum*, *S. villosum*, *S. americanum*, and *S. scabrum* significantly cause toxicity (Jain et al., 2011). Notably, various ANS processing methods such as boiling, drying, and fermentation effectively remove antinutritional factors (Essack et al., 2017).

5.1 | Phytate in leaves

Phytate is an antinutrient when present in higher concentrations (Bhowmik et al., 2017). Phytate can chelate with divalent/trivalent metal ions such as zinc, copper, calcium, and iron and reduce bioavailability (Silva & Bracarense, 2016). *Solanum nigrum* contains the highest phytate content with the lowest in *S. villosum* (Table 5). The calculated molar ratio of phytate:iron was 0.09 in *S. nigrum*. An increase in ANS leaves' phytate content from 0.04 mg/100 g DW in days 21 grown to 0.3 mg/100 g DW in 35 days was reported (Mwanri et al., 2018). Therefore, harvesting at the right maturity is crucial for ANS nutritional quality. The molar ratio above 0.4 has a significant effect on iron bioavailability (Dahdouh et al., 2019; FAO/IZiNCG, 2018). Therefore, the molar ratio was meager to cause the chelating effect of iron in ANS. The phytate intakes reported in the United Kingdom were 692 to 948 mg/day in men and 538 to 807 mg/day for women. The daily phytate requirement for vegetarians is 1600 to 2500 mg/day (European Food Safety Authority [EFSA], 2014). Fermentation, germination, soaking, malting, boiling, solar, and pressure cooking are simple, inexpensive, and convenient techniques for the removal of phytates in ANS (Abdulwaliyu et al., 2019; Essack et al., 2017; Owade et al., 2019; Pasrija & Punia, 2010; Rasane et al., 2015; Wang & Guo, 2021). Water blanching at 95 °C and steam blanching of ANS for 5 min reduce phytate concentration by 25% to 75% (Managa et al., 2020). Besides, enzyme degradation using phytase is the most effective and applicable way to remove phytate (Wang & Guo, 2021). Phytate in unprocessed foods does not reflect the actual quantity consumed; therefore, more emphasis should be placed on assessing phytate in ready-to-eat foods rather than its content in raw forms (Abdulwaliyu et al., 2019).

5.2 | Oxalate in leaves

As an antinutrient, oxalate chelates minerals such as potassium, sodium, and calcium, forming insoluble complexes, thus hindering their absorption. Insoluble calcium oxalate can cause joint pains, kidney stones, and kidney failure (Holmes & Kennedy, 2000; Judprasong et al., 2006; Soto-Blanco et al., 2009). The oxalate content of ANS can go up to 776.2 mg/100 g DM (Table 5); however, the fatal doses range from 1 to 30 g per person (Dassanayake & Gnanathasan, 2012; EMEA, 2004). The oxalate content in ANS ranges from 28.7 to 776.2 mg/100 g DW or 3.7 to 100.9 mg/100 g FW. *Solanum nigrum* contains the highest oxalate content and *S. scabrum* the lowest (Table 5). This amount is lower than the fatal dose, but it is still a concern regarding the risk of toxicity; therefore, monitoring ANS leaves' oxalate levels is necessary. Nonetheless, the amount of oxalate in ANS leaves is significantly lower than in some exotic vegetables (Akhtar et al., 2011; Faudon & Savage, 2014). Fermentation and boiling reduce oxalate content in ANS and other AIVs (Essack et al., 2017; Muchoki et al., 2010; Owade et al., 2019; Wakhanu et al., 2015). Likewise, blanching at 95 °C and steam blanching for 5 min reduce oxalate in ANS by 42% to 75% (Managa et al., 2020). Moreover, the early harvesting stages (21 days) show lower oxalate content (42.9 mg/100 g DW) than the late stages of 35 days (60.9 mg/100 g DW) (Mwanri et al., 2018). Therefore, proper harvesting times and selection of ANS varieties should be the criteria for obtaining leaves with low oxalate content.

5.3 | Tannins in leaves

Tannin, either nonhydrolyzable (condensed) or hydrolyzable (Sharma et al., 2019), forms a complex with proteins, digestive enzymes, starches, and minerals, thus reducing food's nutritional value (Chung, 1998; Polycarp et al., 2012). Tannin is responsible for decreasing feed intake, feed efficiency, protein digestibility, and net metabolic energy. It also increases the excretion of protein and essential amino acids, damages the mucosa lining of the gastrointestinal tract, and alters cations' excretion (Chung, 1998). Tannins are toxic when precipitating with heavy metals and alkaloids (Khanbabaee & van Ree, 2001; Sangija & Wu, 2020). Tannin causes a browning reaction (darkening of food) due to polyphenol oxidase (Chung, 1998). Tannin at a concentration of 0.13 to 1 g/kg body weight (BW) decreases erythrocyte counts in pigs' hemoglobin and hematocrit (Lee et al., 2010). Tannin content above 3 g/100 g caused mortality in test chicks (Chung, 1998). Tannin also causes liver, skin, oesophageal, stomach, lung, kidney, and nasal cancers in humans (Chung, 1998). The RDA of proanthocyanidin (tannin) is 53.6 to 450 mg/person/day and 1250 mg/person/day for hydrolyzable tannins in the Spanish population. Nevertheless, the total tannin content of *S. nigrum* of 360.1 mg/100 g DW or 46.81 mg/100 g FW is relatively low to harm the consumers. Therefore, consumption of ANS is safe with potential health effects. In case of sufficient tannin content to cause potential health problems, cooking is an effective removal method because it is heat-labile and facilitates its degradation (Essack et al., 2017; Kakati et al., 2010; Owade et al., 2019; Serrano et al., 2009). Further, lactic acid fermentation, drying, canning, boiling, soaking in water, and freezing can also remove tannins (Essack et al., 2017; Serrano et al., 2009). Managa et al. (2020) reported a decrease in tannin content by 7% to 14% through blanching at 95 °C and steam blanching for 5 min.

5.4 | Nitrates/nitrites in leaves

Fruits and vegetables are the significant nitrate/nitrite sources and contribute 50% to 85% of overall dietary intake (EFSA, 2008; Nuñez et al., 2015). Several fruits and vegetables contain 200 to 2500 mg of nitrate per kilogram (WHO, 2003). Nitrates/nitrites are easily absorbed in the body; about 60% to 70% are excreted in the urine, whereas 3% appear in the urine as urea and ammonia (Karwowska & Kononiuk, 2020). In the stomach, blood, and tissue, nitrates are converted into bioactive reactive nitrogen oxide species (NO). The reactive NO contributes to the formation of carcinogenic nitrosamines of toxicological importance (Ding et al., 2018). Nitrates can contribute to carcinogenic, such as breast cancer, gastric cancer, renal cell carcinoma, adult glioma, colorectal cancer, esophageal cancer, and thyroid cancer (Karwowska & Kononiuk, 2020; Keszei et al., 2012; Yang et al., 2017). Besides, it contributes to genotoxicity, cytotoxicity, inhibition of enzymatic reactions and proteolysis, and altered immunogenicity (D'Ischia et al., 2011). Antioxidants, such as vitamins C and E, inhibit nitrosamines' generation (Ding et al., 2018; Karwowska & Kononiuk, 2020). Mwanri et al. (2018) reported the nitrate content of 630 to 856 mg/kg DW in *S. villosum*; however, there is limited information on leaves of other ANS species. Some exotic vegetables such as spinach, rucola, celery, rhubarb, lettuce, beets, chard, and beetroot contain significantly higher nitrates than ANS (Karwowska & Kononiuk, 2020). Seasonality and the cultivation systems contribute to nitrites variation in ANS. Late harvested Nduruma BG 16 and Olevolosi SS

49 showed lower nitrate content than early harvested ones (Mwanri et al., 2018). Similarly, the nitrate content was higher in 21-day harvested leaves (856 mg/kg DW/111.3 mg/kg FW and significantly lower at day 35 (754 mg/kg DW/98 mg/kg FW) (Mwanri et al., 2018). Therefore, farmers should consider late harvest for lower nitrate content in ANS. Human generally consumes between 1.2 and 3.0 mg of nitrite daily (WHO, 2016). The RDA of nitrite and nitrates is 0.06 to 0.07 mg/kg BW/day and 7 mg/kg BW/day, respectively (Karwowska & Kononiuk, 2020).

Therefore, the nitrate content in ANS leaves is low comparing to the RDA (Table 5). Besides, the consumption of more than 600 to 700 g of ANS per day is beyond the RDA of nitrate and can cause health effects. The application of heat treatments, high-temperature storage conditions, and fermentation reduced nitrate content in vegetables (Ding et al., 2018; Prasad & Chetty, 2011), similarly to ANS leaves.

5.5 | Glycoalkaloids in leaves

The solasonine, solanine, solamargine, and chaconine are major glycoalkaloids in the ANS, with steroidal glycoalkaloids (SGAs) as minor (Ronoh et al., 2017). Glycoalkaloids are toxic to humans and animals with symptoms such as constipation, dark-colored diarrhea, nausea, vomiting, and abdominal pain. These toxins affect the nervous system to cause drowsiness, apathy, weakness or paralysis, salivation, circulatory and respiratory depression, and unconsciousness. Toxic effects are primarily irritation of the digestive tract and sometimes neurological problems. (Abbas et al., 1998; Defelice, 2003; Mensinga et al., 2005). Young leaves and unripe berries of ANS have a higher SGA concentration than matured ones (Ronoh et al., 2017). The SGA is associated with bitterness in ANS and causes toxic effects to animals when consumed above 5 mg/kg BW (Ronoh et al., 2017). The recommended upper limit of total glycoalkaloids (TGA) in plant foods is 200 mg/kg FW (1 g/kg DW) (Nono-Womdim et al., 2012). Alkaloid content in *S. nigrum* and *S. villosum* is 1722 and 1448 mg/100 g DW, respectively (Table 5). The quantity of solanine in *S. nigrum* and *S. villosum* is 470 and 150 mg/100 g DW, respectively (Mohy-Ud-Din et al., 2010). This content is significantly low to cause a potential toxic health effect on humans. Also, Yuan et al. (2018) reported a solasodine content of less than 5 mg/100 g DW and 1 mg/100 g FW in *S. nigrum* and *S. scabrum*, respectively. This amount is low compared to other vegetables such as eggplant (6.25 to 20.5 mg/100 g FW) (Yuan et al., 2018). The SGA solasodine is absent in *S. scabrum* (Yuan et al., 2018; Yuan, Dinssa, et al., 2020). According to Yuan, Lyu, et al. (2020), the levels of total alkaloids in *S. nigrum*, *S. villosum*, and *S. scabrum* are safe for human consumption. Alkaloids content in ANS leaves can be removed by boiling (Defelice, 2003; Edmonds & Chweya, 1997; Essack et al., 2017). The TGA content in *S. scabrum*, *S. villosum*, and *S. tarderemotum* leaves is 116.80, 100.82, and 112.97 mg/kg FW, respectively, with no maximum toxic levels of SGAs (Mwai, 2007). It is noteworthy that several factors such as the amount of TGA eaten, BW, and metabolism rate of SGA facilitate its toxicosis (Nono-Womdim et al., 2012).

Breeding and genetic improvement would also remove the toxicity commonly associated with ANS, that is, mainly attributed to SGA presence (Nono-Womdim et al., 2012). Although SGAs are harmless and enhance the flavor at low levels, they cause toxicity and even death in animals and humans at a high dose. TGA content above 140 mg/kg FW is associated with unpleasant flavor and bitter taste (Nono-Womdim et al., 2012). In Tanzania and Kenya, several improved cultivars of *S. scabrum* and *S. villosum* are available (https://www.tosci.go.tz/; Dinssa et al., 2016; Ojiewo, Mbwambo, et al., 2013; Ronoh et al., 2019). *Solanum scabrum* has a less bitter taste with large succulent and broad leaves (Figure 1), high seed yield, rapid new leaf sprouting after harvest, late flowering, and 40 days' maturity, and picking can continue for 6 to 8 weeks. Besides, it is resistant to *Fusarium* wilt (Nono-Womdim et al., 2012; Ojiewo, Mbwambo, et al., 2013; https://www.tosci.go.tz/). *Solanum villosum* is bitter, with a narrow and low yield than *S. scabrum*; also, it has broad leaves and high yield than the original variety (Figure 1). People in rural areas, old peoples, and men prefer bitter variety; therefore, all varieties fetch the same demand in the market. Nduruma and Olevolosi leaves contain no glycoalkaloid aglycone; therefore, they are safe for consumption. Moreover, these varieties have high total phenols and high vitamin E and β-carotene (Yuan et al., 2018).

5.6 | Glycoalkaloids in berries

ANS berries are commonly considered toxic and not consumed in SSA (Lyu et al., 2020). The young berries of *S. nigrum* contain the highest level of SGA compared with the whole plant or leafy and stem parts (Abbas et al., 1998; Defelice, 2003; Edmonds & Chweya, 1997; Mohy-Ud-Din et al., 2010; Ronoh et al., 2017; Yang & Ojiewo, 2013). The toxic level of matured berries is too low to harm but can harm children (Defelice, 2003; Edmonds & Chweya, 1997). *Solanum nigrum* accession (USDA PI 381239) contains trace levels of glycoalkaloids (Lyu et al., 2020). However, the glycoalkaloids (solasodine, solanine, and solamargine) are high in berries compared to shoots and leaves of *S. nigrum*, with solasonine being high in the shoots of *S. nigrum* (Al-Ashaal, 2019). Glycoalkaloids in unripe berries of *S. nigrum* are equivalent to 356 mg/100 g DW. Environment conditions such as frost contribute to a significant increase in glycoalkaloids by five to 15 times higher than mature berries. Yuan, Lyu, et al. (2020) reported a solasodine content of 380 to 930 mg total aglycone/100 g DW in unripe berries but was not detected in ANS leaves. This variation could be attributed to genetic diversity, environmental conditions, and cultural practices (Ojiewo, Mwai, et al., 2013). Glycoalkaloid concentration is low in matured berries. *Solanum scabrum* mature berries contain up to 1500 mg of glycoalkaloids (Yuan et al., 2019). Such a high concentration of glycoalkaloids in berries could be essential for medicinal purposes (Al-Ashaal, 2019). Mature berries of some accessions contain low amounts of glycoalkaloids and could be potential for consumption in SSA. For such, the promotion of berry products for consumption is essential. Therefore, intensive research in breeding for selecting desirable lines and subsequent cultivars for release ensuring the quality of the final product and safety to consumers is mandatory (Yuan, Dinssa, et al., 2020; Yuan, Lyu, et al., 2020).

5.7 | Cyanogenic glycosidase in leaves

When hydrolyzed, cyanogenic glycosidase produces the toxic hydrogen cyanide (HCN) (Selmar, 2018). Only *S. nigrum* contains cyanogenic glycosidase (Table 5), which is of safety concern. HCN inhibits cytochrome oxidase in the mitochondria. Also, it interacts with copper and iron ions to inhibit respiration and the inability to produce adenosine triphosphate (Sangija & Wu, 2020). Cyanide intoxication can cause mental confusion, diarrhea, vomiting, stomach pains, dizziness, diaphoresis, cardiac arrest, and rapid respiration (Gracia & Shepherd, 2004; Venketesh, 2014). A chronic low dose of cyanide may cause an elevation in the blood and induces a variety of symptoms such as kidney or mild liver damage (Manzano et, al., 2007), miscarriage (Soto-Blanco et al., 2009), hypothyroidism (Soto-Blanco et al., 2009), paralysis, nervous lesions, and weakness (Soto-Blanco et al., 2002, 2008). The fatal dose of HCN can be as low as 0.5 to 3.5 mg/kg/BW (EFSA, 2019; Essack et al., 2017). In contrast, the cyanide content of *S. nigrum* is 320 mg/100 g FW (Essack et al., 2017); moreover, no information is available for other ANS species. HCN content in ANS is significantly low compared to that in raw cassava leaves (1905 mg/kg) (Umuhozariho et al., 2014). FAO (2005) suggested an acceptable limit of 500 mg/kg HCN, whereas the EFSA (2004) considers the maximum of 10 mg/kg HCN to be safe for human consumption. Fresh ANS contains low HCN content to cause potential health effects as per (FAO, 2005). Cassava leaves' cooking reduces HCN similar to ANS (Umuhozariho et al., 2014).

6 | SAFETY REGULATIONS FOR ANS

ANS safety is still a challenge, with a risk of toxicity to consumers if consumed at a high dose. Some ANS leaves accessions contain glycoalkaloids, potentially causing health concerns (Sivakumar et al., 2020). To date, there are no policy issues, regulations, or bay laws guiding the safety of consuming ANS in SSA or other parts of the world (Nono-Womdim et al., 2012). Therefore, the SSA countries need to develop and implement policies and strategies to promote sustainable production and ANS safety (Abukutsa-Onyango, 2010). There is a need for policy-makers at the national, regional, and international levels to address the significant safety issues on ANS to attain maximum benefits. The EFSA, FAO, and WHO have set guidelines for minimal levels of toxic compounds such as GA, HCN, nitrate, and nitrites in foods. Therefore, these guidelines can be used as a benchmark in preparing safety regulations for ANS in SSA. Further, intensive research is needed to generate data on the toxic compounds and their levels in *Solanum* spp.

7 | THE UTILIZATION OF ANS

7.1 | Leaves

In some societies, the consumption of ANS is influenced by the consumer's local beliefs. For instance, most people in Kenya consume ANS believing that it is nutritious and healthy (Abukutsa-Onyango, 2015). ANS uses differ in SSA; however, it is used for leafy vegetables, medicinal, cosmetic, and spiritual purposes (Abukutsa-Onyango, 2007; Keller, 2004; Ontita et al., 2017; Yang & Ojiewo, 2013). Generally, ANS consumption is based on availability, taste, and affordability (Sato et al., 2002).

Consumption of ANS in some African societies is associated with hunger, shortage of food, and poverty; therefore, eating them is regarded as humiliating (Shackleton et al., 2009). Abukutsa-Onyango (2015) observed that most Western and Nyanza provinces in Kenya prefer ANS for its nutritional value. In Tanzania, moreover, ANS is highly consumed by the wealthiest households for their known nutritional and health benefits (Ambrose-Oji, 2009). ANS is generally said to be more palatable for adults, especially the old age group (Ontita et al., 2017; Onyango et al., 2016). Nevertheless, some parts of ANS are toxic to humans and livestock, including youngberries, which contain a high concentration of alkaloids (Kuete et al., 2017; Ronoh et al., 2017).

In Kenya, ANS is used spiritually by older men to pronounce a curse on an offender (Ontita et al., 2017). ANS are consumed based on gender, whereby men prefer bitter dark variety. Some consume to recover the lost or poor appetite due to illness (Ontita et al., 2017; Shackleton et al., 2009). However, wrong beliefs, perishability, environmental degradation, limited storage, poor infrastructure, draughts, markets, arable land shortage, diseases, pests, and high production costs are factors hindering ANS utilization (Ayua & Omware, 2013; Ondieki et al., 2011). Henceforth, research on how to address the constraints to the utilization of ANS is mandatory.

7.2 | Berries/fruits

Green, orange, yellow, purple, red, black, and violet berries are edible; they can be consumed raw, at the same time, the juice of ripe berries is used as ink by children (Edmonds & Chweya, 1997). The berries are used as an ingredient in pies, food colorants, preservatives, and substitute for raisins in plum puddings (Edmonds & Chweya, 1997; Lotter et al., 2014; Schippers, 2002; Yang & Ojiewo, 2013). Berries can sometimes be mixed with colorful fruits such as apples. Also, berries can make a nice jam and preserve tea with bread and butter (Edmonds & Chweya, 1997; Yang & Ojiewo, 2013). Occasionally, the berries are used as a vegetable in soup, yam, and cocoyam porridges in some parts of Nigeria (Akubugwo et al., 2007). The berries are processed into value-added products, such as beverages, juices, jams, and nectars for international markets (Akinola et al., 2020).

8 | ROLES OF ANS IN HEALTH PROMOTION AND PROTECTION

8.1 | Leaves

Different ANS species and parts have various medicinal functions (Yang & Ojiewo, 2013). The leaf extracts of *S. americanum* relieve chronic conjunctivitis, treat sores, heart pain, skin problems, and treat worms in chicken. Simultaneously, the leaf extracts of *S. scabrum* treat diarrhea in children and cure jaundice and eye infections. Also, the leaf extracts of *S. villosum* treat stomach aches, tonsillitis, wounds, leucorrhea, nappy rash, as well as an ointment for boils (Zahara et al., 2019). Fresh leaves or cooked or leaf juice can also be taken orally as a liver tonic or used to treat indigestion, stomach ache, and stomach ulcers (Jain et al., 2011). In Kenya, ANS is used to heal ailments relating to stomach complications (Abukutsa-Onyango, 2015). Leaves are eaten raw for heart pain and swellings; also, the leaf extract restores body skin pigment. Fermented leaves treat boils, ulcers, and swollen glands. ANS leaves also treats tonsillitis, swelling, and conjunctivitis. The Xhosa also use ANS for disinfecting anthrax-infected meat (Edmonds & Chweya, 1997).

In European traditional medicine (TM), nightshades are potent analgesic, sudorific, and sedative, containing powerful narcotic properties. In Indian tradition, the nightshades have been used as medicines to cure stomach complaints, dysentery, fever, and tuberculosis (Kaushik et al., 2009; Kuete et al., 2017; Lotter et al., 2014). TM is "the total of knowledge, skills, and practices based on the theories, beliefs, and experiences indigenous to different cultures that are used to maintain health, as well as to prevent, diagnose, improve, or treat physical and mental illnesses" (Che et al., 2017). TM has gained popularity in the last few decades and continued to be useful for the poor's primary health care in SSA (Lezotre, 2014; Sivakrishnan, 2018).

The juice of the ANS leaves cures ulcers and other skin diseases. The BNS is used broadly as antitumorigenic, antioxidant, anti-inflammatory, hepatoprotective, diuretic, and antipyretic agent (Jain et al., 2011; Kuete et al., 2017). The *S. nigrum* leaves are used to treat fungal skin infections, reduce stress, relieve joint pain, treat malaria, and recover lost food appetite (Jain et al., 2011; Kuete et al., 2017; Ontita et al., 2017). The bitter dark green leaves are used for an alcohol-related hangover (Jain et al., 2011; Ontita et al., 2017). Also, ANS can treat the new circumcised patient and pregnant and lactating mothers (Ontita et al., 2017). Leaf paste is applied directly to rabies for healing wounds (Jain et al., 2011). Aqueous extracts of leaves from both *S. villosum* and *S. nigrum* var. *sarrachoides* possessed significant antidiabetic effects in the Streptozotocin-induced diabetes mice model (Nyaga et al., 2019; Nyaga, 2020).

8.2 | Berries and roots

The ripe berries of edible ANS are anticarcinogenic; other plant parts are also used as TM (Kuete et al., 2017). The raw berries of *S. scabrum* treat stomach aches and stomach ulcers. They are also used as a tonic, laxative, remedial for asthma, and restoring appetite, especially for people who recover from disease (Jain et al., 2011). Unripe berries relieve aching teeth and reduce the pain of babies' gum during teething. The juice of berries treats sore eyes. *Solanum nigrum* berries and juices cure stomach ailments, blood impurities, and fevers. In East Africa, the raw berries treat stomach ulcers or general abdominal upsets (Edmonds & Chweya, 1997; Yang & Ojiewo, 2013). A mixture of ground ANS leaves and seeds is scrubbed onto the gums of children with crooked teeth. In Tanzania, unripe berries treat ringworms and roots for stomach ache. The Zulus use an infusion as an enema for abdominal upsets in children. The burnt and powdered root is rubbed to scarification on the back for the relief of lumbago. Unripe berries paste is used to treat ringworm (Edmonds & Chweya, 1997; Yang & Ojiewo, 2013). The berries have been used as ancient Indian medicine to treat inflammation, diuretics, and tuberculosis (Kaushik et al., 2009). In Tanzania, the ripe berries in the edible form are given to kids to stop bed-wetting (Jain et al., 2011). However, in Algeria, berries' diluted infusion treats blindness, conjunctivitis, glaucoma, trachoma, and cataract (Jain et al., 2011). The berries juice calms sore eyes, whereby the unripe berries soothe toothache (Yang & Ojiewo, 2013).

In contrast, the juice from roots treats cough and asthma. In many African cultures, various plant roots are used in traditional, complementary, and alternative medicine (Akinola et al., 2020). Berries and roots can control vomiting and treat tetanus after abortion and can also be used as sedatives (Ogwu et al., 2016). In India, consuming boiled roots with a little sugar increases fertility in women, whereas the juice of roots is extracted and used to cure asthma and whooping cough (Jain et al., 2011). Children take the tonic obtained after boiling roots in milk.

9 | TRADITIONAL METHODS FOR PREPARATION OF ANS

Processing and preservation (PaP) of ANS can compensate for the low availability of vegetables during the off-season, hence improving the nutritional shortage during these seasons (Engle & Altoveros, 1999). Most of the ANSs are nutritious if well cooked, although the preparations and cooking methods significantly affect the nutritional contents (Keller, 2004; Ngegba, 2007; Oluoch et al., 2012). Therefore, it is necessary to develop recipes for optimizing nutritional value, increasing ANS intake, and reducing iron deficiency in children, pregnant women, children, and nursing mothers in SSA (Oluoch et al., 2012). A correlation between taste and appearance was observed in Kenya. Singly prepared ANS or combined with other vegetables did not influence sensory acceptability, although a mixture of ANS and cowpea increased carotenoids and vitamin C (Habwe, 2008; Habwe et al., 2008; Oluoch et al., 2012). Stir-frying can be the best method of retaining vitamin C, copper, and iron, although mixing slender leaves in ANS reduce iron content (Habwe et al., 2008). In Tanzania, different recipes for the preparation of ANS exist, making use of variable quantities of ingredients; hence, it is difficult to obtain a standard recipe to be adapted (Weinberger & Msuya, 2004). Traditional recipes for the preparation of ANS vary among different communities in SSA (Figure 2).

In Tanzania, ANS is cooked by stir-frying or steaming, with ingredients such as milk, coconut milk, peanut, carrots, sweet pepper, onion, tomatoes, and peppers (Keller, 2004; Ngegba, 2007). Similarly, ANS can be prepared by boiling and adding milk or cream for enrichment or boiling and frying with onions, tomatoes, spices, and salt (Figure 2). In Kenya, most local consumers boil the leaves and add salt and milk to improve taste (Ontita et al., 2017; Yang & Ojiewo, 2013). Furthermore, ANS can be mashed with potatoes or boiled with sweet potatoes, tuber, milk, pumpkin, and blood or immature gourd (Ontita et al., 2017). In Senegal, ANS is cooked with meat or fish (Figure 2) (Chagomoka et al., 2014; Keller, 2004; Shackleton et al., 2009). Besides, cooking of ANS with meat can increase cooking time and facilitate the degradation of vitamins B and C, β-carotene, and iron. Diabetic consumers prepare ANS by boiling and adding milk, but neither fry nor add salt for health reasons (Ontita et al., 2017).

Traditional cooking methods can retain carotenoids in a range between 16% and 70%, whereas long cooking and reheating of cooked ANS reduce carotenoids and iron (Oluoch et al., 2012). Various cooking methods can degrade some essential micronutrients (Table 2), such as iron, β-carotene, and vitamin C (Ngegba, 2007). In East Africa, ANS can be cooked with other vegetables such as spinach, kale, amaranth, and cabbages (Figure 2) and accompanied with staples such as stiff porridge (*ugali*), rice, yams, banana, and cassava (Abukutsa-Onyango, 2007; Schippers, 2002; Yang & Ojiewo, 2013).

Most studies have focused on ANS production aspects and forget different cooking methods, consequently altering the nutritional and functional properties. The absence of suitable recipes and information on proper use led to the low utilization of ANS and distortion of essential nutrients. Formulation of appropriate ANS recipes can maximize nutrient availability, eliminate seasonality, and guarantee their availability yearly. Additionally, it can reduce losses and improve dietary diversification, contributing to nutrition and food security.

10 | ANS VALUE CHAIN

ANS is common in rural and urban markets in Africa, especially in Cameroon, Kenya, Ghana, Burkina Fasso, Madagascar, Nigeria, South Africa and Tanzania, Guatemala, New Guinea, and the Mediterranean (Edmonds & Chweya, 1997; Essack et al., 2017; Ojiewo, Mbwambo, et al., 2013). ANS is highly demanded and expensive than many vegetables, such as kale or spinach (Onyango et al., 2016). The AIVs value chains play a significant role in food

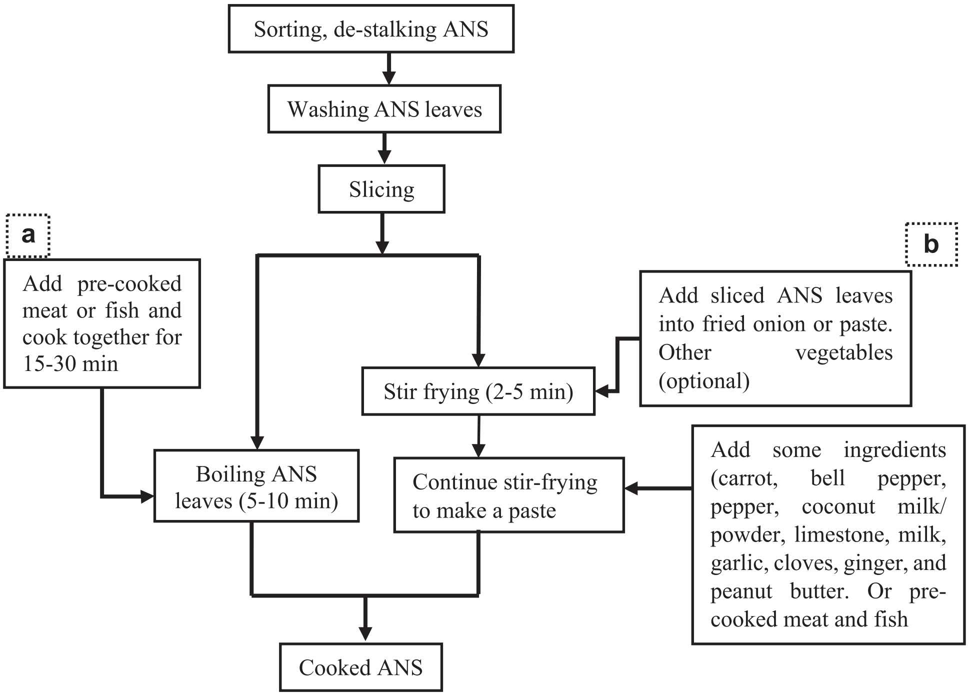

FIGURE 2 Recipes for ANS preparation in different SSA communities: (a) boiling and (b) frying
Sources: Chagomoka et al. (2014); Keller (2004); Ngegba (2007).

security and poverty reduction. ANS supports a large number of microbusinesses along the supply chain (Ojiewo, Mbwambo, et al., 2013). Nevertheless, it is yet to penetrate the international market (Edmonds & Chweya, 1997). ANS faces typically stiff competition with other exotic vegetables such as cabbage, spinach, amaranths, kale, and lettuce (Abukutsa-Onyango, 2007); moreover, lack of formal reports on its value chain is the bottleneck. According to Gogo et al. (2017), the standard chain level of AIVs in SSA includes harvesting, transportation, and marketing. However, the lack of PaP in the chain limits AIVs utilization, ANS inclusive. Therefore, mapping the ANS value chain is vital to create well-functioning linkages between different actors for mutual benefits. In Eldoret, Kenya, consumers prefer to purchase ANS over exotic vegetables; however, the ANS price varies between towns. In the open market, the price for a bunch of ANS is Kenyan shilling (KSH) 18.8, whereas in the supermarket, the average price is KSH 34 (Chelang'a et al., 2013). In Tanzania, the wholesale price for an AIVs bunch of 40 to 50 kg is 20,000 Tanzanian shillings (TZS) (US$12.50) and can even fetch a low price of 10,000 TZS (US$6.25) during the bumper season (Lotter et al., 2014). The price of selling 1 kg of ANS is between 517–1065 TZS (Everaarts et al., 2017; Molina et al., 2020). The prices of 1 kg of ANS vary in different seasons and stages of the value chain: farmgate (400 to 1350 TZS), wholesalers (2200 TZS), and retailers (2400 TZS) (Molina et al., 2020). During the rainy season, a bed of AIVs of the same size can be sold at a wholesale price of up to 100,000 TZS (US$62.50) as rain disrupts production (Lotter et al., 2014). Generally, the value chain and distribution channels for ANS are not well established in SSA. A value chain analysis in Kenya earmarked supermarkets and local markets as key distribution channels for ANS. Smallholder farmers can directly supply ANS to retailers or wholesalers, and supermarkets with no specific entry point (Figure 3). Besides, the supply of AIVs is from the small farmers to different outlets (Figure 3). Lack of appropriate infrastructure, market information, extension services, acceptable products, and storage facilities hinders the proper distribution of AIVs (Senyolo et al., 2018; Temu & Temu, 2005).

In Tanzania, the ANS value chain is an informal sector where its marketing involves small-scale producers, retailers, and whole sellers. PHL is low in the market with a robust sales system, which keeps in touch producers, buyers, and retailers with their customers daily (Lotter et al., 2014; Shackleton et al., 2009). The use of mobile phones facilitates the selling of ANS because producers can keep in touch with the middlemen, retailers, and wholesalers (Edmonds & Chweya, 1997). Most Tanzania retailers sell on an average of 1.5 kg of ANS, with 62% of all retailers store unsold produce for the next day (Lotter et al., 2014). Men can sell 3 kg per day more than women, despite female dominance (96%) in ANS marketing. The sales volume has a significant effect on location, with an average of 2 kg per day in Dodoma and more than 5 kg in Arusha (Lotter et al.,

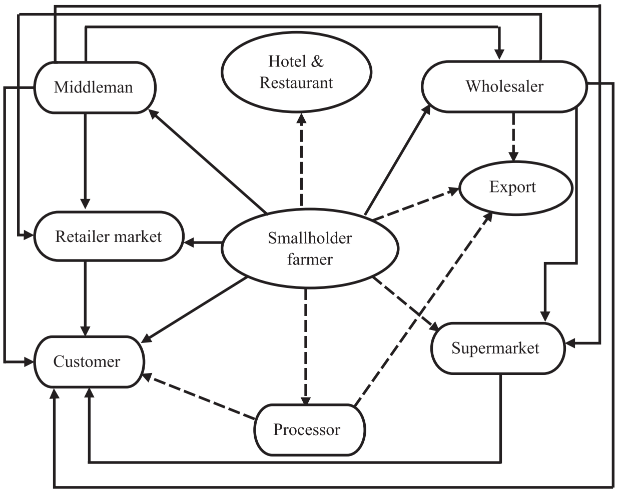

FIGURE 3 The traditional AIVs value chain in SSA. Dotted arrows indicate occasional pathway. Black arrows indicate the common pathway
Sources: Acedo and Katinka (2009); Sangija et al. (Unpublished).

2014). Furthermore, sellers at district and ward markets sell 2 kg more than a seller at a street stall (Lotter et al., 2014).

Over 60% of farmers in Kenya and Tanzania were able to market the ANS and penetrate several markets. The majority of farmers in East Africa have changed their perception of production ANS for family use and shifted to business production to support their families and improve livelihood. Commercializing of ANS has been considered a profitable business by most farmers because it has many benefits, including the low use cost, less infestation by pests and diseases, high maturity, high consumer demand, and market opportunities (Muhanji et al., 2011). Economic returns from the use of ANS as vegetables have not yet been quantified, hence the low market price and a low economic value (Edmonds & Chweya, 1997).

On the other hand, the annual mean profit obtained by small-scale farmers from selling ANS in Kenya ranges from 5641 to 141,144 KSH (US$564.12 to US$1411.44) (Onyango et al., 2016). The profitability of ANS in Kenya is estimated to be US$754/month and US$766/ha (Mwangi & Kimathi, 2006). Production of ANS gives high yields and low fertilizer application than other exotic vegetables (Everaarts et al., 2017). The annual profit based on producing 1 ha of ANS in Tanzania was 8,129,280 TZS/ha/year (US$3505.51) (Everaarts et al., 2017). However, Molina et al. (2020) reported an annual net value of 5,612,042.25 TZS (US$2420.02), higher than exotic vegetables, Chinese cabbage, and spinach. The relatively high ANS price maintained yearly around in all markets, traders, and farmers signifies its preference and demand (Molina et al., 2020). This further shows the potential of ANS in improving the livelihood of people in SSA; therefore, exploiting its value chain is necessary to maximize the benefits of all actors.

11 | POSTHARVEST HANDLING

ANS needs proper handling after harvesting to maintain the quality before processing or being sent to the market (Arah et al., 2016). Harvesting is recommended in the morning with no dew or late in the evening (Abukutsa-Onyango, 2015). Because ANS is highly perishable, the chance of spoilage increases rapidly with time, mainly when poorly handled (Onyango & Imungi, 2007). Therefore, cooling is mandatory to remove field heat within a short period. The traditional cooling methods include putting the vegetable under the shade, sprinkling with water, and dipping in water (Figure 4) (Gogo et al., 2016). Water sprinkling has proven effective in quickly removing field heat and maintaining freshness for a longer time (Arah et al., 2016; Gogo et al., 2016). The chance of ANS deterioration increases within 24 hr if not immediately sold after harvest. Some farmers/sellers sprinkle water and leave the vegetable in the open space overnight; however, the problem of microbial contamination still hinders their effort (Gogo et al., 2016). Excessive field heat increases metabolic activity, favors microbial activity, and increases respiration rate and ethylene production (Akbudak et al., 2012).

After harvest, cleaning, sorting, de-stalking, grading, and packaging of ANS are performed. Cleaning of ANS is necessary to remove any dirt or residue particles and microbial contamination agents (Nyaura et al., 2014). However, most farmers forget to dry leaves after washing and consequently encounter a higher prevalence of microbial contamination, mainly fungi and bacteria (Arah et al., 2016; Gogo et al., 2016). Lotter et al. (2014) observed that 52% of growers do not wash the harvested ANS, increasing the chances of microbial infection and deterioration. To extend its shelf life, ANS is kept on cold shelves in the supermarkets at about 5 to 10 °C (Abukutsa-Onyango, 2007; Gogo et al., 2016).

Vegetables contain high water activity (a_w) of 0.970 to 0.996; this amount is sufficient to favor spoilage microorganisms (Barbosa-Cánovas et al., 2003). Pathogen bacteria cannot grow at $a_w < 0.86$; yeasts and molds can be tolerant to low a_w, and usually, no growth occurs at $a_w < 0.62$. Also, low a_w of 0.3 prevents lipid oxidation, enzymatic browning, and nonenzymatic browning. Besides, lowering a_w prevents the growth of vegetative microbial cells, germination of spores, and toxin production by molds and bacteria (Barbosa-Cánovas et al., 2003; Erkmen & Bozoglu, 2016). Heating, freeze-drying, dehydration, freeze

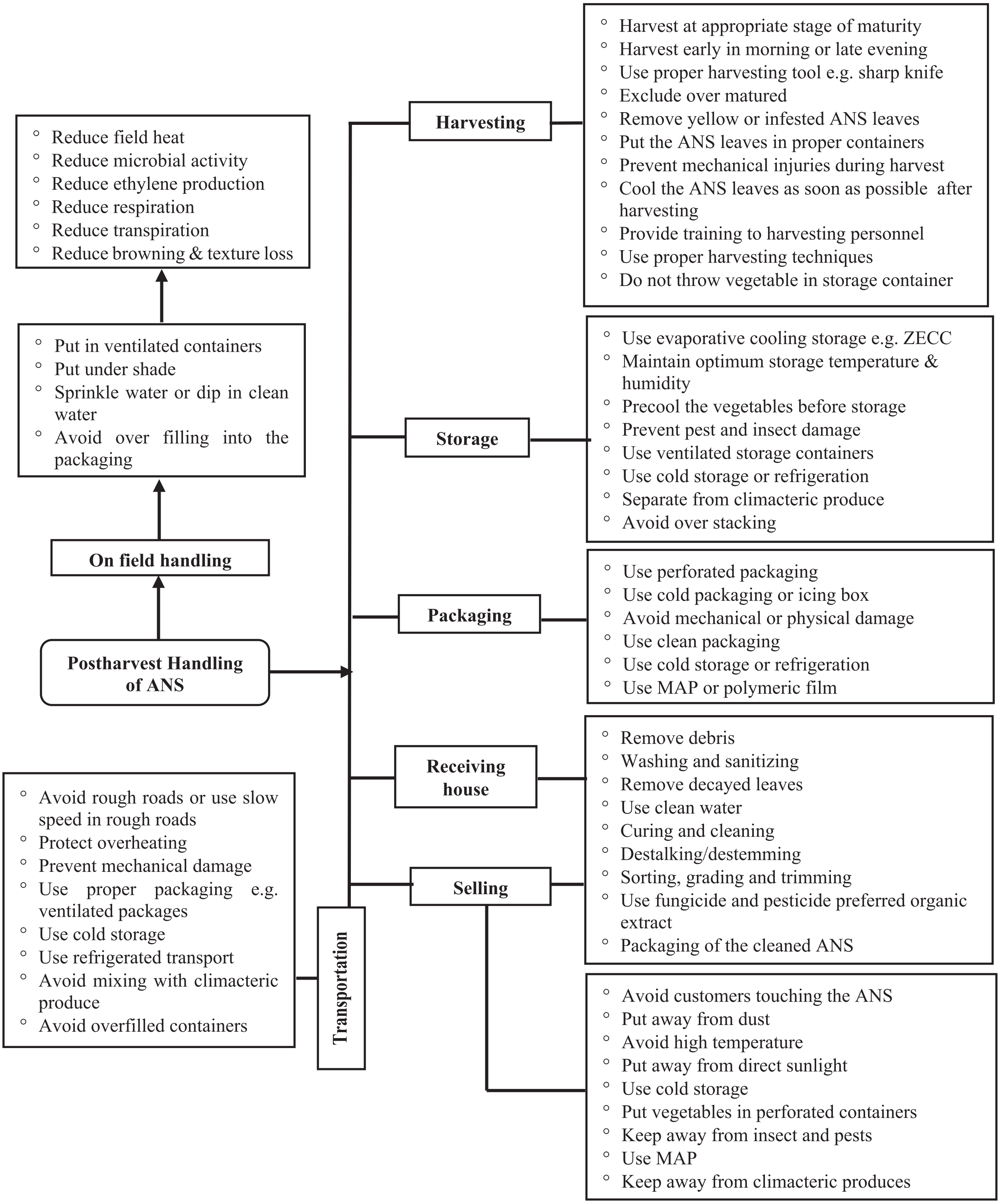

FIGURE 4 Key points to consider during postharvest handling of ANS from farm to market. MAP, modified atmospheric packaging; ZECC, Zero-Energy Cooling Chamber

Sources: Barbosa-Cánovas et al. (2003); Ekhuya et al. (2018); Gogo et al. (2018); Habwe et al. (2008); Nono-Womdim et al. (2012); Tournas (2005); Paltrinieri (2014).

concentration, crystallization, and osmotic dehydration reduce the a_w of foods (Barbosa-Cánovas et al., 2003; Erkmen & Bozoglu, 2016).

PHH of vegetables has led to safe and nutritious food for the consumers (Shiundu & Oniang'o, 2007; Smith & Eyzaguirre, 2007). Lack of scientific and economic knowledge among farmers and food handlers to develop, use, implement, and sustain PHH systems in SSA results in PHL of ANS. Despite having several effective postharvesting technologies, especially in developed countries (Acedo, 2010), some are difficult to implement in SSA (Arah et al., 2016; Atanda et al., 2011; Kitinoja et al., 2011). Most small-scale farmers and sellers in SSA do not afford to use standard cold rooms due to insufficient power supply and high investment and maintenance costs (Ambuko et al., 2017). Furthermore, farmers have limited knowledge of the benefits of using low-temperature storage (Gogo et al., 2016). Lotter et al. (2014) observed that none of the sellers had access to refrigeration storage in public markets in Tanzania. Lack of low-temperature storage facilities accelerates PHL of ANS and reduces its utilization. Vegetable deterioration affects the qualitative and quantitative loss, including appearance, flavor, texture, shape, and nutritional composition (Affognon et al., 2015; Global Panel, 2018; Wakholi et al., 2015). Also, it causes food and nutrition insecurity in individuals and households in SSA (FAO et al., 2019). Therefore, farmers and food handlers must follow proper PHH techniques from the farm to the fork (Figure 4).

12 | POSTHARVEST LOSSES OF ANS

PHL of AIVs are a significant problem facing SSA (Onyango & Imungi, 2007). The leaves' quality deteriorates within 4 days of harvest if stored at ambient temperatures (Edmonds & Chweya, 1997). Loss of vegetables in developing countries accounts for about 20% to 50% of total production, reflecting the ANS. Both quantitative and qualitative losses of ANS occur at various stages along the value chain, that is, from harvesting, handling, packing, storage, processing, and transportation to the consumers. According to Gogo et al. (2017), significant losses of nutritional, quantitative, and economic values of ANS in Kenya occur at harvest, transportation, and market. Therefore, proper planning is needed to solve the problem in SSA (Kitinoja & Kader, 2015; Kitinoja et al., 2018). Due to the high demand for nutritious food from the growing populations in SSA, PHL management is unavoidable.

Lack of appropriate PHH technologies results in a high loss of ANS, especially during the peak season. Consequently, limited supply during the off-season is accompanied by high prices, as most of the AIVs are seasonal (Abukutsa-Onyango, 2007; Habwe et al., 2008). Deterioration of vegetables results in partial or total loss of produce; it can happen during preharvest, harvest, and PHH (Acedo, 2010), although factors affecting PHL vary widely from place to place (Munhuweyi, 2012; Yang & Ojiewo, 2013).

Vegetables undergo physiological deterioration and pathological and mechanical/physical damage if not adequately handled (Acedo, 2010; Castro et al., 2005; Munhuweyi, 2012). The incidence of the losses affects the physical and nutritional quality (Munhuweyi, 2012). Physiological deterioration reduces 5% to 10% FW of vegetables, which renders vegetables unsuitable for consumption (Yang & Ojiewo, 2013). Ethylene production results in oxidation of vitamin C, destruction of chlorophyll, yellowing, and increased phenylpropanoid metabolism (Munhuweyi, 2012; Yang & Ojiewo, 2013). A low concentration of ethylene, about 0.01 ppm, accelerates vegetable loss; however, about 0.02 to 0.06 ppm of ethylene resulted in a 10% to 30% loss of product quality (Yang & Ojiewo, 2013). Therefore, the leafy vegetables should be stored away from high ethylene–producing fruits or vegetables (Munhuweyi, 2012; Yang & Ojiewo, 2013).

Furthermore, low crop variety, inappropriate cultural practice, lack of harvesting techniques, unfavorable climate, improper handling, poor storage conditions, lack of competent human resources, lack of technological knowledge, ineffective commercialization and functioning value chain, lack of logistical support, and lack of enabling policy are primary causes of PHL (Acedo, 2010).

Mechanical damage of vegetables causes leafy tearing and crushing, midrib breakage, head cracking, or bruising. It increases oxidation to phenolic compounds and increases susceptibility to decay. Also, damaged leaves increase water loss by about three to four times of undamaged vegetables (Acedo, 2010; Kanlayanarat, 2007). High-temperature storage and high relative humidity cause wilting to the vegetables, which results in loss of freshness of vegetables (Acedo, 2010; Edmonds & Chweya, 1997; Yang & Ojiewo, 2013). Onyango and Imungi (2007) reported 3.5% of *S. scabrum* losses due to excessive wilting. Thus, wilting is a challenge that increases ANS deterioration rate during marketing, especially when vegetables are stored at the ambient temperature (Abukutsa-Onyango, 2007; Onyango & Imungi, 2007). Failure to sell ANS harvested on the same day can result in deterioration due to lack of proper storage facilities (Shiundu & Oniang'o, 2007).

Unfinished day supply of ANS from local markets and supermarkets in Kenya is thrown as waste, thus increasing vegetable loss in SSA (Figure 5), consequently contributing to high PHL (Onyango & Imungi, 2007). Therefore, due to high PHL loss in SSA, there is a need to promote the use of appropriate PHH and PaP technologies to extend the shelf life of AIVs and ensure regular supply from farm to the table in rural, peri-urban, urban all year round (Habwe et al., 2008; Smith & Eyzaguirre,

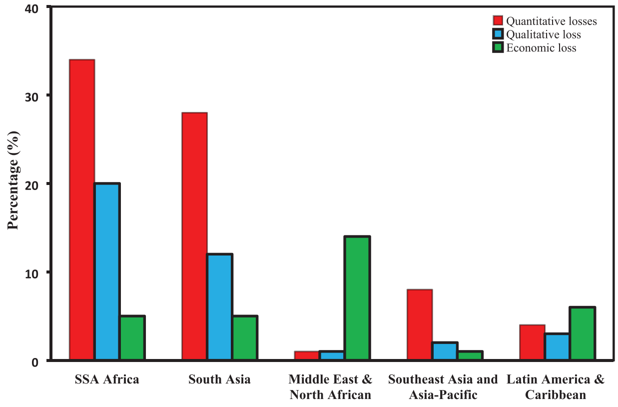

FIGURE 5 The quantitative, qualitative, and economic losses of vegetables in various regions in the world
Source: Kitinoja et al. (2018).

2007). Reducing PHL of vegetables using appropriate technologies can further increase food availability to the exponentially growing world population and conserve natural resources by reducing the area needed for production (Acedo, 2010) and reducing inputs. It will also reduce fungi and bacteria growths and insect infestation (Acedo, 2010; Bradford et al., 2018) and improve food quality, food safety, and financial opportunities. For that reason, there is a need to develop strategies that could improve the PHH of ANS in SSA. Solar drying and fermentation technologies play a significant role in ensuring the long-term preservation of foods for sustaining food security in SSA (Sivakumar et al., 2020). Therefore, training on feasible and affordable preservation techniques can add value to the ANS in SSA.

Microorganisms are the primary causative agents of PHL of fresh vegetables if they are not well handled (Acedo, 2010; Gil et al., 2015). They contribute about 55% of the total production losses in developing countries (Sanzani et al., 2016). Vegetables can also harbor higher numbers of microorganisms during harvesting due to preharvest and postharvest contamination (Tournas, 2005). Bacteria, yeasts, and molds can contaminate the ANS in the value chain. The microbial number of fresh vegetables differs from location, PHH, and storage conditions. Not all microorganisms can grow on fresh vegetables, but some microorganisms can grow and cause spoilage (Tournas, 2005). Cutting and mincing can increase microbial contamination of vegetables (Tournas, 2005). Washing, blanching, sanitary handling, and clean packaging containers and processing environment substantially decrease microbial contamination. Microbial numbers in fresh vegetables per gram differ from species: total bacteria count, 1.0×10^{10}; coliforms, 3.1×10^{7}; fecal coliforms, 5.5×10^{6}; and lactic acid bacteria (LAB), 1.0×10^{6} (Tournas, 2005). The most common spoilage bacteria of vegetables are LAB, pseudomonads, and *Xanthomonas campestris* (Moss, 2008; Tournas, 2005; Wafula, 2017). The fungi *Aspergillus*, *Penicillium*, *Fusarium*, *Alternaria*, and *Mucor* were isolated in spinach and tomatoes (Sanzani et al., 2016; Suleiman et al., 2017). These fungi can also cause spoilage of ANS and production of their toxins (mycotoxins). Sanzani et al. (2016) reported different mycotoxins (aflatoxin, ochratoxins, and patulin) on fruits and vegetables and fumonisins in tomatoes fruits but the absence of Alternaria toxin in vegetables. Suleiman et al. (2017) observed the presence of aflatoxin (B1, B2, GI, and G2) contamination in fresh spinach, fresh and dried tomatoes, and bitter leaves (*Vernonia amygdalina*).

13 | PROCESSING AND PRESERVATION OF ANS

The PaP of ANS has many benefits, mainly reducing the seasonality problem beyond the growing season (Acedo, 2010; Kirigia et al., 2019). Moreover, PaP improves dietary diversity, gives a wide choice of products, eliminates potentially toxic compounds, improves nutrients bioavailability, and improves flavor, texture, and aroma. It also improves the micronutrient bioavailability, improves digestibility, and provides probiotics for the GIT health (Belitz et al., 2009; Osum et al., 2013; Traoré et al., 2017; Wafula et al., 2016). The production of ANS is seasonal and becomes scarce during the off-season; therefore, there is a need to establish an appropriate preservation method to ensure that these vegetables are available year-round with acceptable quality. However, some PaP techniques degrade essential nutrients (Table 2) and are costly to implement in SSA, especially by households and farmers.

The most common traditional PaP technologies for AIVs include cooling, blanching, drying, salting, cooking, fermentation, and osmotic dehydration (Odongo et al., 2018). Although some of these technologies preserve vegetables for a short period, if combined with other techniques (hurdle technology), they can improve storability (James & Kuiper, 2003). The influence of harvesting methods (uprooting and cutting), age, and storage conditions (5 °C and room temperature) on the ANS leaves has been reported (Kirigia et al., 2019). These technologies are affordable and do not require sophisticated equipment; hence, small farmers, individuals, and households in SSA can implement them.

13.1 | Drying techniques

Drying preserves leafy vegetables to make them accessible during the off-season (Maseko et al., 2017; Smith &

Eyzaguirre, 2007). Drying has been used for a century and has been a critical method of preserving vegetables in SSA (Kiringia et al., 2017; Smith & Eyzaguirre, 2007; Vorster et al., 2007). Drying results in a minimal change in texture, flavor, and color (Gogo et al., 2016) and reduced weight, which improves handling, storability, lower transport cost, and microbial degradation of the product (James & Kuiper, 2003; Kiringia et al., 2017; Maseko et al., 2017). Drying is an economically feasible way to preserve AIVs at the local level in most SSA societies (Gogo et al., 2016). There are several drying techniques used for vegetables; however, the standard technique in SSA is open sun-drying, with less use of solar drying (Abukutsa, 2003; Gogo et al., 2016).

13.1.1 | Open sun-drying

Sun-drying is the oldest, simplest, and most commonly used method for the preservation of AIVs. It is considered the least expensive method (Atanda et al., 2011; Gogo et al., 2016; Oniang'o et al., 2008). Low-quality sun-dried AIVs are a consequence of physical and biological hazards contamination (Habwe et al., 2008; Keller, 2004). Open sun-drying was reported as a standard technology in areas with low production of vegetables, such as Singida and Kongwa, Tanzania (Keller, 2004), to preserve the vegetables during the off-season. Performing sun-drying under shade for preserving vitamins is highly recommended Match Maker Associates Limited ([MMA], 2008; Traoré et al., 2017). About 45% and 55.6% of farmers sun-dry their vegetables in Siaya county Kenya and Bahi district Tanzania (Ayua & Omware, 2013; Kandonga et al., 2019). Sun-drying under shade increased carbohydrate, ash, and lipid content of *S. nigrum* but reduced protein and β-carotene to 4.03 and 1.76, respectively (Traoré et al., 2017). Besides, sun-drying concentrated mineral elements and reduced antinutritional factors in other AIVs (Kandonga et al., 2019).

13.1.2 | Solar drying

The solar dryer is a simple device that reduces the adverse effects of sun-drying. Solar drying technology is more effective in utilizing solar energy (Gogo et al., 2016; James & Kuiper, 2003; MMA, 2008). The indirect solar dryer is a more complicated and expensive solar drying method (MMA, 2008); however, the technology gives high-quality products in terms of nutritional and other physicochemical properties compared to the direct and mixed solar dryers. Solar drying reduced antioxidant activity, flavonoid, vitamin C, and β-carotene in the *S. nigrum* (Cheptoo et al., 2019); however, it increased carbohydrate and lipids content of ANS (Traoré et al., 2017). Solar drying of *S. scabrum* reduced vitamin C and β-carotene by 96.2% and 92.7 %, respectively, but it did not affect mineral content (Mibei et al., 2011). Additionally, it retained β-carotene about 693.55 μg/g (68%) of *S. nigrum* (Nyambaka et al., 2012). Likewise, solar drying of ANS leaves increases sucrose and glucose, with no significant effect on protein and vitamins B_1 and B_2 and E, and a significant decrease in Vitamin C and ash contents (Wafula, 2017). On the other hand, blanching and solar drying of ANS improved β-carotene and vitamin C content (Kiringia et al., 2017; Nyambaka et al., 2012; Traoré et al., 2017). Solar drying is yet to be fully exploited in SSA countries despite its economic feasibility and quality benefits. Nonetheless, the cost for installing a full mixed solar drier is US$75 (Ayua & Omware, 2013). Therefore, solar drying is a relatively cheap and feasible technique for many small farmers and processors.

13.2 | Low-temperature storage

Many studies recommended that most vegetables, including ANS, should be stored at about 10 to 15 °C and 85% to 95% relative humidity to avoid chilling injuries (Castro et al., 2005; Gogo et al., 2016). The technologies to be used in developing countries should suit their needs and be comfortable and less costly than the technology to be applied in developed countries (Arah et al., 2016).

Alternative of inaccessible convection cold rooms have been developed; evaporative cooling (zero-energy cooling chamber) is among these technologies. This technology uses the principle of latent heat of evaporation, and heat exchange occurs when water evaporates; moreover, the chamber does not require electricity to operate. It is appropriate for smallholder farmers and sellers in rural areas with limited electricity supply (Ambuko et al., 2017; Workneh & Woldetsadik, 2004). Additionally, the chamber's construction is inexpensive, and it uses locally available materials and unskilled labor, making the cost affordable for the resource-poor smallholder farmers (Acedo, 2010; Edmonds & Chweya, 1997; Yang & Ojiewo, 2013). A zero-energy cooling chamber can store the vegetable for 3 to 5 days or more inside the chamber (Yang & Ojiewo, 2013).

13.3 | Blanching

Blanching is a primary, intermediate heat treatment process aiming to improve food preservation and quality by inactivating enzymes that can facilitate vegetable spoilage (Habwe et al., 2008; Huang et al., 2016). It also enhances the drying rate, kills plant tissues, improves the peeling of products, removes foreign matters, and reduces oil uptake.

Also, it reduces microbial loads before further processing or storing and removes pesticide and toxic residues. However, timing and temperature of blanching are crucial, as too little temperature is ineffective and too much temperature damages the vegetables and leads to loss of essential nutrients (Huang et al., 2016; Traoré et al., 2017). Blanching is performed using hot water, steam, microwave, radiofrequency, ohmic, and infrared (Liu et al., 2014; Xiao et al., 2017).

Blanching with water at 80 °C for 10 min, followed by solar drying, was shown to retain essential nutrients in AIVs (Acedo, 2010; Halim et al., 2017; Njoroge et al., 2015). On the other hand, blanching, combined with the drying at about 100 °C for 30 min, can degrade essential nutrients in AIVs (Njoroge et al., 2015). Blanching of ANS, followed by lyophilization, can extend the shelf life (Habwe et al., 2008). Also, hot water blanching of ANS at 90 to 92 °C decreases ash content by 1.73% with a high loss of β-carotene but did not affect protein and high carbohydrate content (Traoré et al., 2017). *Solanum scabrum* leaves' phenolic content was reduced by 85% after blanching (Odongo et al., 2018). Blanching of *S. nigrum* reduced antioxidant activity, flavonoid, vitamin C, and β-carotene (Cheptoo et al., 2019) (Table 2). Also, it decreases phytate and tannin contents (Amalraj & Pius, 2015). Besides, blanching improves texture and flavor and retains color (Reis, 2017). Blanching of *S. nigrum* at 100 °C for 30 and 60 min increased carbohydrate but decreased ash content, protein, and β-carotene (Traoré et al., 2017). Therefore, adopting blanching as an intermediate treatment should be recommended as a preservation method for ANS.

13.4 | Fermentation

Fermentation is a sustainable postharvest strategy for improving quality and product safety in Africa (Wafula et al., 2017). Vegetable fermentation is an inexpensive and attractive preservation technique for small-scale farmers and food processors in SSA. Fermentation is often combined with boiling, drying, salting, steaming, and frying (Adam & Moss, 2008; Adams & Nout, 2001; Wafula et al., 2016). About 32% of people in Kenya use fermentation to preserve ANS and other AIVs (Ayua & Omware, 2013). Fermentation of AIVs such as ANS and cowpeas leaves has been reported in Africa (Kasangi et al., 2010; Oguntoyinbo et al., 2016; Owade et al., 2019; Stoll et al., 2021; Wafula, 2017). Despite high PHL in SSA, fermentation of AIVs has not been given enough priority and is highly underutilized in Africa (Oguntoyinbo et al., 2016; Wafula et al., 2016). Therefore, tapping the potential of ANS fermentation is essential in reducing PHL and improving nutrition and food security.

LAB are convenient starter cultures for fermented plant products, such as fermented pickles. *Lactobacillus plantarum*, *Lactobacillus fermentum*, *Leuconostoc mesenteroides*, *Lactobacillus acidophilus*, and *Lactococcus lactis* are some LAB used (Behera et al., 2020; Wafula et al., 2016). Relishes and other pickled products are prepared from fermented ANS pickles (Hutkins, 2006).

Lactic acid fermentation can preserve vegetables for a long time and retain their original freshness and nutritive value (Madson & Coleman, 2007; Ray & Didier, 2014). LAB improves the bioavailability of vitamins and minerals and production of vitamins such as B vitamins; also, they contribute to the improvement of flavor, texture, and appearance (Madson & Coleman, 2007; Ray & Didier, 2014; Rodríguez et al., 2009; Soccol et al., 2010). *Lactobacillus plantarum* 75 strain did not affect the color of fermented ANS leaves but increases total phenol content and antioxidant activity (Degrain et al., 2020).

During fermentation, LAB produces antimicrobial compounds such as lactic acid, acetic acids, bacteriocins, alcohol, carbon dioxide, diacetyl, hydrogen peroxide, aldehyde, and esters. They inhibit spoilage microorganisms in fermented food, hence ensure food quality (Adam & Moss, 2008; Adams & Nout, 2001; Leroy & De Vuyst, 2004; Ray & Didier, 2014; Soccol et al., 2010; Wafula, 2017). LAB survive and stabilize in fermented vegetables, then dominate other microbial populations. LAB produces acetic acid, lactic, carbon dioxide, bacteriocins, and biosurfactants that inhibit undesirable microorganisms. Also, the acids contribute to lowering the product's pH (Adam & Moss, 2008; Adams & Nout, 2001). Owade et al. (2021) reported 13 LAB isolates from spontaneous fermentation (SF) of cowpea leaves with *Lactobacillus brevis* and *Lactococcus lactis* dominating the onset stage, with only *Lactobacillus brevis* dominating the onset stage of optimized fermentation.

Lactic acid fermentation can eliminate natural toxins such as phytic acid, oxalate, cyanogen, tannin, and alkaloids and therefore ensure food safety (Fang et al., 2017; Indrastuti et al., 2018; Leblanc et al., 2011; Leroy & De Vuyst, 2004; Muchoki et al., 2010). *Lactobacillus plantarum* 75 strain ANS extract exhibited a 60% reduction of aflatoxin B1-induced DNA damage and a 38% reduction in $FeSO_4$-induced oxidative stress (Odongo et al., 2018).

Furthermore, it improves digestion in the human gastrointestinal tract and hence increases the absorption of nutrients. Additionally, it improves antioxidant activity by increasing the number of phenolic and flavonoids compounds (Hur et al., 2014). Consumption of fermented food contributes to the lowering of cholesterol, inhibiting infectious diseases and food allergies. Also, it reduces diarrhea, reduces inflammation, and improves digestion of various food in the body, such as the lactose in intolerant people (Deshpande et al., 2011; Hur et al., 2014; Kaprasob et al., 2018; Leroy & De Vuyst, 2004; Soccol et al., 2010)

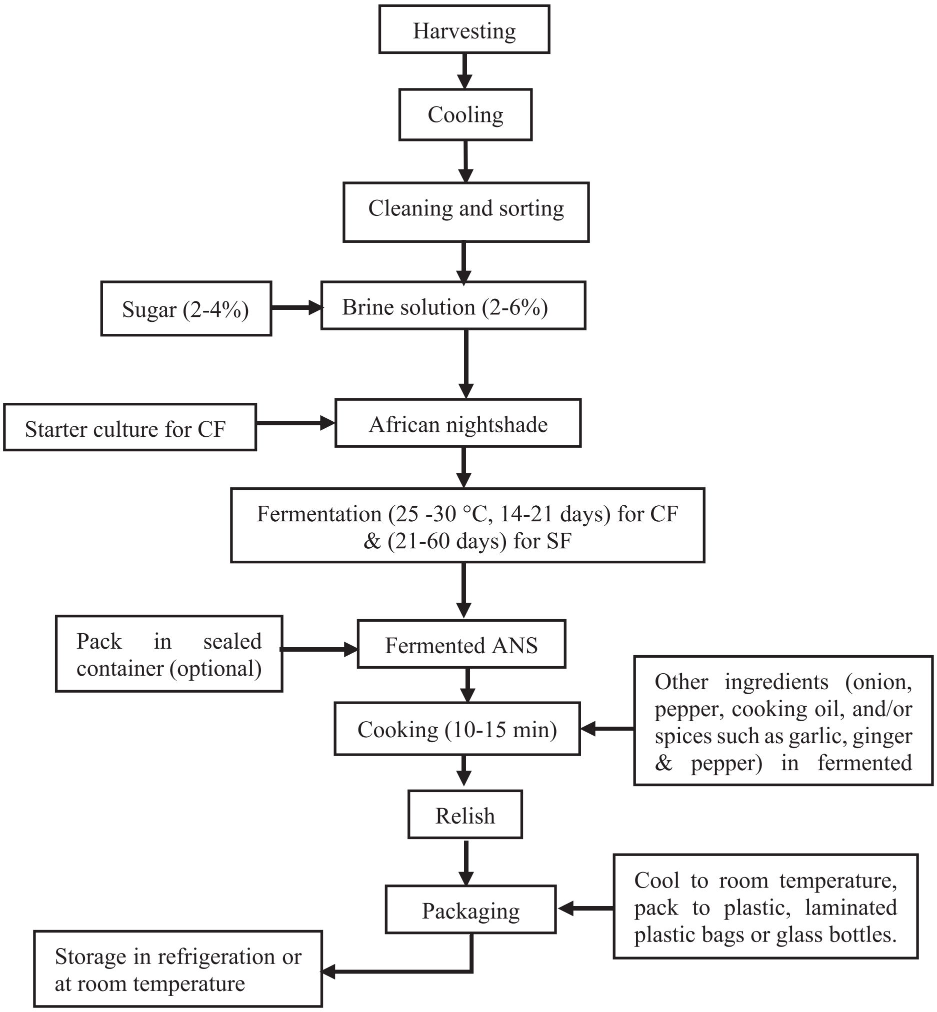

FIGURE 6 Fermentation of ANS. CF, Controlled fermentation; SF, spontaneous fermentation
Sources: Adam and Moss (2008); Adams and Nout (2001); Battcock and Ali (1998); Belitz et al. (2009); Wafula et al. (2016).

Vegetable fermentation can be achieved either by spontaneous or controlled fermentation (CF) (Figure 6). In SF, natural flora is the fermenting agent. This technique is simple and affordable even to small-scale processors. Also, back-slopping techniques can be used, where a small quantity of materials from the previous batch of fermented products is used to inoculate the next batch (Kim et al., 2018). In back-slopping, the initial phase of fermentation is short and reduces the risk of fermentation failure (Ghnimi & Guizani, 2018). Furthermore, it reduces the risk of proliferation of contaminant bacteria and acid-resistant bacteria (Adams & Nout, 2001). During SF of cabbage, cucumber, and ANS, heterofermenters, mainly *Leuconostoc mesenteroides* and *L. brevis*, initiate the fermentation process, whereas *L. plantarum* and *Pediococcus cerevisiae* occur later (Belitz et al., 2009; Hutkins, 2006; Wafula, 2017).

A commercial starter culture is used in CF, which requires high initial investment and maintenance costs, pausing a challenge to small-scale farmers and processors. Two commercial starter cultures, *Lactobacillus plantarum* BFE 5092 and *Lactobacillus fermentum* BFE 6620, were used to ferment nightshade leaves (Wafula, 2017). In another study by Stoll et al. (2021), *Lactiplantibacillus plantarum* BFE5092 and *Limosilactobacillus fermentum* BFE 6620 were two starter culture strains in the fermentation of *S. scabrum* leaves. *Lactobacillus fermentum* BFE 6620, isolated from fermented cassava, was reported as a potential starter culture for AIVs (Wafula et al., 2017). SF and CF significantly affected the nutritional and sensory quality of ANS leaves (Wafula, 2017). Thus, proper selection of commercial starter cultures is essential in the CF of ANS leaves for value addition (Stoll et al., 2021).

Fermentation of *S. scabrum* leaves increases ash content and reduces protein and vitamin C by 36–38.3% and 66–81%, respectively (Wafula et al., 2017). In contrast, *S. scabrum* leaves' fermentation decreases vitamins E, B_1, and B_2 by 10–34%, 68–76%, and 30–47.3%, respectively (Wafula et al., 2017). Furthermore, fermentation of *S. scabrum* reduces chlorophyll and total polyphenol but increases carotenoid content by 67% (Odongo et al., 2018). Fermentation is a suitable technique for preserving ANS, thus improving nutrition and food security and enhancing the livelihoods of millions of people in SSA (Behera et al., 2020; Stoll et al., 2021; Wafula et al., 2016).

14 | GENERAL CHALLENGES FACING ANS

ANS production lacks good extension services from the government to indicate neglect of the crop, despite its significance in improving health and rural livelihoods (Weinberger & Msuya, 2004). Information on ANS yield in most SSA is not available, showing that these vegetables have not been given priority as other vegetables or crops (Edmonds & Chweya, 1997; Weinberger & Msuya, 2004). Furthermore, there is little information on indigenous knowledge on the utilization of ANS; this information could facilitate the consumption, value addition, and commercialization of ANS (Onyango et al., 2016).

Seasonal availability is another challenge as the ANS becomes scarce and expensive during the rainy season or off-season (Lotter et al., 2014). The lack of proper management consequently results in a decline in ANS supply, especially during the off-season (Edmonds & Chweya, 1997; Weinberger & Msuya, 2004). Heavy rainfall reduces the yields, especially for cultivated ANS (Lotter et al., 2014); therefore, screen houses can be used.

Pests and diseases are the key concern that hinders ANS production in SSA (Abukutsa-Onyango, 2007; Sangija et al., unpublished). Lack of appropriate technical skills in farmers such as PHH, processing, and preservation hinders the availability of ANS, especially during the off-season. Some preservation technologies require a high initial cost for the implementation, which becomes difficult for small farmers. Indeed, lack of proper infrastructure hinders the supply of ANS, especially from the production areas to the markets. Production is solely on a small scale by smallholder farmers and local households; therefore, it facilitates the low availability and utilization of ANS. Unsold raw ANSs get spoiled due to a lack of storage facilities along the value chain. Of importance, very minimal value addition is done to ANS, resulting in short shelf life, low market price, and low utilization.

Other challenges that hinder ANS utilization are foodborne diseases and their toxin. Common pathogens causing foodborne diseases in vegetables are *Listeria monocytogenes*, *Clostridium* spp., *Bacillus cereus*, *Campylobacter jejuni*, *Salmonella* spp., *Shigella* and *Vibrio cholera*, and *Yersinia* spp. and pathogenic strains of *Escherichia coli* (Balali et al., 2020; Hernández-Cortez et al., 2017; Micali, 2016; Sant'Ana et al., 2011; Waturangi et al., 2019; Zhu et al., 2017). Pathogens can cause gastroenteritis, abortion, and central nervous system infection (Kilonzo-Nthenga & Makuna, 2018; Zhu et al., 2017). Wafula (2017) isolated pathogenic bacteria, that is, *Providencia rettgeri*, *Enterobacter cloacae*, *E. coli*, *Klebsiella oxytoca*, *Enterobacter asburiae*, *Klebsiella* spp., and *Enterobacter ludwigii*, from fermented ANS leaves. These pathogenic bacteria may cause pneumonia, urinary tract and respiratory infection, and postsurgical peritonitis (Singh et al., 2016; Wie, 2015; Zhu et al., 2017). Also, they produce hemolytic enterotoxins and pore-forming toxins (Davin-Regli & PagÃÍs, 2015). Simultaneously, *E. coli* causes diarrhea and produces Shiga toxin, causing severe diarrhea or hemorrhagic colitis (Smith & Fratamico, 2017). However, the presence of pathogenic bacteria differs from sources of ANS (Wafula, 2017).

Also, fungi can contaminate vegetables, but the risk of mycotoxin production is low compared to cereal foods. However, Sanzani et al. (2016) and Suleiman et al. (2017) reported mycotoxin in pepper, fresh spinach, tomatoes and onion; perhaps they can also contaminate ANS. Pathogens can contaminate vegetables at any point along the vegetable value chain (Hernández-Cortez et al., 2017; Kilonzo-Nthenga & Makuna, 2018; Waturangi et al., 2019; Zhu et al., 2017). The contamination sources include animals, insects, water, soil, dirty equipment, human, manure, sewage water, and feces (Kilonzo-Nthenga & Makuna, 2018; Zhu et al., 2017). Therefore, farmers must follow good agricultural practices to avoid contamination. Contaminated vegetables can affect human health and result in several health problems. Mycotoxins are carcinogenic, mutagenic, and teratogenic (Sanzani et al., 2016). The consumption of fresh vegetables should be encouraged, but significant measures that ensure safety before consumption should be in place (Balali et al., 2020).

UV radiation, washing, low-temperature storage, and washing with diluted acetic acid, salted water, and vinegar can control PHH for vegetables (Balali et al., 2020; Kilonzo-Nthenga & Makuna, 2018; Verbikova et al., 2018; Zhu et al., 2017). Additionally, another essential factor in ensuring food safety and quality is the adequate control of time and temperature during processing, cooling, and storing food (Hernández-Cortez et al., 2017). Additionally, fermented pickles should be well pasteurized to ensure safety.

15 | POSSIBLE SOLUTIONS AND SUGGESTIONS FOR FUTURE RESEARCH

Through feasible PaP technologies, value addition can improve ANS nutritional and sensory quality, reduce losses, and improve its utilization. Awareness on PaP techniques and nutritional and health benefits of ANS is necessary for dietary diversity and also for improving nutritional status in communities where malnutrition is prevalent and ANS is highly underutilized and wasted. Furthermore, PaP can ensure the supply of ANS yearly. Also, greenhouse and screen houses should be encouraged because they use low input levels, improve yields, and protect against pests and diseases. Organic pesticides and fertilizer should be promoted over synthesized ones to reduce health effects on consumers and environmental protection.

More emphasis should be on improving ANS production, providing extension services to the farmers, and supporting agricultural inputs, including quality seeds, fertilizer, and organic pesticides, Besides, ANS data documentation for enhancing traceability and control should be encouraged. Specifically, data on production, postharvest handling, value addition, utilization, marketing, cultivars diversity, and improved varieties are missing in most SSA countries due to lack of precise documentation .

Research and development should focus on ANS breeding to improve local cultivars for improved yield, tolerance to climatic change such as drought, resistance to pests and disease, and low-toxicity varieties. Sensitization on the adoption of recently improved ANS varieties such as *Nduruma*, *Olevolosi*, *Ambureni*, and *Malala* to improve yield and returns is mandatory. Furthermore, technologies for PaP should be feasible and affordable. Presently, most consumers utilize the leaves despite the nutraceutical potential and commercial value of other ANS parts. Therefore, research focusing on the nutritional, functional, and safety of ANS berries is inevitable for their further utilization.

The promotion of urban farming (UA) in SSA can boost and ensure environmentally friendly food production, that is, increasing green spaces in urban areas, beautifying, and enhancing bioavailability (Stewart et al., 2013). UA is also thought to increase income, prevent hunger and malnutrition, and improve health (Beach, 2013; Stewart et al., 2013). In Uganda, UA has been linked to improving child nutrition, especially for mothers engaging in UA (Beach, 2013). Likewise, in Kampala, about 70% of heads of farming households earn more than the national annual income per capita (US$330) (Prain & Lee-Smith, 2010). Therefore, urban cities can benefit from UA through easy access to fresh and nutritious vegetables, reduced transportation costs and pollution, shortening of the ANS value chain, reducing PHL, easily accessible and available markets, and employment opportunities. Nevertheless, UA is given little recognition, regulation, and support, with only 40% of urban farmers in most SSA countries (FAO, 2012). Therefore, more support is required to improve the efficiency of UA for sustainable livelihood in SSA.

16 | CONCLUSION

ANSs' contribution to human nutrition is never to be ignored; regardless of the huge PHL, it remains an essential source of livelihood to local SSA communities. Appropriate PHH techniques such as drying and fermentation can further improve ANSs' distribution and sustainability along the value chain if well adopted. The use of improved ANS varieties can address issues of pests and diseases and safety. Furthermore, good agriculture practices and appropriate PHH are vital in improving ANS production and reducing PHL. The safety of ANS should be taken as a priority as it contains some antinutrients and toxic compounds. Great market opportunities should be tapped by mapping the ANS value chain for income generation. Therefore, good agriculture practices and proper PHH and processing, if well adopted, can further improve ANS supply and hence its contribution to human nutrition and livelihoods in SSA.

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AUTHOR CONTRIBUTIONS

Frank Sangija planned, designed, drafted, and finalized the manuscript. Haikael Martin revised the manuscript. Athanasia Matemu revised the drafted manuscript and proofread and approved the final manuscript.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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REFERENCES

Abbas, H. K., Paul, R. N., Riley, R. T., Tanaka, T., & Shier, W. T. (1998). Ultrastructural effects of AAL-toxin TA from the fungus *Alternaria alternata* on black nightshade (*Solanum nigrum L.*) leaf discs and correlation with biochemical measures of toxicity. *Toxicon*, *36*(12), 1821–1832. https://doi.org/10.1016/S0041-0101(98)00091-9

Abdel-Aal, E.-S., Akhtar, H., Zaheer, K., & Ali, R. (2013). Dietary sources of lutein and zeaxanthin carotenoids and their role in eye health. *Nutrients*, *5*(4), 1169–1185. https://doi.org/10.3390/nu5041169

Abdulwaliyu, I., Arekemase, S. O., Adudu, J. A., Batari, M. L., Egbule, M. N., & Reuben Okoduwa, S. I. (2019). Investigation of the medicinal significance of phytic acid as an indispensable anti-nutrient in diseases. *Clinical Nutrition Experimental*, *28*, 42–61. https://doi.org/10.1016/j.yclnex.2019.10.002

Abe, T. K., & Taniguchi, M. (2014). Identification of Myo-inositol hexakisphosphate (IP6) as a β791 secretase 1 (BACE 1) inhibitory molecule in rice grain extract and digest. *FEBS Open Bio*, *4*, 162–167. https://doi.org/10.1016/j.fob.2014.01.008

Abukutsa, M. O. (2003). Unexploited potential of indigenous African vegetables in western Kenya. *Maseno Journal of Education Arts and Science*, *4*, 103–122

Abukutsa-Onyango, M. O. (2007). The diversity of cultivated African leafy vegetables in three communities in western Kenya. *African Journal of Food Agriculture Nutrition and Development*, *7* (3), 1–15. http://www.bioline.org.br/request?nd07021

Abukutsa-Onyango, M. O. (2010). *Strategic repositioning of African indigenous vegetables in the horticulture sector*. Second RUFORUM Biennial Meeting 20 - 24 September 2010, Entebbe, Uganda, no. September; pp. 1413–1419.

Abukutsa-Onyango, M. O. (2015). African nightshade: Broad leaved nightshade. *Jomo Kenyatta University of Agriculture and Technology*. https://doi.org/10.13140/RG.2.1.2169.9929

Acedo, A. L. (2010). *Postharvest technology for leafy vegetables*. AVRDC Publication No. 10–733. AVRDC - The World Vegetable Center.

Acedo, L. A., Jr., & Katinka, W. (Eds.). (2009). *Best practices in postharvest management of leafy vegetables in greater Mekong subregion countries*. AVRDC - The World Vegetable Center.

Adam, M. R., & Moss, M. O. (Eds.). (2008). *Food microbiology* (3rd ed.). The Royal Society of Chemistry.

Adams, M. A., & Nout, M. J. R. (Eds.). (2001). *Fermentation and food safety*. Aspen Publishers, Inc.

Adebooye, O. C., Vijayalakshmi, R., & Singh, V. (2008). Peroxidase activity, chlorophylls, and antioxidant profile of two leaf vegetables (*Solanum nigrum* (L.) and *Amaranthus cruentus* (L.) under six pretreatment methods before cooking. *International Journal of Food Science and Technology*, *43* (1), 173–178. https://doi.org/10.1111/j.1365-2621.2006.01420.x

Affognon, H., Mutungi, C., Sanginga, P., & Borgemeister, C. (2015). Unpacking postharvest losses in Sub-Saharan Africa: A meta-analysis. *World Development*, *66*, 49–68. https://doi.org/10.1016/j.worlddev.2014.08.002

Agudo, A., & Joint FAO/WHO Workshop on Fruit and Vegetables for Health. (2004). *Measuring intake of fruit and vegetables*. https://apps.who.int/iris/handle/10665/43144

Akbudak, B., Akbudak, N., Seniz, V., & Eris, A. (2012). Effect of pre-harvest harpin and modified atmosphere packaging on quality of cherry tomato cultivars 'Alona' and 'Cluster. *British Food Journal*, *114*(2), 180–196. https://doi.org/10.1108/00070701211202377

Akhtar, M. S., Israr, B., Bhatty, N., & Ali, A. (2011). Effect of cooking on soluble and insoluble oxalate contents in selected Pakistani vegetables and beans. *International Journal of Food Properties*, *14*(1), 241–249. https://doi.org/10.1080/10942910903326056

Akinola, R., Pereira, L. M., Mabhaudhi, T., de Bruin, F.-M., & Rusch, L. (2020). A review of indigenous food crops in Africa and the implications for more sustainable and healthy food systems. *Sustainability*, *12*(8), 3493. https://doi.org/10.3390/su12083493

Akubugwo, I. E., Obasi, A. N., & Ginika, S. C. (2007). Nutritional potential of the leaves and seeds of black nightshade-*Solanum nigrum* L. Var *virginicum* from Afikpo-Nigeria. *Pakistan Journal of Nutrition*, *6*(4), 323–326. https://doi.org/10.3923/pjn.2007.323.326

Al-Ashaal, H. A. A. (2019). Glycoalkaloids as medicinal agents from callus and regenerated plants of *Solanum nigrum* var. *judiacium*. *Comunicata Scientiae*, *10*(3), 325–337. https://doi.org/10.14295/cs.v10i3.2840

Al-Fatlawi, A. B., Rizvi, M. M. A., & Ahmad, A. (2014). Anti-carcinogenic activity of rice bran phytic acid against human breast cancer cell line (MCF-7). *Asian Journal of Pharmaceutical and Clinical Research*, *7*(1), 151–155.

Amalraj, A., & Pius, A. (2015). Bioavailability of calcium and its absorption inhibitors in raw and cooked green leafy vegetables commonly consumed in India. An in vitro study. *Food Chemistry*, *170*, 430–436. https://doi.org/10.1016/j.foodchem.2014.08.031.

Ambrose-Oji, B. (2009). Urban food systems and African indigenous vegetables: Defining the spaces and places for African indigenous vegetables in urban and peri-urban agriculture. In C. M. Shackleton, M. W. Pasquini, & A. W. Drescher (Eds.), *African indigenous vegetables in urban agriculture* (pp. 1–33). Earthscan. https://doi.org/10.4324/9781849770019

Ambuko, J., Wanjiru, F., Chemining'wa, G. N., Owino, W. O., & Mwachoni, E. (2017). Preservation of postharvest quality of leafy amaranth (*Amaranthus* spp.) Vegetables using evaporative cooling. *Journal of Food Quality*. https://doi.org/10.1155/2017/5303156

Arah, I. K., Ahorbo, G. K., Anku, E. K., Kumah, E. K., & Amaglo, H. (2016). Postharvest handling practices and treatment methods for tomato handlers in developing countries: A mini-review. *Advances in Agriculture*. https://doi.org/10.1155/2016/6436945

Atanda, S. A., Pessu, P. O., Agoda, S., Ikotun, I., & Isong, I. U. (2011). The concepts and problems of postharvest food losses in perishable crops. *African Journal of Food Science*, *5*(11), 603–613. https://doi.org/10.5897/AJFS.9000281

Ayua, E., & Omware, J. (2013). Assessment of processing methods and preservation of African leafy vegetables in Siaya county, Kenya. *Global Journal of Biology Agriculture and Health Sciences*, *2*(2), 46–48.

Balali, G. I., Yar, D. D., Dela, V. G. A., & Adjei-Kusi, P. (2020). Microbial contamination, an increasing threat to the consumption of fresh fruits and vegetables in today's world. *International Journal of Microbiology*. https://doi.org/10.1155/2020/3029295

Barbosa-Cánovas, G. V., Fernández-Molina, J. J., Alzamora, S. M., Tapia, M. S., López-Malo, A., & Chanes, J. W. (2003). *Handling and preservation of fruits and vegetables by combined methods for rural areas*. Technical manual (No. 149). Food & Agriculture Organization.

Battcock, M. K., & Ali, S. A. (1998). *Fermented fruits and vegetables*. A global perspective (No. 134). Food and Agriculture Organization of the United Nations.

Beach, M. (2013). *Urban agriculture increases food security for poor people in Africa*. https://www.prb.org/urban-agriculture-poor-africa/

Behera, S. S., El Sheikha, A. F., Hammami, R., & Kumar, A. (2020). Traditionally fermented pickles: How the microbial diversity associated with their nutritional and health benefits? *Journal of Functional Foods*, *70*, 103971. https://doi.org/10.1016/j.jff.2020.103971

Belitz, H. D., Grosch, W., & Schieberle, P. (2009). *Food chemistry* (4th ed.). Springer-Verlag.

Bhowmik, A., Ojha, D., Goswami, D., Das, R., Chandra, N. S., Chatterjee, T. K., Chakravarty, A., Chakravarty, S., & Chattopadhyay, D. (2017). Inositol hexa phosphoric acid (phytic acid), a nutraceutical, attenuates iron-induced oxidative stress and alleviates liver injury in iron overloaded mice. *Biomedicine & Pharmacotherapy*, *87*, 443–450. https://doi.org/10.1016/j.biopha.2016.12.125

Blake, S. (2008). *Vitamins and minerals demystified*. The McGraw-Hill Companies, Inc.

Boudet, A. M. (2007). Evolution and current status of research in phenolic compounds. *Phytochemistry*, *68*(22–24), 2722–2735. https://doi.org/10.1016/j.phytochem.2007.06.012

Bradford, K. J., Dahal, P., Van Asbrouck, J., Kunusoth, K., Bello, P., Thompson, J., & Wu, F. (2018). The dry chain: Reducing postharvest losses and improving food safety in humid climates. *Trends in Food Science and Technology*, *71*, 84–93. https://doi.org/10.1016/j.tifs.2017.11.002

Castro, L. R., Vigneault, C., Charles, M. T., & Cortez, L. A. B. (2005). Effect of cooling delay and cold-chain breakage on Santa Clara tomato. *Journal of Food, Agriculture & Environment*, *3*(1), 49–54.

Chagomoka, T., Kamga, R. T., Tenkouano, A., & Mecozzi, M. (2014). *Traditional vegetable recipes from Cameroon*. AVRDC - The World Vegetable Center.

Che, C.-T., George, V., Ijinu, T. P., Pushpangadan, P., & Andrae-Marobela, K. (2017). Traditional medicine. In S. Badal & R. Delgoda (Eds.), *Pharmacognosy* (pp. 15–30). Academic Press. https://doi.org/10.1016/B978-0-12-802104-0.00002-0

Chelang'a, P. K., Obare, G. A., & Kimenju, S. C. (2013). Analysis of urban consumers' willingness to pay a premium for African leafy vegetables (ALVs) in Kenya: A case of Eldoret town. *Food Security*, *5*(4), 591–595. https://doi.org/10.1007/s12571-013-0273-9

Cheptoo, G., Owino, W., & Kenji, G. (2019). Nutritional quality, bioactive compounds, and antioxidant activity of selected African indigenous leafy vegetables as influenced by maturity and minimal processing. *African Journal of Food, Agriculture, Nutrition and Development*, *19*(3), 14769–14789. https://doi.org/10.18697/ajfand.85.17835

Chung, K. T., Wong, T. Y., Wei, C. I., Huang, Y. W., & Lin, Y. (1998). Tannins and human health: A review. *Critical Reviews in Food Science and Nutrition*, *38*(6), 421–464. https://doi.org/10.1080/10408699891274273

D'Ischia, M., Napolitano, A., Manini, P., & Panzella, L. (2011). Secondary targets of nitrite-derived reactive nitrogen species: Nitrosation/nitration pathways, antioxidant defense mechanisms and toxicological implications. *Chemical Research in Toxicology*, *24*(12), 2071–2092. https://doi.org/10.1021/tx2003118

Dahdouh, S., Grande, F., Espinosa, S. N., Vincent, A., Gibson, R., Bailey, K., King, J., Rittenschober, D., & Charrondière, U. R. (2019). Development of the FAO/INFOODS/IZINCG Global Food Composition Database for Phytate. *Journal of Food Composition and Analysis*, *78*, 42–48. https://doi.org/10.1016/j.jfca.2019.01.023

Dassanayake, U., & Gnanathasan, C. A. (2012). Acute renal failure following oxalic acid poisoning: A case report. *Journal of Occupational Medicine and Toxicology*, *7*(1), 17. https://doi.org/10.1186/1745-6673-7-17

Davin-Regli, A., & PagÃÍs, J.-M. (2015). *Enterobacter aerogenes* and *Enterobacter cloacae*; versatile bacterial pathogens confronting antibiotic treatment. *Frontiers in Microbiology*, *6*, 392. https://doi.org/10.3389/fmicb.2015.00392

Defelice, M. S. (2003). The black nightshades, *Solanum nigrum* L. et al.—Poison, poultice, and pie. *Weed Technology*, *17*(2), 421–427. https://doi.org/10.1614/0890-037X(2003)0170421:TBNSNL2.0.CO;2

Degrain, A., Manhivi, V., Remize, F., Garcia, C., & Sivakumar, D. (2020). Effect of lactic acid fermentation on color, phenolic compounds and antioxidant activity in African nightshade. *Microorganisms*, *8*(9), 1324. https://doi.org/10.3390/microorganisms8091324

Dehmer, K. J., & Hammer, K. (2004). Taxonomic status and geographic provenance of germplasm accessions in the Solanum nigrum (L.) complex: AFLP data. *Genetic Resources and Crop Evolution*, *51*, 551–558. https://doi.org/10.1023/B:GRES.0000024163.86762.fc

Delimont, N. M., Rosenkranz, S. K., Haub, M. D., & Lindshield, B. L. (2017). Salivary proline-rich protein may reduce tannin-iron chelation: A systematic narrative review. *Nutrition & Metabolism*, *14*(1), 47. https://doi.org/10.1186/s12986-017-0197-z

Deshpande, G., Rao, S., & Patole, S. (2011). Progress in the field of probiotics: Year 2011. *Current Opinion in Gastroenterology*, *27*(1), 13–18. https://doi.org/10.1097/MOG.0b013e328341373e

Dilworth, L. L., Omoruyi, F. O., Simon, O. R., Morrison, E. Y., & Asemota, H. N. (2005). The effect of phytic acid on the levels of blood glucose and some enzymes of carbohydrate and lipid metabolism. *West Indian Medical Journal*, *54*(2), 102–106. https://doi.org/10.1590/s0043-31442005000200003

Ding, Z., Johanningsmeier, S. D., Price, R., Reynolds, R., Truong, V.-D., Payton, S. C., & Breidt, F. (2018). Evolution of nitrate and nitrite content in pickled fruit and vegetable products. *Food Control*, *90*, 304–311. https://doi.org/10.1016/j.foodcont.2018.03.005

Dinssa, F. F., Hanson, P., Dubois, T., Tenkouano, A., Stoilova, T., Hughes, J. d'A., & Keatinge, J. D. H. (2016). AVRDC - The World Vegetable Center's women-oriented improvement and development strategy for traditional African vegetables in sub-Saharan Africa. *European Journal of Horticultural Science*, *81*(2), 91–105. https://doi.org/10.17660/eJHS.2016/81.2.3

Edmonds, J. M., & Chweya, J. A. (1997). Black nightshades, Solanum nigrum L. and related species. Promoting the conservation and use of underutilized and neglected crops. International Plant Genetic Resources Institute.

European Food Safety Authority (EFSA). (2004). Opinion of the scientific panel on food additives, flavourings, processing aids and materials in contact with food (AFC) on hydrocyanic acid in flavourings and other food ingredients with flavouring properties. *European Food Safety Authority Journal*, *2*(11), 105. https://doi.org/10.2903/j.efsa.2004.105

European Food Safety Authority (EFSA). (2008). Nitrate in vegetables. Scientific Opinion of the Panel on Contaminants in the Food Chain. *European Food Safety Authority Journal*, *6*(6), 689. https://doi.org/10.2903/j.efsa.2008.689. https://doi.org/10.2903/j.efsa.2008.689

European Food Safety Authority (EFSA). (2014). Scientific Opinion on the essential composition of infant and follow-on formulae. *European Food Safety Authority Journal*, *12*(7), 3760. https://doi.org/10.2903/j.efsa.2014.3760

European Food Safety Authority (EFSA). (2019). Evaluation of the health risks related to the presence of cyanogenic glycosides in foods other than raw apricot kernels. *European Food Safety Authority Journal*, *17*(4), 5662 https://doi.org/10.2903/j.efsa.2019.5662

Eggersdorfer, M., & Wyss, A. (2018). Carotenoids in human nutrition and health. *Archives of Biochemistry and Biophysics*, *652*, 18–26. https://doi.org/10.1016/j.abb.2018.06.001

Ekhuya, N. A., Wesonga, J. M., & Abukutsa–Onyango, M. O. (2018). Production, processing and storage techniques of African nightshade (*Solanum* spp.) Seeds and their correlations with farmers' characteristics in western Kenya. *African Journal Food Agriculture Nutrition & Development*, *18*(2), 13338–13351.

EMEA. (2004). *Committee for veterinary medicine products (Oxalic acid)*. The European Agency for Evaluation Products Veterinary Medicines and Inspections.

Engle, L. M., & Altoveros, N. (1999). *Collection, conservation and utilization of indigenous vegetables*. Proceedings of a Workshop AVRDC, Shanhua, Tainan, Taiwan, pp. 16–18.

Erkmen, O., & Bozoglu, T. F. (2016). Food preservation by reducing water activity. In O. Erkmen & T. F. Bozoglu (Eds.), *Food microbiology: Principles into practice* (pp. 44–58). John Wiley & Sons. https://doi.org/10.1002/9781119237860.ch30

Essack, H., Odhav, B., & Mellem, J. J. (2017). Screening of traditional south African leafy vegetables for specific antinutritional factors before and after processing. *Food Science and Technology*, *37*(3), 467–471. https://doi.org/10.1590/1678-457x.20416

Everaarts, A. P., de Putter, H., & Maerere, A. P. (2017). Profitability, labour input, fertilizer application and crop protection in vegetable production in the Arusha region, Tanzania. *Journal of Animal and Plant Sciences*, *32*(3), 5181–5202.

Fang, H., Kang, J., & Zhang, D. (2017). Microbial production of vitamin B12: A review and future perspectives. *Microbial Cell Factories*, *16*(1), 1–14. https://doi.org/10.1186/s12934-017-0631-y

FAO & WHO. (2004). *Vitamin and mineral requirements in human nutrition* (2nd ed.). WHO Library Cataloguing-in-Publication Data.

FAO, IFAD, UNICEF, WFP, & WHO. (2019). *Food security and nutrition in the world*. Author.

Food and Agricultural Organization (FAO). (2005). *National mission on bamboo applications. Recommended nutritional composition*. Food and Agricultural Organization.

Food and Agricultural Organization (FAO). (2012). *Growing greener cities in Africa. First status report on urban and peri-urban horticulture in Africa*. Food and Agriculture Organization of the United Nations.

FAO/IZiNCG (2018). *Global food composition database for phytate version 1.0.* Phytate food composition. Author.

Faudon, S., & Savage, G. (2014). Manufacture of a low oxalate mitsumame-type dessert using rhubarb juice and calcium salts. *Food and Nutrition Sciences*, *5*, 1621–1627. http://doi.org/10.4236/fns.2014.517174

Gebru, H. (2015). A review on the comparative advantages of intercropping to mono-cropping system. *Journal of Biology, Agriculture and Healthcare*, *5*(9), 1–13.

Ghnimi, S., & Guizani, N. (2018). Vegetable fermentation and pickling. In M. Siddiq & M. A. Uebersax (Eds.), *Handbook of vegetables and vegetable processing* (2nd ed., pp. 407–427). John Wiley & Sons. https://doi.org/10.1002/9781119098935.ch17

Gido, E. O., Ayuya, O. I., Owuor, G., & Bokelmann, W. (2017). Consumption intensity of leafy African indigenous vegetables: Towards enhancing nutritional security in rural and urban dwellers in Kenya. *Agricultural and Food Economics*, *5*, 14.

Gil, M. I., Selma, M. V., Suslow, T., Jacxsens, L., Uyttendaele, M., & Allende, A. (2015). Pre-and postharvest preventive measures and intervention strategies to control microbial food safety hazards of fresh leafy vegetables pre-and postharvest preventive measures and intervention strategies to co. *Critical Reviews in Food Science and Nutrition*, *55*(4), 453–468. https://doi.org/10.1080/10408398.2012.657808

Gilbert, C. A. (2006). American black nightshade (*Solanum americanum* Mill.) interference in watermelon (*Citrullus lanatus* L.) (Master's thesis). The University of Florida. http://etd.fcla.edu/UF/UFE0015860/gilbert_c.pdf

Global Panel. (2018). *Preventing nutrient loss and waste across the food system: Policy actions for high-quality diets*. Policy Brief No. 12. Global Panel on Agriculture and Food Systems for Nutrition. https://scalingupnutrition.org/news/preventing-nutrient-loss-and-waste-across-the-food-system/

Gogo, E. O., Opiyo, A. M., Ulrichs, C., & Huyskens-Keil, S. (2017). Nutritional and economic postharvest loss analysis of African indigenous leafy vegetables along the supply chain in Kenya. *Postharvest Biology and Technology*, *130*, 39–47. https://doi.org/10.1016/j.postharvbio.2017.04.007

Gogo, E. O., Trierweiler, B., Opiyo, A. M., Frommherz, L., Frechen, M., Ulrichs, C., & Huyskens-Keil, S. (2018). Reducing postharvest losses using modified atmosphere packaging bags for African nightshade (*Solanum scabrum* Mill.) leaves. *Acta Horticulturae*, *1205*, 97–108. https://doi.org/10.17660/ActaHortic.2018.1205.11

Gogo, O. E., Opio, M. A., Ulrichs, C., & Huyskens-Keil, S. (2016). Postharvest treatments of African leafy vegetables for food security in Kenya: A review. *African Journal of Horticultural Sciences*, *9*, 32–40. http://www.hakenya.net/ajhs/index.php/ajhs/article/view/153

Gracia, R., & Shepherd, G. (2004). Cyanide poisoning and its treatment. *Pharmacotherapy*, *24*(10), 1358–1365. https://doi.org/10.1592/phco.24.14.1358.43149

Ha, D. O., Park, C. U., Kim, M. J., & Lee, J. H. (2012). Antioxidant and prooxidant activities of β-carotene in accelerated autoxidation and photosensitized model systems. *Food Science and Biotechnology*, *21*, 607–611. https://doi.org/10.1007/s10068-012-0078-1

Habwe, F. O., Walingo, K. M., & Onyango, M. O. A. (2008). Food processing and preparation technologies for sustainable utilization of African indigenous vegetables for nutrition security and wealth creation in Kenya. In G. Robertson & J. Lupien (Eds.), *Using food science and technology to improve nutrition and promote national development* (1st ed., pp. 1–8). International Union of Food Science & Technology.

Habwe, F. O. (2008). *Development of high iron recipes of African indigenous vegetables from east Africa* (Unpublished MSc thesis). Maseno University.

Halim, Y., Onasie, N. C. P., & Nurwitri, C. C. (2017). The utilization of black nightshade (*Solanum nigrum* L.) fruit in the fermented beverage. *Journal of Chemical and Pharmaceutical Research*, *9*(12), 235–241.

Hernández-Cortez, C., Palma-Martínez, I., Gonzalez-Avila, L. U., Guerrero-Mandujano, A., Solís, R. C., & Castro-Escarpulli, G. (2017). Food poisoning caused by bacteria (Food toxins). In N. Malangu (Ed.), *Poisoning from specific toxic agents to novel rapid and simplified techniques for analysis*. IntechOpen.

Holmes, R. P., & Kennedy, M. (2000). Estimation of the oxalate content of foods and daily oxalate intake. *Kidney International*, *57*(4), 1662–1667. https://doi.org/10.1046/j.1523-1755.2000.00010.x

Huang, Y., Xiao, D., Burton-Freeman, B. M., & Edirisinghe, I. (2016). Chemical changes of bioactive phytochemicals during thermal processing. In *Reference module in food science*. https://doi.org/10.1016/b978-0-08-100596-5.03055-9

Hur, S. J., Lee, S. Y., Kim, Y.-C., Choi, I., & Kim, G.-B. (2014). Effect of fermentation on the antioxidant activity in plant-based foods.

Food Chemistry, *160*, 346–356. https://doi.org/10.1016/j.foodchem.2014.03.112

Hussein, M. R., EL-Aziz, M. A. A., Ahmad, N. S., Omran, F., & Abdulhameed, M. (2006). The biochemical changes associated with phytic acid on induced breast cancer proliferative lesions in rats. *Cancer Biology & Therapy*, *5*(9), 1129–1133.

Hutkins, R. W. (2006). *Microbiology and technology of fermented foods* (1st ed.). Wiley Blackwell publishing.

İnanç, A. L. (2011). Chlorophyll: Structural properties, health benefits and its occurrence in virgin olive oils. *Akademik Gıda/Academic Food Journal*, *9*(2), 26–32.

Indrastuti, Y. E., Estiasih, T., Christanti, R. A., Pulungan, M. H., & Zubaedah, E. (2018). Microbial and some chemical constituent changes of high cyanide cassava during simultant spontaneous submerged and solid-state fermentation of "gadungan pohung". *International Food Research Journal*, *25*(2), 487–498.

Jacoby, A., Labuschagne, M. T., & Viljoen, C. D. (2003). Genetic relationships between southern African solanum retroflexum dun and other related species measured by morphological and DNA markers. *Euphytica*, *132*(1), 109–113. https://doi.org/10.1023/A:1024657827796

Jain, R., Sharma, A., Gupta, S., Sarethy, I. P., & Gabrani, R. (2011). *Solanum nigrum*: Current perspectives on therapeutic properties. *Alternative Medicine Review*, *16*(1), 78–85.

James, I. F., & Kuipers, B. (2003). *Preservation of fruits and vegetables* (4th ed.). Agromisa Foundation.

Judprasong, K., Charoenkiatkul, S., Sungpuag, P., Vasanachitt, K., & Nakjamanong, Y. (2006). Total and soluble oxalate contents in Thai vegetables, cereal grains and legume seeds and their changes after cooking. *Journal of Food Composition and Analysis*, *19*(4), 340–347. https://doi.org/10.1016/j.jfca.2005.04.002

Kakati, P., Deka, S. C., Kotoki, D., & Saikia, S. (2010). Effect of traditional methods of processing on the nutrient contents and some antinutritional factors in newly developed cultivars of green gram [*Vigna radiata* (L.) Wilezek] and black gram [*Vigna mungo* (L.) Hepper] of Assam, India. *International Food Research Journal*, *17*(2), 377–384.

Kandonga, A. C., Makule, E. E., & Matemu, A. O. (2019). Effect of processing on the nutritional and antinutritional composition of false sesame (*Ceratotheca sesamoides*) and common bean leaves (*Phaseolus* vulgaris). *International Journal of Biosciences*,*15*(2), 519–531. https://doi.org/10.12692/ijb/15.2.519-531

Kanlayanarat, S. (2007). *Postharvest technologies for fresh leafy vegetables in Thailand*. Paper Presented during the RETA 6376 Workshop on Best Practices in Postharvest Management of Leafy Vegetables in GMS Countries, Hanoi, Vietnam, pp. 25–27.

Kaprasob, R., Kerdchoechuen, O., Laohakunjit, N., & Somboonpanyakul, P. (2018). B vitamins and prebiotic fructooligosaccharides of cashew apple fermented with probiotic strains Lactobacillus spp., Leuconostoc mesenteroides and Bifidobacterium longum. *Process Biochemistry*, *70*, 9–19. https://doi.org/10.1016/j.procbio.2018.04.009

Karwowska, M., & Kononiuk, A. (2020). Nitrates/nitrites in food—Risk for nitrosative stress & benefits. *Antioxidants*, *9*(3), 241. https://doi.org/10.3390/antiox9030241

Kasambula, P., Pichop, G., Maro, F., & Marealle, R. (2007). *Indigenous vegetables supply chain in Uganda: Significance, constraints and opportunities – Case of Kampala and Mbale Districts, NARO, Kampala, Uganda*. Report presented to the 6th Thematic Meeting of the IndigenoVeg Project.

Kasangi, D. M., Shitandi, A. A., Shalo, P. L., & Mbugua, S. K. (2010). Effect of spontaneous fermentation of cowpea leaves (*Vigna unguiculata*) on proximate composition, mineral content, chlorophyll content, and beta-carotene content. *International Food Research Journal*, *17*(3), 721–732.

Kaushik, D., Jogpal, V., Kaushik, P., Lal, S., Saneja, A., Sharma, C., & Aneja, K. R. (2009). Evaluation of activities of *Solanum nigrum* fruit extract. *Archives of Applied Science Research*, *1*, 43–50.

Keller, G. B. (2004). *African nightshade, eggplant, spiderflower et al.—Production and consumption of traditional vegetables in Tanzania from the farmers point of view*. Masterarbeit Im Wissenschaftlichen Studiengang Agrarwissenschaften an der Georg-August Universität Göttingen.

Keszei, A. P., Goldbohm, R. A., Schouten, L. J., Jakszyn, P., & van den Brandt, P. A. (2012). Dietary N-nitroso compounds, endogenous nitrosation, and the risk of esophageal and gastric cancer subtypes in the Netherlands Cohort Study. *American Journal of Clinical Nutrition*, *97*(1), 135–146. https://doi.org/10.3945/ajcn.112.043885

Khanbabaee, K., & van Ree, T. (2001). Tannins: Classification and definition. *Natural Product Reports*, *18*(6), 641–649. https://doi.org/10.1039/b101061l.

Kilonzo-Nthenge, A., & Mukuna, W. (2018). Salmonella and antimicrobial resistance in fresh produce. In M. T. Mascellino (Ed.), *Salmonella - A re-emerging pathogen*. IntechOpen. https://doi.org/10.5772/intechopen.72894

Kim, D.-H., Jeong, D., Song, K.-Y., & Seo, K.-H. (2018). Comparison of traditional and backslopping methods for kefir fermentation based on physicochemical and microbiological characteristics. *LWT*, *97*, 503–507. https://doi.org/10.1016/j.lwt.2018.07.023

Kirigia, D., Winkelmann, T., Kasili, R., & Mibus, H. (2019). Nutritional composition in African nightshade (*Solanum scabrum*) influenced by harvesting methods, age, and storage conditions. *Postharvest Biology and Technology*, *153*, 142–151. https://doi.org/10.1016/j.postharvbio.2019.03.019

Kiringia, D., Kasili, R., & Mibusi, H. (2017). African leafy vegetables pre-harvest and post-harvest constrains and technologies for losses reduction along the field to consumer chain. *African Journal of Horticultural Sciences*, *12*, 51–60.

Kitinoja, L., & Kader, A. A. (2015). *Measuring postharvest losses of fresh fruits and vegetables in developing countries*. PEF White Paper 15-02. Postharvest Education Foundation.

Kitinoja, L., Saran, S. Roy, S. K., & Kader, A. A. (2011). Postharvest technology for developing countries: Challenges and opportunities in research, outreach, and advocacy. *Journal of the Science of Food and Agriculture*, *91*(4), 597–603. https://doi.org/10.1002/jsfa.4295

Kitinoja, L., Tokala, V. Y., & Brondy, A. (2018). A review of global postharvest loss assessments in plant-based food crops: Recent findings and measurement gaps. *Journal of Postharvest Technology*, *6*(4), 1–15.

Kuete, V., Karaosmanog, O., & Sivas, H. (2017). Anticancer activities of African medicinal spices and vegetables. In V. Kuete (Ed.), *Medicinal spices and vegetables from Africa* (pp. 271–297). Academic Press. https://doi.org/10.1016/B978-0-12-809286-6.00010-8

Kumar, A., Sagwal, S., & Rani, S. (2012). An updated review on molecular pharmacology and physiology of black nightshade (*Solanum* *nigrum*). *International Journal of Pharmaceutical Science and Research*, *3*, 2956–2977

Lanfer-Marquez, U. M., Barros, R. M. C., & Sinnecker, P. (2005). Antioxidant activity of chlorophylls and their derivatives. *Food Research International*, *38*(8-9), 885–891. https://doi.org/10.1016/j.foodres.2005.02.012

LeBlanc, J. G., Laiño, J. E., del Valle, M. J., Vannini, V., van Sinderen, D., Taranto, M. P., de Valdez, G. F., de Giori, G. S., & Sesma, F. (2011). B-Group vitamin production by lactic acid bacteria - Current knowledge and potential applications. *Journal of Applied Microbiology*, *111*(6), 1297–1309. https://doi.org/10.1111/j.1365-2672.2011.05157.x

Lee, S. H., Shinde, P. L., Choi, J. Y., Kwon, I. K., Lee, J. K., Pak, S. I., Cho, W. T., & Chae, B. J. (2010). Effects of tannic acid supplementation on growth performance, blood hematology, iron status and faecal microflora in weanling pigs. *Livestock Science*, *131*(2-3), 281–286. https://doi.org/10.1016/j.livsci.2010.04.013

Lee, S. H., Hong, J. P., Chun, H. K., Cho, S. Y., & Cho, S. M. (2006). Dietary phytic acid lowers the blood glucose level in diabetic KK mice. *Nutrition Research*, *26*(9), 474–479. https://doi.org/10.1016/J.NUTRES.2006.06.017

Leroy, F., & De Vuyst, L. (2004). Lactic acid bacteria as functional starter cultures for the food fermentation industry. *Trends in Food Science & Technology*, *15*(2), 67–78. https://doi.org/10.1016/j.tifs.2003.09.004.

Lezotre, P.-L. (2014). State of play and review of major cooperation initiatives. In P.-L. Lezotre (Ed.), *International cooperation, convergence and harmonization of pharmaceutical regulations* (pp. 7–170). Academic Press. https://doi.org/10.1016/b978-0-12-800053-3.00002-1

Liu, P., Mujumdar, A. S., Zhang, M., & Jiang, H. (2014). Comparison of three blanching treatments on the color and anthocyanin level of the microwave-assisted spouted bed drying of purple flesh sweet potato. *Drying Technology*, *33*(1), 66–71. https://doi.org/10.1080/07373937.2014.936558.

Lobell, D. B., & Gourdji, S. M. (2012). The influence of climate change on global crop productivity. *Plant Physiology*, *160*(4), 1686–1697. https://doi.org/10.1104/pp.112.208298

Lotter, D. W., Marshall, M. I., Weller, S., & Mugisha, A. (2014). African indigenous and traditional vegetables in Tanzania: Production, post-harvest management, and marketing. *African Crop Science Journal*, *22*(3), 181–189.

Luoh, J. W., Begg, C. B., Symonds, R. C., Ledesma, D., & Yang, R. Y. (2014). Nutritional yield of African indigenous vegetables in water-deficient and water-sufficient conditions. *Food and Nutrition Sciences*, *5*, 812–822. https://doi.org/10.4236/fns.2014.59091

Lyu, W., Yuan, B., Dinssa, F. F., Simon, J. E., & Wu, Q. (2020). Rapid screening of glycoalkaloids in *Solanum scabrum and S. nigrum* berries using ultra-high-performance liquid chromatography with pathway-specified in-source fragmentation tandem mass spectrometry. *Rapid Communications in Mass Spectrometry*, *34*(19), e8882. https://doi.org/10.1002/rcm.8882

Madson, D., & Coleman, E. (2007). *Preserving food without freezing or canning: Traditional techniques using salt, oil, sugar, alcohol, vinegar, drying, cold storage, and lactic fermentation*. Chelsea Green Publishing.

Manach, C., Mazur, A., & Scalbert, A. (2005). Polyphenols and prevention of cardiovascular diseases. *Current Opinions in Lipidology*, *16*(1), 77–84. https://doi.org/10.1097/00041433-200502000-00013

Managa, M. G., Mpai, S., Remize, F., Garcia, C., & Sivakumar, D. (2020). Impact of moist cooking methods on colour, anti-nutritive compounds and phenolic metabolites in African nightshade (*Solanum retroflexum* Dun.). *Food Chemistry*, *325*, 126805. https://doi.org/10.1016/j.foodchem.2020.126805

Manzano, H., de Sousa, A. B., Soto-Blanco, B., Guerra, J. L., Maiorka, P. C., & Gorniak, S. L. (2007). Effects of long-term cyanide ingestion by pigs. *Veterinary Research Communication*, *31*(1), 93–104. https://doi.org/10.1007/s11259-006-3361-x

Maseko, I., Mabhaudhi, T., Tesfay, S., Araya, H. T., Fezzehazion, M., & Du Plooy, C. P. (2017). African leafy vegetables: A review of status, production, and utilization in South Africa. *Sustainability*, *10*(1), 1–16. https://doi.org/10.3390/su10010016

Match Maker Associates Limited. (2008). *Dried fruit and vegetables for urban and export markets sub sector and value chain analysis study commissioned by SME competitiveness facility and conducted by matchmaker associates limited (MMA), no. January: 67*. https://pdfslide.net/download/link/fresh-fruit-vegetable-sub-sector-value-fruit-vegetable-sub-sector-value

Maundu, P. M., Ngugi, M. G., & Kabuye, C. H. S. (1999). *Traditional food plants of Kenya*. Kenya Resource Centre for Indigenous Knowledge (KENRIK), National Museum of Kenya.

Mensinga, T. T., Sips, A. J. A. M., Rompelberg, C. J. M., van Twillert, K., Meulenbelt, J., van den Top, H. J., & van Egmond, H. P. (2005). Potato glycoalkaloids and adverse effects in humans: An ascending dose study. *Regulatory Toxicology and Pharmacology*, *41*(1), 66–72. https://doi.org/10.1016/j.yrtph.2004.09.004

Mibei, E. K., Ojijo, N. K. O., Kalanja, S. M., & Kinjua, J. K. (2011). Compositional attributes of the leaves of some indigenous African leafy vegetables commonly consumed in Kenya. *Annals. Food Science and Technology*, *12*(2), 146–154.

Micali, M. (2016). *Clostridium botulinum and C. perfringens* in vegetable foods: Chemistry of related toxins. In A. Bhagat, G. Caruso, M. Micali, & S. Parisi (Eds.), *Foods of non-animal origin*. Springer. https://doi.org/10.1007/978-3-319-25649-8_2

Mishra, V. K., Bacheti, R. K., & Husen, A. (2011). Medicinal uses of chlorophyll: A critical overview. In H. Le & E. Salcedo (Eds.), *Chlorophyll: Structure, function and medicinal uses* (pp.177–196). Nova Science Publishers, Inc.

MoALF/SHEP PLUS. (2019). *Black nightshade production*. https://www.jica.go.jp/project/english/kenya/015/materials/c8h0vm0000f7o8cj-att/materials_04.pdf

Mohy-Ud-Din, A., Khan, Z. U. D., Ahmad, M., & Kashmiri, M. A. (2010). Chemotaxonomic value of alkaloids in *Solanum nigrum* complex. *Pakistan Journal of Botany*, *42*(1), 653–660.

Molina, P. B., D'Alessandro, C., Dekeyser, K., & Marson, M. (2020). *Sustainable food systems through diversification and indigenous vegetables. An analysis of the Arusha area*. European Centre for Development Policy Management (ECDPM).

Mora-Boza, A., López-Donaire, M. L., Saldaña, L., Vilaboa, N., Vázquez-Lasa, B., & San Román, J. (2019). Glycerylphytate compounds with tunable ion affinity and osteogenic properties. *Scientific Reports*, *9*(1), 11491. https://doi.org/10.1038/s41598-019-48015-5

Moss, M. O. (2008). Fungi, quality and safety issues in fresh fruits and vegetables. *Journal of Applied Microbiology*, *104*(5), 1239–1243. https://doi.org/10.1111/j.1365-2672.2007.03705.x

Muchoki, C. N., Lamuka, P. O., & Imungi, J. K. (2010). Reduction of nitrates, oxalates, and phenols in fermented solar-dried stored cowpea (*Vigna unguiculata* L.) leaf vegetables. *African Journal of*

Food, Agriculture, Nutrition, and Development, *10*(11), 4398–4412. https://doi.org/10.4236/fns.2012.33054

Muhanji, G., Roothaert, R. L., Webo, C., & Stanley, M. (2011). African indigenous vegetable enterprises and market access for small-scale farmers in East African Indigenous vegetable enterprises and market access for small-scale farmers in East Africa. *International Journal of Agricultural Sustainability*, *9*(1), 194–202. https://doi.org/10.3763/ijas.2010.0561

Munhuweyi, K. (2012). *Postharvest losses and changes in quality of vegetables from retail to consumer: A case study of tomato, cabbage, and carrot* (MSc. Thesis). Stellenbosch University. http://scholar.sun.ac.za

Mwai, G. N. (2007). *Morphological and molecular characterization and yield evaluation of vegetable African nightshades (*Solanum *L. section* Solanum*) under varying cultural practices* (Doctorate thesis). Maseno University.

Mwambo, O., Dinssa, F. F., Mallogo, R., Matovolwa, M., & Mushi, S. (2021). Performance and release of two African nightshade lines from World Vegetable Center (WorldVeg) germplasm in Northern Tanzania. Retrieved from https://avrdc.org/download/tav-posters/MWAMBO-Omary_African-Nightshade.pdf. Accessed on 15, February 2021.

Mwangi, S., & Kimathi, M. (2006). *African leafy vegetables evolves from underutilized species to commercial cash crops*. Research Workshop on Collective Action and Market Access for Smallholders, 2–5 October 2006, Cali, Columbia, pp. 1–19.

Mwanri, A. W., Mamboleo, T. F., Msuya, J. M., & Gowele, V. F. (2018). Oxalate, phytate, and nitrate content in African nightshade, spider plant, and amaranths at different stages of maturity. *African Journal of Food Science*, *12*(11), 316–322. https://doi.org/10.5897/AJFS2018.1735.

Nassar, R., & Nassar, M. (2016). Antimicrobial effect of phytic acid on *Enterococcus faecalis. The International Arabic Journal of Antimicrobial Agents*, *6*(4), 1–7. http://doi.org/10.3823/796

Navarro, S., Neuhouser, M., Cheng, T.-Y., Tinker, L., Shikany, J., Snetselaar, L., & Lampe, J. (2016). The Interaction between dietary fiber and fat and risk of colorectal cancer in the women's health initiative. *Nutrients*, *8*(12), 779. https://doi.org/10.3390/nu8120779

Neugart, S., Baldermann, S., Ngwene, B., Wesonga, J., & Schreiner, M. (2017). Indigenous leafy vegetables of Eastern Africa - A source of extraordinary secondary plant metabolites. *Food Research International*, *100*, 411–422. https://doi.org/10.1016/j.foodres.2017.02.014

Ngegba, J. B. (2007). *Traditional vegetable preparation methods in rural Tanzania and carotenoids retention and in-vitro iron bioavailability in vegetable dishes* (MSc Thesis). Sokoine University of Agriculture.

Njoroge, E. W., Matofari, J. W., Mulwa, R. M. S., & Anyango, J. O. (2015). Effects of blanching time/temperature combination coupled with solar-drying on the nutritional and microbial quality of indigenous leafy vegetables in Kenya. *African Journal of Food Science and Technology*, *6*(7), 209–219. https://doi.org/10.14303/ajfst.2015.068

Nono-Womdim, R., Ojiewo, C., Abang, M., & Oluoch, M. O. (Eds.). (2012). *Good agricultural practices for African indigenous vegetables*. ISHS.

Nuñez de González, M. T., Osburn, W. N., Hardin, M. D., Longnecker, M., Garg, H. K., Bryan, N. S., & Keeton, J. T. (2015). A survey of nitrate and nitrite concentrations in conventional and organic-labeled raw vegetables at retail. *Journal of Food Science*, *80*(5), C942–C949. https://doi.org/10.1111/1750-3841.12858

Nyaga, S. N. (2020). *Evaluation of anti-diabetic properties of Solanum villosum and Solanum nigrum var. sarrachoides using a streptozotocin-induced diabetes mouse model* (Master's thesis). The University of Nairobi. http://erepository.uonbi.ac.ke/bitstream/handle/11295/153160/Thesis%20final%20-Signed.pdf?sequence=1&isAllowed=y

Nyaga, S. N., Mathiu, P. M., Onyango, C. M., & Areba, G. O. (2019). Antidiabetic properties of *Solanum villosum* and *Solanum nigrum* var *sarrachoides* in a streptozotocin-induced diabetic mice model. *International Journal Basic and Clinical Pharmacology*, *8*(11), 2396–2402. https://doi.org/10.18203/2319-2003.ijbcp20194774

Nyambaka, H., Nderitu, J., Nawiri, M., & Murungi, J. (2012). Use of kitchen steel wool as oxygen absorber improves storage retention of beta-carotene in solar-dried vegetables. *Mediterranean Journal of Chemistry*, *1*(6), 326–333. https://doi.org/10.13171/mjc.1.6.2012.26.07.21

Nyaura, J. A., Sila, D. N., & Owino, W. O. (2014). Post-harvest stability of vegetable amaranthus (*Amaranthus dubius*) combined low temperature and modified atmospheric packaging. *Food Science and Quality Management*, *30*, 66–73.

Odongo, G., Schlotz, N., Baldermann, S., Neugart, S., Huyskens-Keil, S., Ngwene, B., & Lamy, E. (2018). African nightshade (*Solanum scabrum* Mill.): Impact of cultivation and plant processing on its health promoting potential as determined in a human liver cell model. *Nutrients*, *10*(10), 1532. https://doi.org/10.3390/nu10101532

Oguntoyinbo, F. A., Fusco, V., Cho, G.-S., Kabisch, J., Neve, H., Bockelmann, W., Huch, M., Frommherz, L., Trierweiler, B., Becker, B., Benomar, N., Gálvez, A., Abriouel, H., Holzapfel, W. H., & Franz, C. M. A. P. (2016). Produce from Africa's gardens: Potential for leafy vegetable and fruit fermentations. *Frontiers in Microbiology*, *7*, 981. https://doi.org/10.3389/fmicb.2016.00981

Ogwu, M. C., Osawaru, M. E., Aiwansoba, R. O., & Iroh, R. N. (2016). *Status and prospects of vegetables in Africa*. Proceedings of NTBA/NSCB Joint Biodiversity Conference, Unilorin, pp. 47–57.

Ojiewo, C. O., Mbwambo, O., Swai, I., Samali, S., Tilya, M. S., Mnzava, R. N., Mrosso, L., Minja, R., & Oluoch, M. (2013). Selection, evaluation and release of varieties from genetically diverse African nightshade germplasm. *International Journal of Plant Breeding*, *7*(2), 76–89

Ojiewo, C. O., Mwai, G. N., Abukutsa-Onyango, M. O., Agong, S. G., & Nono-Womdim, R. (2013). Exploiting the genetic diversity of vegetable African nightshades. *Bioremediation, Biodiversity and Bioavailability*, *7*(1), 6–13.

Oluoch, M. O., Habwe, F. O., Ngegba, J. B., Koskei, K. R., & Yang, R. Y. (2012). Food preparation and processing methods on nutrient retention and accessibility in selected indigenous vegetables from east Africa. *Scripta Horticulturae*, *15*, 233–241.

Ondieki, M. J., Aguyoh, J. N., & Opiyo, A. (2011). Variations in growth and yield characteristics of three black nightshade species grown under high altitude conditions. *Agriculture and Biology Journal of North America*, *2*(3), 401–406. https://doi.org/10.5251/abjna.2011.2.3.401.406

Oniang'o, R., Grum, M., & Obel-Lawson, E. (Eds.). (2008). *Developing African leafy vegetables for improved nutrition*. The regional workshop, 6–9 December 2005. Rural Outreach Program.

Ontita, E., Onyango, C., Onwonga, R., & Nyamongo, D. (2017). Indigenous knowledge on the uses of African nightshades (*Solanum nigram* L.) species among three Kenyan communities. *Asian Journal of Agricultural Extension, Economics & Sociology*, *14*(3), 1–8. https://doi.org/10.9734/ajaees/2016/31099

Onyango, C., Ontita, E., Onwong'a, R., Desterio, N., & Gapusi, J. R. (2016). Status and production practices of African vegetable nightshade (*Solanum nigrum* L.) in selected communities of Kenya. *Journal of Experimental Agriculture International*, *13*(3), 1–12. https://doi.org/10.9734/ajea/2016/27363.

Onyango, C. M., & Imungi, J. K. (2007). Post-harvest handling and characteristics of fresh-cut traditional vegetables sold in Nairobi-Kenya. *African Crop Science Society*, *8*, 1791–1794.

Osum, F. I., Okonkwo, T. M., & Okafor, G. I. (2013). Effect of processing methods on the chemical composition of *Vitex doniana* leaf and leaf products. *Food Science & Nutrition*, *1*(3), 241–245. https://doi.org/10.1002/fsn3.31

Owade, J. O., Abong', G., Okoth, M., & Mwang'ombe, A. W. (2019). A review of the contribution of cowpea leaves to food and nutrition security in East Africa. *Food Science & Nutrition*, *8*(1), 36–47. https://doi.org/10.1002/fsn3.1337

Owade, J. O., Abong', G. O., Okoth, M. W., Mwang'ombe, A. W., & Jobor, J. O. (2021). Comparative profiling of lactic acid bacteria isolates in optimized and spontaneous fermentation of cowpea leaves. *Food Science and Nutrition*, *9*(3), 1651–1664. https://doi.org/10.1002/fsn3.2140

Paltrinieri, G., & Staff, FAO (2014). *Handling of fresh fruits, vegetables and root crops: A training manual for grenada*, Rome, Italy: Food and Agriculture Organization of the United Nations.

Park, J., Kim, T. S., Kim, M.-J., & Lee, J. (2013). Prooxidative and antioxidative properties of β-carotene in chlorophyll and riboflavin photosensitized oil-in-water emulsions. *Food Chemistry*, *140*(1-2), 255–261. https://doi.org/10.1016/j.foodchem.2013.02.036

Pasrija, M., & Punia, D. (2010). Effect of pressure and solar cooking on phytic acid and polyphenol content of cowpeas. *Nutrition & Food Science*, *3*(3), 133–137. https://doi.org/10.1108/00346650010319732

Perrone, S., Tei, M., Longini, M., & Buonocore, G. (2016). The multiple facets of lutein: A call for further investigation in the perinatal period. *Oxidative Medicine and Cellular Longevity*. https://doi.org/10.1155/2016/5381540

Polycarp, D., Afoakwa, E. O., Budu, A. S., & Otoo, E. (2012). Characterization of chemical composition and antinutritional factors in seven species within the Ghanaian yam (*Dioscorea*) germplasm. *International Food Research Journal*, *19*(3), 985–992.

Prasad, S., & Chetty, A. A. (2011). Flow injection assessment of nitrate contents in fresh and cooked fruits and vegetables grown in Fiji. *Journal of Food Science*, *76*, C1143–C1148. https://doi.org/10.1111/j.1750-3841.2011.02346.x

Prain, G., & Lee-Smith, D. (2010). Urban agriculture in Africa: What has been learned? *African urban harvest: Agriculture in the cities of Cameroon, Kenya and Uganda*, (pp. 13–35). New york (USA): Springer. https://doi.org/10.1007/978-1-4419-6250-8_2

Raina, K., Rajamanickam, S., Singh, R. P., & Agarwal, R. (2008). Chemopreventive efficacy of inositol hexaphosphate against prostate tumor growth and progression in TRAMP mice. *Clinical Cancer Research*, *14*(10), 3177–3184. https://doi.org/10.1158/1078-0432.ccr-07-5275

Raman, G., Haslam, D., Avendano, E., & Johnson, J. J. (2019). Lutein/zeaxanthin intake and visual outcomes in adults with healthy eyes: Qualitative gap analysis. *Cogent Medicine*, *6*(1), 1683939. https://doi.org/10.1080/2331205X.2019.1683939

Ranard, K. M., Jeon, S., Mohn, E. S., Griffiths, J. C., Johnson, E. J., & Erdman, J. W. (2017). Dietary guidance for lutein: Consideration for intake recommendations is scientifically supported. *European Journal of Nutrition*, *56*(S3), 37–42. https://doi.org/10.1007/s00394-017-1580-2

Rasane, P., Jha, A., Kumar, A., & Sharma, N. (2015). Reduction in phytic acid content and enhancement of antioxidant properties of nutria-cereals by developing a fermented baby food. *Journal of Food Science & Technology*, *52*(6), 3219–3234. https://doi.org/10.1007/s13197-014-1375-x

Ray, R. C., & Didier, M. (2014). *Microorganisms and fermentation of traditional foods*. CRC Press.

Reis, F. R. (2017). Effect of blanching on food physical, chemical, and sensory quality. In F. R. Reis (Ed.), *New perspectives on food blanching* (pp. 1–48). Springer. https://doi.org/10.1007/978-3-319-48665-9

Rodríguez, H., Curiel, J. A., Landete, J. M., de las Rivas, B., de Felipe, F. L., Gómez-Cordovés, C., Mancheño, J. M., & Muñoz, R. (2009). Food phenolics and lactic acid bacteria. *International Journal of Food Microbiology*, *132*(2-3), 79–90. https://doi.org/10.1016/j.ijfoodmicro.2009.03.025

Ronoh, R., Ekhuya, N. A., Linde, M., Winkelmann, T., Abukutsa-Onyango, M., Dinssa, F. F., & Debener, T. (2017). African nightshades: Genetic, biochemical and metabolite diversity of an underutilised indigenous leafy vegetable and its potential for plant breeding. *The Journal of Horticultural Science and Biotechnology*, *93*(2), 113–121. https://doi.org/10.1080/14620316.2017.1358112

Ronoh, R., Linde, M., Winkelmann, T., Abukutsa-Onyango, M., Dinssa, F. F., & Debener, T. (2019). Morphological characterization, genetic diversity and population structure of African nightshades (section *Solanum* L.). *Genetic Resource and Crop Evolution*, *66*(1), 105–120. https://doi.org/10.1007/s10722-018-0700-z

Sangija, F., & Wu, W. (2020). Bamboo wine: Its production technology and potential as a sustainable health beverage. *Food Reviews International*. https://doi.org/10.1080/87559129.2020.1810699

Sangija, F., Kazosi, M., Martin, H., & Matemu, A. (Unpublished). *Trends and constraints of utilizing African nightshade (*Solanum nigrum *complex) in Tanzania*.

Sant'Ana, A. S., Landgraf, M., Destro, M. T., & Franco, B. D. G. M. (2011). Prevalence and counts of *Salmonella* spp. in minimally processed vegetables in São Paulo, Brazil. *Food Microbiology*, *28*(6), 1235–1237. https://doi.org/10.1016/j.fm.2011.04.002

Sanzani, S. M., Reverberi, M., & Geisen, R. (2016). Mycotoxins in harvested fruits and vegetables: Insights in producing fungi, biological role, conducive conditions, and tools to manage postharvest contamination. *Postharvest Biology and Technology*, *122*, 95–105. https://doi.org/10.1016/j.postharvbio.2016.07.003

Sato, T., Nagata, M., & Engle, L. M. (2002). *Evaluation of antioxidant activity of indigenous vegetables from south and southeast Asia*. Biological Resources Division, JIRCAS.

Schippers, R. R. (2002). *African indigenous vegetables: An overview of the cultivated species* (2nd ed.). Natural Resources Institute International, University of Greenwich and Horticultural Development Services LLP.

Schreinemachers, P., Simmons, E. B., & Wopereis, M. C. S. (2018). Tapping the economic and nutritional power of vegetables. *Global Food Security*, *16*, 36–45. https://doi.org/10.1016/j.gfs.2017.09.005

Selmar, D. (2018). Biosynthesis of cyanogenic glycosides, glucosinolates and non-protein amino acids. *Annual Plant Reviews*. https://doi.org/10.1002/9781119312994.apr0425

Senyolo, G. M., Wale, E., & Ortmann, G. F. (2018). Analysing the value chain for African leafy vegetables in Limpopo province, South Africa. *Cogent Social Sciences*, *4*(1), 1–16. https://doi.org/10.1080/23311886.2018.1509417

Serrano, J., Puupponen-Pimiä, R., Dauer, A., Aura, A.-M., & Saura-Calixto, F. (2009). Tannins: Current knowledge of food sources, intake, bioavailability and biological effects. *Molecular Nutrition & Food Research*, *53*(S2), S310–S329. https://doi.org/10.1002/mnfr.200900039

Shackleton, C. M., Pasquini, M. W., & Drescher, A. W. (Eds.). (2009). *African indigenous vegetables in urban agriculture*. CPI Antony Rowe.

Shahidi, F., & Ambigaipalan, P. (2015). Phenolics and polyphenolics in foods, beverages and spices: Antioxidant activity and health effects – A review. *Journal of Functional Foods*, *18*, 820–897. https://doi.org/10.1016/j.jff.2015.06.018

Sharma, K., Kumar, V., Kaur, J., Tanwar, B., Goyal, A., Sharma, R., & Kumar, A. (2019). Health effects, sources, utilization and safety of tannins: A critical review. *Toxin Reviews*. https://doi.org/10.1080/15569543.2019.1662813

Shin, J., Song, M.-H., Oh, J.-W., Keum, Y.-S., & Saini, R. K. (2020). Pro-oxidant actions of carotenoids in triggering apoptosis of cancer cells: A review of emerging evidence. *Antioxidants*, *9*(6), 532. https://doi.org/10.3390/antiox9060532

Shiundu, K. M., & Oniang'o, R. K. (2007). Marketing African leafy vegetables: Challenges and opportunities in the Kenyan context. *African Journal of Food Agriculture Nutrition and Development*, *7*(4), 1–17.

Silva, E. O., & Bracarense, A. P. F. R. L. (2016). Phytic acid: From antinutritional to multiple protection factors of organic systems. *Journal of Food Science*, *81*(6), R1357–R1362. https://doi.org/10.1111/1750-3841.13320

Singh, L., Cariappa, M. P., & Kaur, M. (2016). *Klebsiella oxytoca*: An emerging pathogen? *Medical Journal Armed Forces India*, *72*, S59–S61. https://doi.org/10.1016/j.mjafi.2016.05.002

Sivakrishnan, S. (2018). Traditional herbal medicines-A review. *International Journal of Research and Analytical Reviews*, *5*(4), 611–614

Sivakumar, D., Thi Phan, A. D., Slabbert, R. M., Sultanbawa, Y., & Remize, F. (2020). Phytochemical and nutritional quality changes during irrigation and postharvest processing of the underutilized vegetable African nightshade. *Frontiers in Nutrition*, *7*, 576532. https://doi.org/10.3389/fnut.2020.576532

Smith, F. I., & Eyzaguirre, P. (2007). African leafy vegetables: Their role in the world health organization's global fruit and vegetables initiative. *Africa Journal of Food Agriculture Nutrition and Development*, *7*(3), 1–17.

Smith, J. L., & Fratamico, P. M. (2017). Escherichia coli as a pathogen. In C. E. R. Dodd, T. Aldsworth, R. A. Stein, D. O. Cliver, & H. P. Riemann (Eds.), *Foodborne diseases* (3rd ed., pp. 189–208). Academic Press. https://doi.org/10.1016/B978-0-12-385007-2.00007-3

Soccol, C. R., Vandenberghe, L. P. D. S., Spier, M. R., Medeiros, A. B. P., Yamaguishi, C. T., Lindner, J. D. D., Pandey, P., & Thomaz-Soccol, V. (2010). The potential of probiotics: A review. *Food Technology and Biotechnology*, *48*(4), 413–434.

Soto-Blanco, B., César Marioka, P., & Lima Górniak, S. (2002). Effects of long-term low-dose cyanide administration to rats. *Ecotoxicology and Environmental Safety*, *53*(1), 37–41. https://doi.org/10.1006/eesa.2002.2189

Soto-Blanco, B., Pereira, F. T. V., Carvalho, A. F. d., Miglino, M. A., & Górniak, S. L. (2009). Fetal and maternal lesions of cyanide dosing to pregnant goats. *Small Ruminant Research*, *87*(1-3), 76–80. https://doi.org/10.1016/j.smallrumres.2009.09.029

Soto-Blanco, B., Stegelmeier, B. L., Pfister, J. A., Gardner, D. R., & Panter, K. E. (2008). Comparative effects of prolonged administration of cyanide, thiocyanate and chokecherry (*Prunus Virginiana*) to goats. *Journal of Applied Toxicology*, *28*(3), 356–363. https://doi.org/10.1002/jat.1286

Stevens, G. A., Bennett, J. E., Hennocq, Q., Lu, Y., De-Regil, L. M., Rogers, L., Danaei, G., Li, G., White, R. A., Flaxman, S. R., Oehrle, S.-P., Finucane, M. M., Guerrero, R., & Ezzati, M. (2015). Trends and mortality effects of vitamin A deficiency in children in 138 low-income and middle-income countries between 1991 and 2013: A Pooled analysis of population-based surveys. *The Lancet Global Health*, *3*(9), e528–e536. https://doi.org/10.1016/S2214-109X(15)00039-X.

Stewart, R., Korth, M., Langer, L., Rafferty, S., Da Silva, N., & Rooyen, C. v. (2013). What are the impacts of urban agriculture programs on food security in low and middle-income countries? *Environmental Evidence*, *2*(1), 7. https://doi.org/10.1186/2047-2382-2-7

Stoll, D. A., Wafula, E. N., Mathara, J. M., Trierweiler, B., Kulling, S. E., & Huch, M. (2021). Fermentation of African nightshade leaves with lactic acid bacterial starter cultures. *International Journal of Food Microbiology*, *342*, 109056. https://doi.org/10.1016/j.ijfoodmicro.2021.109056

Suleiman, M. S., Nuntah, L. C., Muhammad, H. L., Mailafiya, S. C., Makun, H. A., Saidu, A. N., Apeh, D. O., & Iheanacho, H. E. (2017). Fungi and aflatoxin occurrence in fresh and dried vegetables marketed in Minna, Niger State, Nigeria. *Journal of Plant Biochemistry & Physiology*. https://doi.org/10.4172/2329-9029.1000176

Tateishi, H., Monde, K., Anraku, K., Koga, R., Hayashi, Y., Ciftci, H. I., DeMirci, H., Higashi, T., Motoyama, k., Arima, H., Otsuka, M., & Fujita, M. (2017). A clue to unprecedented strategy to HIV eradication: "Lock-in and apoptosis. *Scientific Reports*, *7*(1), 1–8.

Temu, A. E., & Temu, A. A. (2005). *High value agricultural products for smallholder markets in Sub-Saharan Africa: Trends, opportunities and research priorities*. International Center for Tropical Agriculture.

Tournas, V. H. (2005). Spoilage of vegetable crops by bacteria and fungi and related health hazards. *Critical Reviews in Microbiology*, *31*(1), 33–44. https://doi.org/10.1080/10408410590886024

Traoré, K., Parkouda, C., Savadogo, A., BaHama, F., Kamga, R., & Traoré, Y. (2017). Effect of processing methods on the nutritional content of three traditional vegetables leaves: Amaranth, black nightshade and jute mallow. *Food Science & Nutrition*, *5*(6), 1139–1144. https://doi.org/10.1002/fsn3.504

U.S. Food and Drug Administration. (n.d.). *Nutrition education resources & materials*. http://www.fda.gov/nutritioneducation

Umuhozariho, M. G., Shayo, N. B., Msuya, J. M., & Sallah, P. Y. K. (2014). Cyanide and selected nutrients content of different preparations of leaves from three cassava species. *African Journal of Food Science*, *8*(3), 122–129.

van Jaarsveld, P., Faber, M., van Heerden, I. Wenhold, F., van Rensburg, W. J., & van Averbeke, W. (2014). Nutrient content of eight African leafy vegetables and their potential contribution to dietary reference intakes. *Journal of Food Composition and Analysis*, *33*(1), 77–84. https://doi.org/10.1016/j.jfca.2013.11.003.

Venketesh, R., Vidya, R., & Kalaivani, K. (2014). Gas chromatography and mass spectroscopy analysis of *Solanum villosum* (MILL) (Solanaceae). *International Journal of Pharmaceutical Sciences and Research*, *5*(12), 5283–5287. https://doi.org/10.13040/IJPSR.0975-8232.5(12).5283-87

Verbikova, V., Borilova, G., Babak, V., & Moravkova, M. (2018). Prevalence, characterization and antimicrobial susceptibility of *Yersinia enterocolitica* and other Yersinia species found in fruits and vegetables from the European Union. *Food Control*, *85*, 161–167. https://doi.org/10.1016/j.foodcont.2017.08.038

Vorster, I. H. J., Van Rensburg, W. J., Venter, S. L., & Van Zijl, J. J. B. (2007). Re-creating awareness of traditional leafy vegetables in communities. *African Journal of Food Agriculture Nutrition and Development*, *7*(4), 1–13.

Vucenik, I., & Shamsuddin, A. M. (2006). Protection against cancer by dietary IP6 and inositol. *Nutrition and Cancer*, *55*(2), 109–125. https://doi.org/10.1207/s15327914nc5502_1.

Vucenik, I., Kalebic, T., Tantivejkul, K., & Shamsuddin, A. M. (1998). Novel anti-cancer function of inositol hexaphosphate: Inhibition of human rhabdomyosarcoma in vitro and in vivo study. *Anticancer Research*, *18*, 1377–1384.

Wafula, E. N. (2017). *Effects of postharvest-processing technologies on the safety and quality of African indigenous leafy vegetables* (Doctorate thesis). The University of Hamburg. https://ediss.sub.uni-hamburg.de/handle/ediss/7392

Wafula, E. N., Brinks, E., Becker, B., Huch, M., Trierweiler, B., Mathara, J. M., Oguntoyinbo, F. A., Cho, G.-S., & Franz, C. M. A. P. (2017). Draft genome sequence of *Lactobacillus fermentum* BFE 6620, a potential starter culture from African vegetable foods isolated from fermented cassava. *Genome Announcements*, *5*(33), e00801-17. https://doi.org/10.1128/genomea.00801-17

Wafula, E. N., Franz, C. M. A. P., Rohn, S., Huch, M., Mathara, J. M., & Trierweiler, B. (2016). Fermentation of African indigenous leafy vegetables. *African Journal of Horticultural Science*, *9*:1–13.

Wakhanu, A. J., Kimiywe, J., & Nyambaka, H. (2015). Oxalate levels in selected African indigenous vegetable recipes from the lake victoria basin, Kenya. *International Journal of Agriculture and Environmental Research*, *1*(2), 88–105.

Wakholi, C., Cho, B. K., Mo, C., & Kim, M. S. (2015). Current state of postharvest fruit and vegetable management in East Africa. *Journal of Biosystems Engineering*, *40*(3), 238–249. https://doi.org/10.5307/JBE.2015.40.3.238

Wang, E., & Wink, M. (2016). Chlorophyll enhances oxidative stress tolerance in *Caenorhabditis elegans* and extends its lifespan. *PeerJ*, *4*:e1879. https://doi.org/10.7717/peerj.1879

Wang, R., & Guo, S. (2021). Phytic acid and its interactions: Contributions to protein functionality, food processing, and safety. *Comprehensive Review Food Science Food Safety*, *20*(2), 2081–2105. https://doi.org/10.1111/1541-4337.12714

Waturangi, D. E., Hudiono, F., & Aliwarga, E. (2019). Prevalence of pathogenic *Escherichia coli* from salad vegetable and fruits sold in Jakarta. *BMC Research Notes*, *12*(1), 1–9. https://doi.org/10.1186/s13104-019-4284-2

Wawszczyk, J., Kapral, M., Lodowska, J., Jesse, K., Hollek, A., & Wegler, L. (2015). Antiproliferative effect of inositol hexaphosphate on human skin melanoma cells in vitro. *Acta Poloniae Pharmaceutica*, *72*(5), 895–900.

Weinberger, K., & Msuya, J.(2004). *Indigenous vegetables in Tanzania: Significance and prospects*. AVRDC.

World Health Organization (WHO). (2003). *Nitrate and nitrite in drinking water. Development of WHO guidelines for drinking water quality*. World Health Organization. https://apps.who.int/iris/handle/10665/75380

World Health Organization (WHO). (2016). *Nitrate and nitrite in drinking-water. Background document for development of WHO guidelines for drinking-water* (No. WHO/FWC/WSH/16.52). World Health Organization.

Wie, S.-H. (2015). Clinical significance of *Providencia* bacteremia or bacteriuria. *The Korean Journal of Internal Medicine*, *30*(2), 167–169. https://doi.org/10.3904/kjim.2015.30.2.167

Workneh, T. S., & Woldetsadik, K. (2004). Forced ventilation evaporative cooling: A case study on banana, papaya, orange, mandarin, and lemon. *Tropical Agriculture*, *81*(3), 179–185

World Vegetable Center (WVC). (2017). *Traditional African vegetables go commercial in Cameroon*. https://avrdc.org/traditional-african-vegetables-go-commercial-cameroon/

Xiao, H.-W., Pan, Z., Deng, L.-Z., El-Mashad, H. M., Yang, X.-H., Mujumdar, A. S., Gao, Z.-J., & Zhang, Q. (2017). Recent developments and trends in thermal blanching.A comprehensive review. *Information Processing in Agriculture*, *4*(2), 101–127. https://doi.org/10.1016/j.inpa.2017.02.001

Xu, Q., Kanthasamy, A. G., & Reddy, M. B. (2011). Phytic acid protects against 6-hydroxydopamine-induced dopaminergic neuron apoptosis in normal and iron excess conditions in a cell culture model. *Parkinson's Disease*. https://doi.org/10.4061/2011/431068

Yang, R. Y., & Ojiewo, C. (2013). African nightshades and African eggplants: Taxonomy, crop management, utilization, and phytonutrients. In H. R. Juliani, J. E. Simon, & C.-T. Ho (Eds.), *African natural plant products volume II: Discoveries and challenges in chemistry, health, and nutrition* (pp. 137–165). American Chemical Society. https://doi.org/10.1021/bk-2013-1127.ch011

Yang, R. Y., Fischer, S., Hanson, P. M., & Keatinge, J. D. (2013). Increasing micronutrient availability from food in sub-Saharan Africa with indigenous vegetables. In H. R. Juliani, J. E. Simon, & C.-T. Ho (Eds.), *African natural plant products volume II: Discoveries and challenges in chemistry, health, and nutrition* (pp. 231–254). American Chemical Society. https://doi.org/10.1021/bk-2013-1127.ch015

Yang, T., Zhang, X.-M., Tarnawski, L., Peleli, M., Zhuge, Z., Terrando, N., Harris, R. A., Olofsson, P. S., Larsson, E., Persson, A. E. G., Lundberg, J. O., Weitzberg, E., & Carlstrom, M. (2017). Dietary nitrate attenuates renal ischemia-reperfusion injuries by modulation of immune responses and reduction of oxidative stress. *Redox Biology*, *13*, 320–330. https://doi.org/10.1016/j.redox.2017.06.002

Yuan, B., Byrnes, D., Dinssa, F. F., Simon, J. E., & Wu, Q. (2019). Quantity assessment of polyphenols, glycoalkaloids and saponins in *Solanum scabrum* berries of different genetic sources and maturity by HPLC/UV-visible/MS methods. *Journal of Science, Food & Agriculture*, *99*, 3578–3587. https://doi.org/10.1002/jsfa.9579

Yuan, B., Byrnes, D., Giurleo, D., Villani, T., Simon, J. E., & Wu, Q. (2018). Rapid screening of toxic glycoalkaloids and micronutrients in edible nightshades (*Solanum* spp.). *Journal of Food and Drug Analysis*, *26*(2), 751–760. https://doi.org/10.1016/j.jfda.2017.10.005

Yuan, B., Dinssa, F. F., Simon, J. E., & Wu, Q. (2020). Simultaneous quantification of polyphenols, glycoalkaloids and saponins in African nightshade leaves using ultra-high-performance liquid chromatography-tandem mass spectrometry with acid assisted hydrolysis and multivariate analysis. *Food Chemistry*, *312*, 126030. https://doi.org/10.1016/j.foodchem.2019.126030

Yuan, B., Lyu, W., Dinssa, F., Hoffman, D., Simon, J. S., & Wu, Q. (2020). African nightshades: Recent advances on the phytochemistry, nutrition, and toxicity. H. R. Juliani, J. E. Simon, & C.-T. Ho (Eds.), *African natural plant products, volume III: Discoveries and innovations in chemistry, bioactivity, and applications* (pp. 103–137). American Chemical Society.

Zahara, K., Ahmad, N., Bibi, Y., Bibi, F., Sadaf, H. M., & Sardar, N. (2019). An insight to therapeutic potential and phytochemical profile of *Solanum villosum* (L). *Medicine in Drug Discovery*, *2*, 100007. https://doi.org/10.1016/j.medidd.2019.100007.

Zempleni, J., Rucker, R. B., McCormick, J. W., & Suttie, J. W. (Eds.). (2007). Handbook of vitamins. Free radical biology and medicine (4th ed., Vol. *11*). Taylor & Francis Group.

Zhao, L., Wang, L., Di, S., Xu, Q., Ren, Q., Chen, S., Huang, N., Jia, D., & Shen, X. (2018). Steroidal alkaloid solanine A from *Solanum nigrum* Linn. exhibits antiinflammatory activity in lipopolysaccharide/interferon γ-activated murine macrophages and animal models of inflammation. *Biomedicine & Pharmacotherapy*, *105*, 606–615. https://doi.org/10.1016/j.biopha.2018.06.019

Zhu, B., Zhang, G.-Q., Lou, M.-M., Tian, W.-X., Li, B., Zhou, X.-P., Wang, G.-f., Liu, H., Xie, G.-L., & Jin, G.-L. (2011). Genome sequence of the *Enterobacter mori* type strain, LMG 25706, a pathogenic bacterium of *Morus alba* L. *Journal of Bacteriology*, *193*(14), 3670–3671. https://doi.org/10.1128/jb.05200-11

Zhu, Q., Gooneratne, R., & Hussain, M. (2017). *Listeria monocytogenes* in fresh produce: Outbreaks, prevalence and contamination levels. *Foods*, *6*(3), 21. https://doi.org/10.3390/foods6030021

Zijp, I. M., Korver, O., & Tijburg, L. B. (2000). Effect of tea and other dietary factors on iron absorption. *Critical Reviews in Food Science and Nutrition*, *40*(5), 371–398. https://doi.org/10.1080/10408690091189194

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