Solanum aethiopicum

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Solanum aethiopicum is a very important vegetable for both rural and urban communities in Africa. The crop is rich in both macro-and micronutrients compared with other vegetables and is suitable for ensuring food and nutritional security.

Keywords: nutraceuticals ; genetic diversity ; breeding ; Solanum aethiopicum ; neglected and underutilized

1. Introduction

Solanum aethiopicum is a horticultural crop species consumed in Africa and it contains a great number of nutrients [1]. The crop is an important food source for many people. The fruits and leaves are employed in the preparation of stews and soups. It is used to treat certain diseases because of the phytochemicals it contains and serves as a rich source of important macro and micronutrients [2]. It is thus a potential curative to hidden hunger [3][4][5]. The crop is one of the most widely grown vegetables in Africa and was brought to Brazil through the slave trade. The crop belongs to the *Solanaceae* family with a chromosome number of 24. It is commonly called African eggplant, scarlet eggplant, garden eggs, and bitter tomato. The species is believed to have originated from Africa and was domesticated from the wild *Solanum anguivi* Lam., via the semi-domesticated *Solanum distichum* Schumach. & Thonn., both of which are found throughout tropical Africa [6][7]. The crop is cultivated in the humid zones of West Africa for its immature fruit, in the savanna area frequently for both its leaves and immature fruits (often called 'djakattou'), and in East Africa, especially Uganda, mainly as a leaf vegetable (called 'nakati'). African eggplant is a good and reliable crop as it yields a harvest of about 25 tons per hectare [8]. The species *Solanum melongena* and *Solanum macrocarpon* are the close relatives of *S. aethiopicum* and both species are commonly grown in Africa. Mwinuka et al. describe this crop as a neglected and underutilized horticultural species, despite possessing the ability to significantly contribute to nutrition and food security. It has been overlooked as there is limited knowledge on the plant and research efforts conducted, especially in terms of climate adaptation and sustainable agricultural growth in Africa and particularly in East Africa [9].

Although African eggplants possess several important properties, knowledge on the genetic improvement potential, the possibility of providing medicinal or nutritional benefits, such as disease prevention and treatment, and its potential for agricultural sustainability are still limited. This is because the crop has not received adequate research attention for years. There is therefore a need to promote the dynamic use, documentation, conservation, and evaluation of genetic resources of this important but neglected crop [10]. Additionally, due to the overdependence on the three major food crops (wheat, maize, and rice) and their subsequent shortages, the conservation, improvement, and utilization of underutilized plant species such as African eggplant are of utmost importance. The cultivation of underutilized crops provides greater genetic biodiversity, and can potentially improve food security [11].

2. Physiological and Genetic Properties of *S. aethiopicum*

2.1. Characterization and Ecophysiology

S. aethiopicum grows to about 2.5 m in height and is often a branched deciduous shrub. On the stems, the leaves are alternately arranged and have smooth or lobed margins. Leaf-blades can reach a length of up to 30 cm and a width of 21 cm. The leaves' petioles are oval or elliptical, reaching a length of up to 11 cm [12]. The species is hermaphrodite (has both male and female organs) and mainly self-pollinated, but insect pollinators complement self-pollination as they provide cross-pollen, which augments gene exchange and hybrids in the natural population and lessens inbreeding depression. The inflorescence is a five-flowered lateral, racemose cyme [13]; peduncle often short or even absent, rachis short to long. The flowers develop into the egg- or spindle-shaped berries, which are red to orange in color with a smooth or grooved surface depending on the variety. The crop becomes ready for harvesting from 100 to 120 days after planting and the fruit should be plucked before it changes color from white to pale yellow. African eggplant seeds are flattened, 2–5 mm in diameter, lenticular to reinforced, and pale brown or yellow in color. Germination is epigeal with cotyledons being thin and leafy [14]. Multiplication of the species is carried out mainly through the seeds.

S. aethiopicum is a complex species consisting of groups that are very distinct morphologically and were formerly regarded as four separate species [15] (Figure 1). It is also described to be a hypervariable species as it is made up of many forms and types that differ morphologically, with hundreds of local varieties [16]. The species *S. aethiopicum* can be classified with respect to its use into four distinct groups. They are the Gilo, Shum, Kumba, and Aculeatum group [17]. The Gilo group gives rise to several differently shaped edible fruit (ranging from a spherically depressed form to elliptic in outline); the Kumba group possess a stout main stem with large hairless leaves that can be picked as a green vegetable, and later produces very large grooved fruit that is picked green or even red; the Shum group is a short much-branched plant with small hairless leaves and shoots that are plucked frequently as a leafy green vegetable but the small (1.5 cm across) very bitter fruits are not eaten; the Aculeatum group produces flat-shaped fruit [18]. The plant is also sometimes grown as an ornamental one.

Figure 1. Fruit vegetable pictures for (**a**) Kumba, (**b**) Aculeatum, (**c**) Shum, and (**d**) Gilo group of *S. aethiopicum.*

Being a tropical plant species, the African eggplant is intolerant to low temperatures and very cold or water-logged conditions. Some level of tolerance to irrigation-induced salinity has been reported from Senegal [19]. The edible groups of African eggplant (Gilo, Kumba, and Shum) are adapted to diverse areas depending on the climate. The Gilo group is commonly found in humid areas all over tropical Africa where its members grow best at the full sun of woodland savanna on fairly deep and well-drained soils of pH 5.5–6.8, with 25–35 °C and 20–27 °C day and night temperatures, respectively [20]. The Kumba group, which is cultivated chiefly in semi-arid areas from Occidental Sahel to the north of Nigeria, is able to put up with environments that are hotter than normal (even to 45 °C day temperature) with occasionally low air humidity of about 20%, especially after irrigation [20]. The Shum group is typically seen to shed its leaves during plant water loss under warm, humid conditions. In Africa, the group is found at high altitudes and very humid areas mainly in Uganda and the southeast of Nigeria [20]. In Uganda, it is grown in swamps during the dry season [21][22].

The hybrids emanating from the cross between *S. aethiopicum* and *S. anguivi* Lam (wild ancestor) are fertile [23]. Characterization of a plant species gives a description of its germplasm and determines the expression of highly heritable traits ranging from morphological or agronomical features to seed proteins or molecular markers. The characterization of cultivated eggplants and their wild relatives has commonly been analyzed by employing conventional morphological descriptors that are highly heritable and simple to assess [15][24]. Studies on the morphological characterization of scarlet eggplant have shown it to be a highly variable crop. The most extensive research was performed by Lester in 1986 [16]. The authors characterized 108 accessions of the scarlet eggplant complex using morphological and taxonomically relevant characters (e.g., fruit size, number of locules, number of flowers per inflorescence, prickliness) and observed that the four cultivar groups could be differentiated by a set of traits (including leaf shape, fruit shape, prickly leaves and stem, bitter taste) detected in a single group. A number of the accessions were also observed to be intermediate between *S.*

anguivi and *S. aethiopicum*. According to Osei et al. [25], a wide variation exists among species *S. aethiopicum*, *S. anguivi,* and *S. macrocarpon*. They also observed a lot of similarities between the lines of *S. aethiopicum* and *S. anguivi*.

2.2. Propagation, Cultivation Techniques, and Systems

The African eggplant is often grown as an annual, but generally a perennial, plant with stems that become more or less woody and persist. It grows well in deep, well-drained soils. The cultivation of African eggplant is mainly dependent on the rain, but irrigation can be applied during the dry seasons. The African eggplant requires a pH of 5.5–6.8 and thrives well at daytime temperatures ranging between 20–30 °C, but it can tolerate 10–40 °C. It cannot tolerate very cold or water-logged conditions [26]. It is more prudent to grow the crop on a minimum to low salinity soil to promote maximum growth and development since salinity plays a part in disturbing the anatomical and morphological features of the crop [27]. *S. aethiopicum* is propagated by seed. The seeds for planting are obtained from fully ripe fruits that should not be exposed to direct sunlight. Seeds remain viable for a long time when stored in a cool, dry place. Seeds also store well inside air-dried fruits, which is the traditional form of seed storage by farmers. The 1000-seed weight of African eggplant is 2–4 g. Its germination takes 5–9 days for the Gilo and Shum groups, but only 3–5 days for the Kumba group, although the latter may express seed dormancy and end up having few seeds per fruit. Seeds are sown in sandy soil in nursery beds or containers. The seedlings are transplanted to the field after 30–35 days when they have 5–7 leaves and are 15–20 cm tall. Plants of the Kumba group grown in dry savanna regions are often planted at a distance of 1 m × 1 m, whereas those of the Gilo group can be spaced at 50–100 cm in the row and 75–100 cm between rows, depending on the cultivar [14]. They can be grown either on flat land or on ridges. The cultivation of Shum Group is somewhat different. Cultivars of the Shum group are grown for their young shoots, which are frequently harvested, and the crop can thus be spaced at 20–30 cm in the row and 60–75 cm between rows. An alternative is to broadcast seeds of the Shum group, for thinned plants to be used as the first harvest. Seeds are sometimes broadcast together with amaranths (*Amaranthus* spp.) and spider plants (*Cleome gynandra* L.), where the latter two crops are harvested early by uprooting and the plants of the *S. aethiopicum* Shum group remain.

Production of African eggplant is created using a range of cultivation techniques. These techniques are aimed at the preservation and modification of the physical and chemical characteristics of the soil (soil preparation and tillage, irrigation, fertilization) while improving plant production (training, pruning, fruiting, production, and pesticide treatments). Some examples of cultivation techniques employed by farmers include intercropping, mixed cultures, and monocultures. On the farm, it can be intercropped with crops such as cowpea, sorghum, *Ziziphus mauritiana* Lam, *Solanum lycopersicum*, *Capsicum annuum, Corchorus olitorius,* and *Abelmoschus esculentus* [28][29]. In mixed cultures, African eggplant is the main crop, whereas *Zea mays* and *Manihot esculenta* are grown as secondary crops. Monoculture is also practiced where an optimal crop density is cultivated on the farm and sometimes under irrigation during the dry season. Most of the farmers in Africa cultivate using conventional and organic systems. From the study of Aguessy et al., the majority of the farmers who were interviewed acknowledged the use of NPK and urea fertilizers a few days before transplanting as compensation for soil deficiency conditions. The other proportions of farmers are into the use of organic manures [30]. Animal manure and compost are being employed in the cultivation of African eggplant. They are helpful in soil amendment due to the needed organic matter and sequester carbon they add, as well as the reduced reliance on chemical pesticides and fertilizers. Compost from false yam (*Icacina oliviformis*) tuber was applied to a field planted with African eggplant and it showed support for plant growth and yield characteristics [31].

Efforts are also underway to optimize the yield of African eggplant. Mwinuka and others in a recent report assessed how irrigation water and nitrogen affect the growth parameters of African eggplant, as well as the yield, fruit quality, water use efficiency (WUE), and nitrogen use efficiency (NUE). They observed that the African eggplant growth variables (plant height and Leaf Area Index) correlated well with fruit yield, and when 100% water was added to a 75% (187 kg/ha) nitrogen treatment, the quality of the fruit was at maximum. Superlative WUE and NUE were obtained at 80% and 100% water supply, respectively, in addition to a nitrogen concentration of 75%. It was further suggested that in soils with a mixture of sand, clay, and loam, under sub-humid circumstances that are tropical, the optimal application for African eggplant will likely be about 80% of the total irrigation requirement and 75% of the nitrogen requirement, in order to minimize the rate of exchange between the various indicators [9].

The crop is affected by several diseases and pests. Common diseases of African eggplant include *Chilli veinal* mottle virus (ChiVMV) borne by the vector green peach aphid (*Myzus persicae*) [32], Stemphylium disease caused by *Stemphylium solani,* and other soil-borne severe diseases such as wilt caused by *Ralstonia solanacearum*, collar rot and wilting caused by *Sclerotium rolfsii* and *Verticillium dahliae,* and root-knot nematodes (*Meloidogyne* spp.) [33]. Pests of the plant include green peach aphid *Myzus persicae,* grasshoppers (*Zonocerus* sp.), fruit, and flower borers (*Leucinodes* and *Scrobipalpa*), leafhopper (*Jacobiasca lybica),* and caterpillars (*Selepa docilis)* [34]. Spider mites (*Hemitarsonemus* and *Tetranychus*) are a serious problem in drier regions; acaricide sprays can normally control them [35].

2.3. Biodiversity and Conservation

Today, the production of crops is based on just a small circle of plant species [36]. Despite this fact, several undermined crops are grown and collected, thereby adding to biodiversity [37]. Although *S. aethiopicum* is one of the less recognized crops, it shows a distinct diversity in the cultivated types of varieties in Ghana. As well as contributing to biodiversity intraspecifically, it also helps to maintain wide intraspecies biodiversity through local cultivation. Limited scale producers keep up the genetic diversity of this crop. Not only is there scattering of cultivars across locations, but their naming is often also set differently. Moreover, the cultivars could be equivalent, yet exhibit differences in their phenotype due to diverse biotic and abiotic factors. *S. aethiopicum* has noticeable qualities such as taste, size, color, shape, and others, but these attributes differ widely. For instance, its color could be deep green, green, white, cream, or even yellow and this could be used as the basis of freshness. The sizes range from small to big with a massive demand for the latter. The shape could be round, elongated, with ridged or smooth surfaces. Taste is additionally a significant quality property pursued by buyers and very frequently identified with the shape. Most often than not, the bitter ones are the round-shaped ones, and this characteristic is genotype-specific but environmental factors could also play a part in it [37]. In Ghana, the research scope to determine the reason for this diversity is very little, though not for lack of diversity in African eggplant germplasm, and due to this myopic research level, to our knowledge, nothing has been implemented to conserve diversity.

Accurate information on the analysis of genetic diversity, which is expressed as variants in a linear sequence of nucleotides in DNA, is relevant to know which genes are responsible for which trait expressed in *S. aethiopicum*. African eggplant differs severely when it comes to agronomic traits, some of which include the time of flowering, fruit yield, fruit maturity, branching habits [25]. Taking the physiology, morphology, and biochemical properties of the eggplant's related species and wild types into consideration, there exists a wide diversity morphologically [38][39]. For any breeding program to be effective, the detail in the genetic magnitude of diversity within the crop species is dire. This is because informed knowledge on genetic diversity could go a long way in sustaining selection gain in the long term [40]. From Sharma and Jana's [41] point of view, a priority for starting an efficient breeding program is the assessment of how species vary genetically since it gives a platform for cutting desirable genes to size. Additionally, knowing how genetically diverse a huge population of African eggplant germplasm is aids in the decision-making of breeding techniques and management schedules for current and future use [42]. The study of genetic diversity allows for the selection of African eggplant parents that are genetically diverse to obtain in the segregating generations, recombinants that are desirable [43]. This choice of parental selection using biodiversity studies is valuable because it showcases how useful variations can be expressed in later offspring. Thus, with African eggplant, diversity studies at their early stages would amount to the creation of cultivars and varieties that are shared across the board and known for their stability and adaptability in terms of performance (consistency intolerance of harsh weather conditions and disease resistance) based on evidential characteristics.

Since there is a lack of large genomic resources for conservation, this implies that *S. aethiopicum* breeding is lagging behind other vegetable crops, especially of the same species. It is thus highly important to evaluate and safeguard *S. aethiopicum*, as it is highly underrepresented in the global conservation system of plant genetic resources and may have hidden genes that are of relevance when it comes to tolerance or resistance of biotic or abiotic stresses [8]. The World Vegetable Center (WorldVeg) secures some amount of public germplasm collection of eggplant, which includes the major cultivated species (*S. melongena*, *S. aethiopicum,* and *S. macrocarpon)*, and more than 30 eggplant wild relatives, with more than 3200 accessions collected from 90 countries of which *S. aethiopicum* is included and considered as important. Over the last 15 years, more than 10,000 seed samples from the Center's eggplant collection have been shared with public and private sector entities, including other genebanks. An analysis of the global occurrences and genebank holdings of cultivated eggplants and their wild relatives reveals that the WorldVeg genebank holds the world's most extensive public collection of the three cultivated eggplant species with *S. aethiopicum* being the third. However, comparing this with other vegetable crops (with huge genomic resources for conservation), there is still a significant deficiency in the conservation of *S. aethiopicum*. The main cluster of *S. aethiopicum* is in West Africa, with a total of 1288 occurrences based on the literature of previous studies and characterization data available at the WorldVeg [8]. From 1981–1986, the International Plant Genetic Resources Institute (IPGRI) performed a collection of genetic resources of African eggplant. In 2001, efforts were made to regenerate and evaluate the collections as part of the EGGNET project, an international project for managing the genetic resources of eggplant. A rich germplasm collection is maintained at INRA in Montfavet, France. A collection is kept at AVRDC in Arusha, Tanzania, and plant breeders in Ghana, Côte d'Ivoire, Nigeria, Senegal, and elsewhere in Africa also maintain some accessions of African eggplant [14].

2.4. Genetics and Breeding

The breeding of African eggplant has received little attention, although germplasm collections of it exist. Most of the cultivated species came about as a result of selection by farmers and consumers' preference for fruit size, color and taste (sweet or bitter), skin toughness, shelf life, as well as yield potential, disease resistance, earliness, and duration of the harvest season, plant architecture and fruit location, and in the case of the Shum group, ease of leaf harvest. *S. aethiopicum* for a long time has been neglected by formal programs involved in the improvement of crops except in breeding programs where some of its specific traits are exploited to improve the resistance of *S. melongena* to diseases. Domesticated and wild relatives of African eggplant possess important traits that remain to be explored. *S. aethiopicum* has been reported to express low susceptibility to pests and diseases than *S. melongena* [44], leading to the selection of *S. aethiopicum* (Aculeatum group) in Japan as a rootstock for tomato and garden egg due to its resistance to wilt. It also shows a higher level of tolerance to drought and heat than tomato and eggplant in the field. Ano et al. [45] reported on *S. aethiopicum* in a breeding program used as a source of the disease resistance gene. From this study, *S. melongena* was crossed with *S. aethiopicum* and the hybrids subsequently backcrossed to *S. melongena*. It was likely to derive families with a high resistance level to bacterial wilt from the second backcross, as well as vast differences in the shape and fruit color. Studies into the molecular mechanism underlying double fertilization between self-crossed *S. melongena* and that hybridized with *S. aethiopicum* have been carried out using comparative transcriptome analysis. A number of differentially expressed genes (DEGs) were found which are involved in plant hormone transduction, cell senescence, metabolism, and biosynthesis pathways. The findings of this study provide insights into the regulatory mechanisms underlying variations between ovaries of self-crossed and hybrid eggplants and a basis for future studies of crossbreeding *Solanum* [46].

In a study by Hamidou et al. [47], 12 scarlet eggplant accessions were assessed via morphological and cytomolecular characterization. This study established the genetic closeness of *S. aethiopicum* and *S. melongena* not only in terms of their chromosome number but also in terms of their genome size. Similarities and contrasts among the 12 scarlet eggplant accessions were observed for 27 quantitative descriptors. The cluster analysis was able to classify the accessions into four distinct groups. A great deal of variability was found among the 12 scarlet eggplant accessions, most of which were associated with flower and fruit-related traits. However, no significant differences among the accessions for the GC content, for seedling and stomatal traits evaluated were found. Additionally, there was no significant difference ($\alpha = 0.05$), with the exception of one accession (PI 420226), among the scarlet eggplants evaluated for their nuclear DNA content.

Availability of the genome information of a neglected crop such as *S. aethiopicum* will hasten a more productive and exact selection of exceptional accessions of the crop and breeding of it, as well as other crops within the *Solanaceae* family. A recently published draft genome sequence of the African eggplant has afforded some insights into disease resistance, drought tolerance, and the evolution of the genome [48]. The 1.02 Gb draft genome assembly of *S. aethiopicum* contained largely repetitive sequences (78.9%). Gene models were annotated including 34,906 protein-coding genes. Expansion of disease resistance genes was found through two rounds of amplification of long terminal repeat retrotransposons, which may have happened ~1.25 and 3.5 million years ago. The resequencing of *S. aethiopicum* and *S. anguivi* genotypes resulted in the identification of 18,614,838 single-nucleotide polymorphisms (SNPs), of which 34,171 were positioned within disease resistance genes [48]. Furthermore, the investigation into the domestication and demographic history showed active selection in both the Gilo and Shum groups for genes involved in drought tolerance. A pan-genome of *S. aethiopicum* was generated containing 51,351 protein-coding genes, 7069 of which were missing from the reference genome [48].

More recently, few researchers have focused their attention on improving the agronomic characters of farmer’s selection. In Senegal, very hairy, mite-resistant cultivars of the Kumba group have been bred. Some promising cultivars for high yield were obtained when *S. anguivi* was crossed with ‘Dwomo’, a cultivar whose fruits resemble an egg in its size and shape. This was achieved by collaboration between the Crops Research Institute in Ghana and the Natural Resources Institute (United Kingdom) [49]. A seed company in Senegal (Technisem Seed Company) is into the commercialization of improved cultivars of African eggplant. The most popular cultivars of the Kumba group are ‘Ndrowa’ (flat, ribbed, green-yellow fruits of 70–80 g, diameter 5 cm, with a mild taste, plant height 60–100 cm, harvestable 50–70 days after planting, yield potential 25 t/ha, resistant to mites), ‘Ngalam’ (flat, strongly ribbed, pale green to white fruits of 120–180 g, diameter 7 cm, slightly bitter taste, plant height 60 cm, harvestable 50–60 days after planting, yield potential 10 fruits per plant, resistant to mites) and ‘Jaxatu Soxna’ (flat, ribbed, pale green to white fruits of 40–50 g, diameter 5–6 cm, bitter taste, plant height 50 cm, harvestable 40–60 days after planting, yield 20–25 fruits per plant or 30 t/ha, or used as a leafy vegetable, resistant to mites, drought, high rainfall, and high temperatures).

The inheritance of some important traits in *S. aethiopicum* has also been studied intensively. Most wild-type characters such as prickles, stellate hairs, and long racemose cymes are often dominant. Imperfect morphogenesis, indicating loss of genetic regulation, was involved in many of the recessive domesticated traits. The F_1 hybrids between cultivars (*S. anguivi* and *S. aethiopicum*) also showed significant heterosis and are recommended for crop production [23]. Research for the yield of fruit and yield component traits on the mode of inheritance, genetic control, heritability, and heterosis has been implemented. Traits such as fruits per cluster, the cluster per plant, and length and width, are the parameters of fruit yield in fruit vegetables. Out of the components of fruit yield studied in an experiment for *S. aethiopicum*, fruit length and fruit clusters per plant were both affected by the additive gene action, while on the other hand, diameter and fruits per cluster required the dominance gene action when it comes to their inheritance. Dominance and dominance by dominance digenic interaction expressed the duplicate type of epistasis for fruit clusters per plant [50]. This genetic information is very imperative for efficient breeding strategy and development of hybrids and open-pollinated varieties.

In vitro regeneration from cotyledonary and true leaf explants (direct organogenesis) of *S. aethiopicum* and *S. macrocarpon* have been reported by Carmina et al. [51]. A higher level of regeneration and the average of shoots per explant has been demonstrated by using low concentrations (0.1 and 0.2 µM) of thidiazuron (TDZ) in the media. The success allows for further genetic transformation and improvement of *S. aethiopicum* through in vitro techniques. Somaclonal variation occurring in tissue culture media has proven to be a potential source of variability for crop improvement [52][53]. Studies have shown that in vitro regeneration of plants through indirect organogenesis (i.e., via callus phase) could induce more variants as compared to direct organogenesis. Hence, tissue culture avenues could be exploited to induce somaclonal variants of African eggplant, so as to broaden the genetic base of the crop for future breeding programs. Mutants of African eggplant demonstrate differences in traits that are agro-morphological and yield attributes with varying doses of Gamma irradiation. The effect of the mutagen on *S. aethiopicum* is assessed in terms of its influence on growth improvement by inducing changes in cells and tissues of the plant that are cytological, genetical, biochemical, physiological, and morphogenetic. Low doses of gamma irradiation (40 Gy and 60 Gy) caused significant variation in some traits that are agro-morphological, like plant height, leaf characteristics, days to first flowering, number of leaves per plant, and number of branches per plant in *S. aethiopicum* [54]. Therefore, mutation breeding by gamma irradiation and other mutagens can be employed as an effective means of inducing genetic variability in African eggplant to improve and select desirable mutants for breeding purposes.

2.5. Phytochemical and Pharmacological Activities

The African eggplant fruits are usually used in the preparation of soups, in stews as a vegetable, and they can sometimes be eaten raw. It is also possible to eat the shoots and leaves in a cooked form. African eggplant contains many proteins, minerals, vitamins, carbohydrates, fat, crude fiber, ash, and water substances that are relevant and massively helpful in nutrient supplement and health promotion. The fruits mostly possess high moisture content and low dry matter [55]. Several fundamental mineral elements, including calcium, magnesium, potassium, sodium, manganese, iron, copper, zinc, and phosphorus are also contained in the fruits of *S. aethiopicum*. These minerals are involved in functions such as maintenance of heart rhythm, muscle contractility, formation of bones and teeth, acid-base balance, regulation of cellular metabolism, and enzymatic reactions [56]. Moreover, *S. aethiopicum* has been shown to be rich in vitamins (such as vitamin A, B, C, D, and E) [57]. Analysis of the nutritional and mineral composition of the fruits and leaves of *S. aethiopicum* brought to light that the crop is rich in major and minor nutrients and all the nutrients are known to be vital for the proper functioning of the body [1]. Of note, the exocarp of both ripe and unripe *S. aethiopicum* fruit bears no incidence of toxic metals (e.g., chromium, cadmium, lead, etc.), which makes it a better source of health products. The nutrient, mineral, and vitamin composition of *S. aethiopicum* fruits are presented in Table 1 as adopted from previous studies [55][56][57]. Chinedu et al. in their study on the proximate and phytochemical analyses of the fruits of *S. aethiopicum* also identified nutrients and mineral elements [58] that had similar values to the ones presented above.

Table 1. Proximate composition of *S. aethiopicum* fruits.

Nutrient	Composition (per 100 g of Fresh Fruit)
Moisture content	**91.20 ± 0.34%**
Crude protein	**1.07 ± 0.01%**
Crude fat	**0.38 ± 0.03%**
Crude fiber	**2.44 ± 0.04%**
Ash content	**0.73 ± 0.03%**
Carbohydrate	**4.18 ± 0.08%**
Dry matter	**8.80 ± 0.19%**
Mineral Element	**Concentration (mg/g Dry Weight Basis)**
Calcium	**0.310~0.360**
Magnesium	**0.595~0.625**

Iron	**0.025~1.125**
Potassium	**4.475~9.525**
Sodium	**0.865~1.005**
Manganese	**0.005**
Copper	**0.007~0.008**
Zinc	**0.077~2.938**
Phosphorus	**1.091~1.245**
Vitamins	**Content (mg/100 g Fresh Fruit)**
Vitamin A (retinol)	**53.550 ± 0.55**
Vitamin B1 (thiamine).	**0.037 ± 0.00**
Vitamin B2 (riboflavin)	**0.034 ± 0.00**
Vitamin B (niacin)	**0.700 ± 0.00**
Vitamin C (ascorbic acid)	**2.300 ± 0.00**
Vitamins D (calciferol)	**0.010 ± 0.00**
Vitamin E (tocopherol)	**0.310 ± 0.00**

Phytochemical screening of the crop showed a copious presence of alkaloids, flavonoids, phytosterols, saponins, and vitamin C, moderate presence of cardiac glycosides, steroids, and tannins, and a trace amount of terpenoids in the fruits [55][58]. Alkaloidal extracts of *Solanum* species have been reported to express analgesic effects and central nervous system depression [59]. The presence of alkaloids, mainly glycoalkaloids, gives the bitterness in eggplants and the relative bitterness determines to a great extent their edibility or otherwise. The incidence of toxic glycoalkaloids leads to poisoning in some *Solanum* species by causing diarrhea or carcinogenic glycosides which bring about excessive deposition of calcium in tissues. Researchers have cautioned that care should be taken when using the fruit and insist that its consumption should be in small quantities [60]. African eggplant is of great medicinal importance and thus has many functional food properties. Its saponins are important dietary supplements and nutraceuticals. They possess antimicrobial properties and protect plants from microbial pathogens. Reports have shown that saponins present in traditional medicine preparations cause hydrolysis of glycosides from terpenoids which avert the toxicity associated with the intact molecule [61][62]. Ascorbic acid and flavonoids have been found to be present in the fruits and stalk of the plant, which contain high antioxidant potential [63][64][65]. Traditionally, many tropical African countries use the fruits of bitter cultivars as medicine to cure certain ailments [66]. The roots and fruits of African eggplant are used as a carminative and sedative, and to treat colic and high blood pressure; leaf juice as a sedative to treat uterine complaints; an alcoholic extract of leaves as a sedative, anxiolytic, anti-emetic and to treat tetanus after an abortion [67][68]. The crushed and softened fruits are also used as a purgative. The juice of boiled roots is used to treat hookworms, while the crushed leaves are used for gastric ailments [19]. Several parts of the plant are used, as powder or ash, to treat diseases such as diabetes, otitis, cholera, toothache, bronchitis, skin infections, dysuria, asthenia, dysentery, and hemorrhoids in decoction. Moreover, antiviral, anticancer, anticonvulsant, and anti-infective effects have been reported in eggplants due to the phytochemicals they contain. Narcotic, anti-asthmatic, and antirheumatic effects are also ascribed to eggplants [69].

A previous study identified four groups of phenolic acids in the fruit of *S. aethiopicum*. Group 1 comprised chlorogenic acid isomers and 3-O-trans, 5-O-trans, 5-O-cis isomers of caffeoylquinic acid (3CQA, neochlorogenic acid; 5-CQA, chlorogenic acid; 4-CQA, cryptochlorogenic acid, and 5-(Z)-CQA, cis-chlorogenic acid). Chlorogenic acid was the predominant compound in Group 1, with average levels 176-, 28.9-, and 92.5-fold higher than levels of neochlorogenic acid, cryptochlorogenic acid, and cis-chlorogenic acid, respectively. Group 2 consisted of two phenolics: 3,5-diCQA and 4,5-diCQA. Group 3 comprised four compounds: N, N′-dicaffeoylspermidine (predominated); N-caffeoylputrescine and their isomers; and Group 4 comprised 3-O-actyl-5-O-caffeoylquinic acid (3-acetyl-5CQA), 3-O-actyl-4-O-caffeoylquinic acid (3-actetyl-4-CQA) [70]. The leaves of African eggplant possess oxalate and alkaloids such as solasodine, with reported glucocorticoid effects [14]. Its characteristic bitter taste is a result of the furostanol glycosides [44][67].

Anosike et al. [71] in their study reported that *S. aethiopicum* fruit had anti-inflammatory properties. Compared to the control group, the fruit extract substantially reduced the fresh egg albumin-15-mediated rat paw edema and reduced the granuloma tissue formation in the fruit-treated groups. According to Tunwagun et al. [72], phytochemicals such as alkaloids, saponin, tannin, volatile oil, phenol, and flavonoids can be found in different anatomical parts of ripe African eggplant fruits. The presence of these phytochemicals in the different parts of the fruit indicates that the fruit might be pharmacologically active against a number of diseases. Another study by Emiloju and Chinedu [73] observed a dose-dependent, weight-reducing effect on rats in their study of the effects of dietary supplements of *S. aethiopicum* and *S. macrocarpon* on weight gain and glucose metabolism in rats. They further concluded that these underutilized crops may be used to alleviate the challenge of obesity.

2.6. Postharvest Factors Affecting their End-Use Quality

African eggplant production is characterized by poor post-harvest handling practices, the short shelf life of approximately three to four days, and fruit spoilage losses estimated at 25% depending on the fruit harvesting stage and storage environment [37][74]. The lack of adequate management practices for post-harvest storage is estimated to cause up to 50 percent of vegetable crop yield losses between harvesting and consumption [75]. The most critical issue affecting the quantity, quality, and thus the market value of fruits is poor harvesting and storage practices [76]. It is estimated that about 40–50% of horticultural crops produced are lost even before consumption in developing countries, mainly due to poor post-harvest handling which results in bruising, water loss, and eventual decay during post-harvest handling [77]. A number of factors will lead to a reduction in the quality of fruits after harvest when not properly handled. Postharvest factors influencing the postharvest quality of fruits include maturity stage, method of harvesting, time of harvesting, sorting, and grading, packaging and packaging materials, storage, type of storage, temperature, and relative humidity during storage.

The maturity stage at harvest is an essential factor that influences the flavor and shelf-life qualities of fruits [78]. Failure to harvest fruits on time causes them to over-mature and ripen while still on the plant. On the other hand, harvesting fruits at the immaturity stage gives rise to increased shriveling and fruits susceptible to mechanical damages [79]. In Tanzania, African eggplant fruits are harvested by farmers based on their size and regularly comprise immature, mature, and over-mature fruits. It is reported that cultivating the fruits at the immature level (fruits with non-shiny peel) is suitable for increasing yield in the number of fruits per hectare and increasing vitamins and minerals content while harvesting at the mature fruits stage (by fruits with shiny peel) is recommended for increasing fruit beta carotene content, carbohydrate and fiber content [80]. An appropriate harvesting method is necessary to prevent bruises or injuries during harvesting as they may later express black or brown patches that make them unattractive. Injury to the peel may serve as an entry point for microorganisms, causing rotting. In Africa, harvesting of *S. aethiopicum* is carried out primarily with the hand by pulling or twisting the fruit pedicel or harvesting individual fruits or fruit bunch with the help of fruit clippers/secateurs/scissors. Time for harvesting also influences quality. Fruits harvested and transported early in the morning for sorting, grading, and packing at the packing house are long-lasting and of better quality. To minimize the risk of heat injury and sunburn, it is advisable that the fruits be harvested during the cooler periods of the day [81]. Harvesting fruits early in the morning facilitates faster pre-cooling and yields better quality.

Sorting and grading after harvest are some of the most critical postharvest practices. This is carried out mainly to remove diseased and defective fruits from the lot. This activity is conducted in a packhouse or farmer’s field and an assurance of quality produce depends on proper sorting and grading. Currently, grading is performed manually by farmers, but mechanical graders can also be employed. Most farmers and traders in Africa neither grade nor sort their produce after harvest. According to Apolot et al. [81], 16.6% of traders in Uganda are generally involved with sorting and grading of their vegetables as against 83.4% who are not. Packaging of fruits is needed in order to protect them from mechanical injuries. The packages should be well-ventilated and care should also be taken to prevent compression damages on the fruit during storage and transportation. A previous report revealed that storing fruits in perforated polyethylene bags reduced water loss and had the longest shelf life, although they faced the highest incidence of decay [82]. In Africa, the most commonly used storage facilities are air-cooled storage houses which rely on natural cold air. Proper management of temperature, ventilation, and relative humidity are the key factors that affect the postharvest quality and storage life of horticultural products. Presently, mechanical refrigerators are employed in the storage of African eggplant, but they are energy-intensive, unaffordable for local farmers, and require constant supplies of electricity which is unavailable in many rural parts of Africa. In a study by Sekulya et al. [83], the shelf life of Shum (leafy vegetable) saw an increase (from one day to four days) when it was submerged into portable water intermittently for 2 to 3 s after every one hour during the day for sample in ambient storage both with roots intact and with roots cut-off. Samples stored in perforated polyethylene and meshed perforated polyethylene maintained more moisture and showed a minimal percentage of weight loss with the highest chlorophyll content when stored in the charcoal cooler, making it the best-tested packaging material.

The most efficient way to preserve quality has been found to be proper temperature control between the time of harvesting and consumption [84]. Since the fruits are alive after harvesting, all physiological processes, such as respiration and transpiration (water loss), begin after harvesting, and the supply of nutrients and water is not possible since the product is no longer attached to the parent plant. Respiration leads to product deterioration, including loss of nutritional value, changes in texture and taste, and weight loss through transpiration. Storing harvested fruits at low temperatures of approximately 20 °C can slow down many metabolic activities that lead to ripening, hence allowing more time for all postharvest handling. The loss of water from the harvested fruit product is primarily due to the amount of humidity present in the ambient air, expressed as relative humidity [85]. Harvested fruits at high levels of relative humidity retain their nutritional quality, weight, appearance, and flavor while reducing the rate at which wilting, softening and juiciness takes place. Fruits of African eggplant are vulnerable to shrinkage after harvest so any small loss of moisture and fruit shrinkage will become apparent. Enzymes are vital in the postharvest degradation of fruits of African eggplant. In order to avoid their degradation, enzymatic activities responsible for hydrolysis and oxidation activities in the fruits have been studied. Out of the enzymatic activities experimented with, phosphatases, N'Acethylglucosaminidase, dopamineoxydase, and pyrocatecholoxydase were the principal enzymatic proteins. Being able to control the activities of these enzymes will be very helpful in the postharvest preservation of the fruits of *S. aethiopicum* [86].

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