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Neglected and underutilized crop species in Kabare and Walungu territories, Eastern D.R. Congo: Identification, uses and socio-economic importance

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ABSTRACT

Neglected and underutilized crop species (NUCS) are valuable sources of food and income for several rural households in the eastern Democratic Republic of Congo (DRC). A thorough understanding of their diversity, uses, socio-economic roles, and factors for their neglect would be necessary for guiding promotion efforts. This study was conducted in two steps: (1) interviews with rural households involved in NUCS production and trade, and (2) greenhouse characterization of the two most popular NUCS′ morphotypes, African nightshade and amaranth, from Walungu and Kabare territories, eastern DRC. About 19% of farmers of the entire study area were involved in NUCS production. We identified 22 and 23 NUCS used in Kabare and Walungu territories, respectively. These species belonged to 19 botanical families, among which *Solanaceae* (~24% in Walungu and ~11 in Kabare) and *Fabaceae* (8% in Walungu and 11% in Kabare) were the most dominant families. They were of different ranges: grasses and herbs (62%), shrubs (20%), thorns (2%), and trees (16%). These species were used whether for nutritional (60%), medicinal (7%), or both nutritional and medicinal values (33%). NUCS' market value was low, and thus, discouraged further investment in their farming. The seed delivery system was informal, dominated by farmer-saved seed, seed from local markets, and farmer seed exchange. Characterization experiment for the most popular leafy NUCS showed differences among collected morphotypes for most traits, with some local genotypes outperforming exogenous commercial varieties. Supply of quality seed, training of farmers on the most appropriate cropping system, processing technologies, increased consumer awareness, linking research to policy, and increasing market opportunities for smallholder farmers are strategies for promoting wide use of these crops in eastern DRC.

1. Introduction

Food security and poverty alleviation are major priorities for most countries and international organizations in the world [1–5]. In several sub-Saharan African (SSA) countries, agriculture is a major economic sector requiring intensification and diversification to unravel its full potential for food security and poverty alleviation [6]. World and African food systems are increasingly dominated by exogenous crop species that are widely grown globally. Among these, various species and varieties of cereals (rice, maize, and wheat) constitute more than half of the food energy sources [4,7-9]. These exogenous crops are economically profitable and benefit from more investment in research and promotion than indigenous species, which tend to gradually disappear due to rapid genetic erosion [4,6,10-12]. However, these indigenous crops, also referred to as neglected and underutilized crop species (NUCS) or orphan crops or minor crops, are sources of valuable nutrients, income,

Abbreviations: NUCS, Neglected and Underutilized Crop Species; DRC/DR Congo, Democratic Republic of Congo; FH, Food for Hungry; FAO, Food and Agriculture Organization of the United Nations; CF, Congolese Francs; UEA, Université Evangélique en Afrique; MUSO, Mutuelle de solidarité; AVEC, Association Villageoise d'Epargne et de Crédit; LSD, Least significant differences of means; NGO, Non-governmental organization; CV, Coefficient of variation; CLIP, Crop livestock integrated project; ANOVA, Analysis of variance; CRD, Completely randomized design; AOCC, African Orphan Crops Consortium.

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therapeutic properties, and possess potential in fighting hidden hunger, overweight, and obesity and are typically embedded within local cultural traditions [4,8,9,13]. Besides, they are climate-resilient and thus adapted to harsh environments (such as poor soil fertility, drought stress, pests and diseases, arid and semi-arid areas, etc.) unfit for conventional crop species [6,8,11,12,14-17]. Thus, NUCS could help protect world/African food supplies, particularly in the context of climate change and provide important germplasm resource for future crop improvements for beneficial traits such as nutritional value and abiotic and biotic stress tolerances since some of them are wild relatives of grown crops [17-19]. These crops are often collected, cultivated and traded by women and thus, their promotion constitutes a mean of empowering indigenous communities, particularly women [8]. Although terms such as "underutilization and neglect", "indigenous, forgotten, minor or orphan crop" might look as relative and controversial terms based on each region reality [6], this work adopted the African Orphan Crops Consortium (AOCC) definition and listing for standardization purposes [20]; http://africanorphancrops.org/meet-the-crops/. This AOCC list includes cereals, legumes, oilseeds, roots and tubers, fruit trees, and leafy vegetables that are comparatively underexploited or underutilized food plants, characterized as having relatively low or no perceived economic importance or agricultural significance in advanced economies, meaning they receive relatively little research and development attention [11,13,21]. In brief, orphan crops are those crops that did not receive the same attention of the research community as in the case of staples like wheat, maize or rice despite their regional and nutritional importance [4,14,22].

The economic importance of NUCS lies in their low production cost, short cycle, and low risk, and thus, favorable to rural women and youth who often possess insufficient land and financial resources [14,23]. NUCS farmers make much less investment in land and inputs while ensuring a certain crop yield. Thus, NUCS can help address hunger, poverty, and climate change adaptation because they are climate-resilient, highly nutritious, and the cultivation cost is affordable

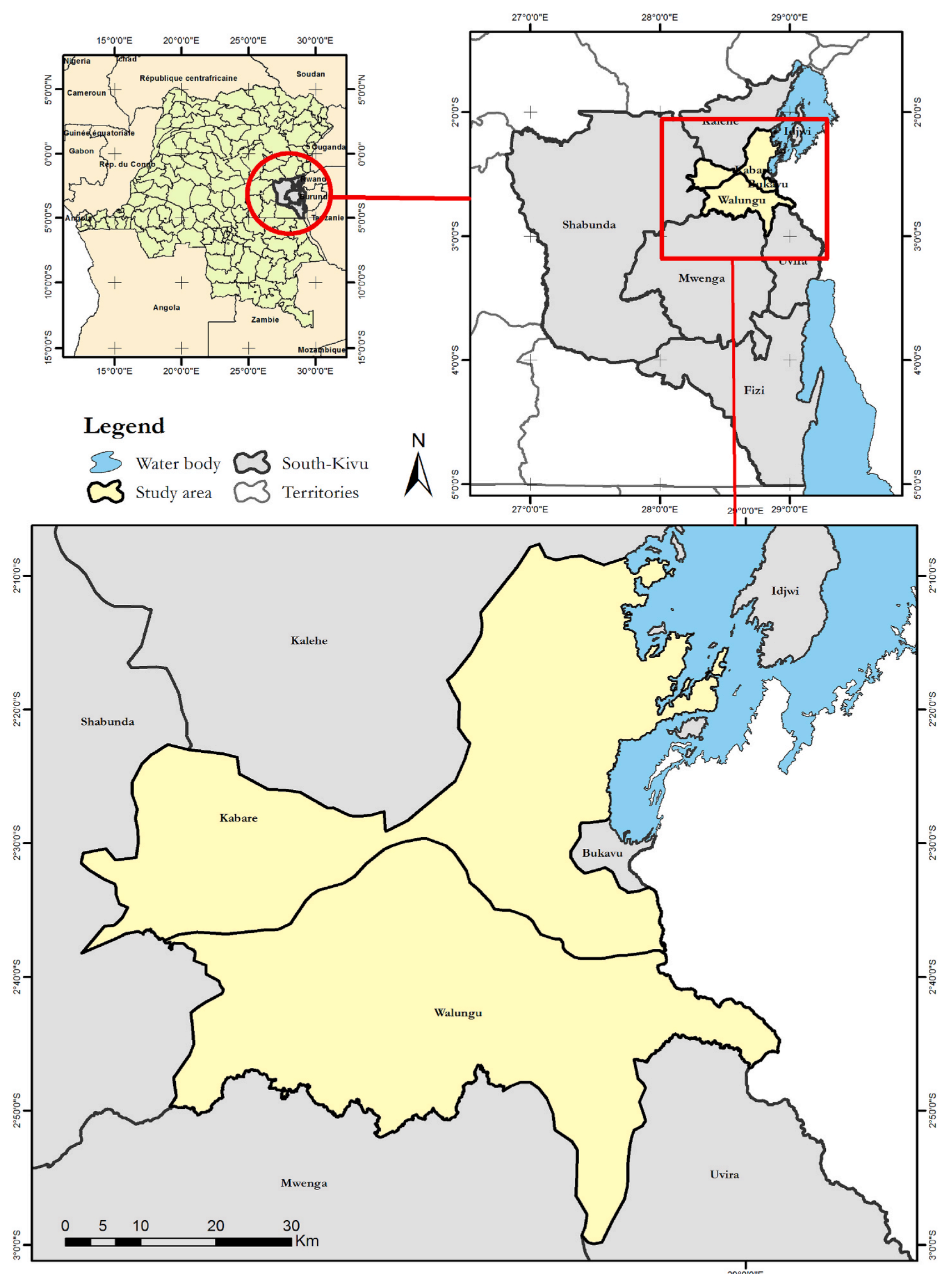

Fig. 1. The study area (Walungu and Kabare territories) located in South-Kivu province, eastern DR Congo.

by resource-poor populations [19,24,25]. Padulosi et al. [8] documented the roles of these crops and five critical development areas were identified: (i) biodiversity conservation, (ii) climate change mitigation and adaptation, (iii) food and nutrition security, (iv) employment and income generation, and (v) culture, gender, and women's empowerment.

Despite numerous virtues above-described, NUCS receive little attention or are largely overlooked by researchers, educators, breeders, extensionists, investors, scientific journals, and policy-makers [8,10,12,14]. Their cultivation and large-scale use are limited due to the lack of awareness and adaptation to agricultural production systems and climate change, low investment in their development, and insufficient human and institutional capacity [13,19,26]. The change in agricultural practices, market forces, crop genetic erosion, and land degradation are also cited as NUCS declining factors [8,11]. The same neglect trend is noticed in the African Great Lakes region, including the Democratic Republic of Congo (DRC), where these species are abandoned by farmers and consumers as a result of rapid urbanization which has translated in changes of diets.

Improving the conservation and utilization of NUCS has been on the international agricultural research agenda for over two decades [8,19]. It was included in the first Global Plan of Action for the Conservation and Sustainable Use of Plant Genetic Resources of the Food and Agriculture Organization of the United Nations in 1996 [27]. Scientific research, in areas such as agronomy, breeding, post-harvest handling and value addition, and linking farmers to markets, is required to promote NUCS. Of these, there is need for reliable information about promising NUCS with potential for commercialization [6]. Amaranth (*Amaranthus* spp.) and African (black) nightshade/morel (*Solanum* spp.) are nutrient providers among grown leafy vegetables in tropical Africa in general and in the South-Kivu province, eastern DRC, in particular [24,28]. One hundred (100) grams of amaranth leaves, for example, contain 3.6 g of protein, 480 mg calcium, 10 mg iron, 1.8 g of cellulose, 6.5–10.7 mg of beta-carotene, 64.6–135 mg of vitamin C, 49 kcal, and valuable antioxidants (betalain, β-xanthin, β-cyanin, anthocyanins, carotenoids, chlorophylls, etc.) while the similar value trend is observed for the African nightshade [24,29-31]. Those nutritional values are comparable or superior to the major staple crop cassava (3 g protein, 1.5 mg beta-carotene, and 44.9 mg vitamin C) and maize (339 kcal, 13.7 g protein, 34 mg calcium, 3 mg iron) [14,32]. These leafy vegetables are short cycle and adapted to a range of agro-ecologies, including poor soil conditions and harsh environments [24,33]. In South-Kivu, the amaranth and African nightshade are sold in markets in the form of bundled branches, mostly by women. The leaves of both species are valued as vegetables, and many of their morphotypes are either grown or wildly harvested as a food resource.

A major production-limiting factor for NUCS (in general) is the poor genetic potential of used cultivars. This could be addressed through plant breeding techniques to develop superior NUCS cultivars and improved seed delivery systems [11,19,34]. In fact, the neglect of NUCS is partly due to their low competitiveness with modern crops such as rice, maize, and wheat which are highly improved to meet food and processing requirements. In addition, there is a shortage in quality seed supply which limits the expansion of cultivated land parcels. Thus, this quality seed shortage has maintained NUCS crops at the state of subsistence crops, hindering any effort to improve processing and value chain [34]. Farmer-saved seed presents no potential in promoting these crops as it has no quality control and the available quantity is too limited. In rural South-Kivu, no seed delivery system exists at all and farmers have to collect NUCS directly from the forest or other wild environments. However, this search for food is often associated with degradation of natural resources including hunting of protected animals, deforestation for firewood, excessive bushfire, etc. Cases of sexual violence have also been reported for women moving to forest for food crops that they could have been producing at home had they been provided with quality seed, trained on adequate farming practices, and linked to potential markets. To promote NUCS in eastern DRC, establishing a robust seed delivery system will be necessary for developing, multiplying, conditioning, and distributing quality seed to farmers. Unfortunately, no scientific evidence exists on these NUCS genetic diversity in South-Kivu. Such information could be useful for diversity conservation and use in plant breeding programs for developing more productive and nutritious varieties.

In this study, we focused on South-Kivu, a province in eastern DRC, and specifically in two territories (Walungu and Kabare) which are part of the most nutritionally-conservative areas of the country. We aimed at contributing to the food and financial security of rural households by raising awareness on the use of NUCS in rural areas of South-Kivu. Specifically, we sought to i) inventory the NUCS, their genetic diversity (morphotypes used per species), and common uses by local populations; ii) determine NUCS economic and socio-cultural importance to South-Kivu rural households; iii) characterize morphologically the collected morphotypes of two most used NUCS (*Amaranthus* spp. and *Solanum* spp.) for selection and genetic improvement interventions. This research serves, therefore, as a valuable baseline study for further in-depth investigations on NUCS diversity and promotion in eastern DRC.

2. Materials and methods

2.1. Study area

This study was conducted in two territories of the South-Kivu province, eastern DRC: Kabare (1960 km^2, 28°45′–28°55′E, 2°30–2°50′S, 1460–3000 m above sea level (masl)) and Walungu (1800 km^2, 28°40′E, 2°38′S, 1500–2500 masl) (Fig. 1). These two territories are characterized by a wet mountainous tropical climate (*Aw3* climate type) with a bimodal rainfall regime. The dry season covers June to August while the wet season is from September to May. Both areas are dominated by the Ferralsols, Nitisols and Cambisols according to the World Reference Base for Soil classification (WRB). These soils are reddish, acidic (pH = 4–6), poor in organic matter and nutrient-deficient, especially in phosphorous. These soils are susceptible to erosion and with low crop yield potential [23,35,36]. Annual rainfalls and temperatures vary from 900 to 1500 mm, and 19–23 °C, respectively, for Walungu and 1300–1800 mm and 22.6 °C, respectively, for Kabare [23,37].

Most of the study area is covered by natural vegetation composed of wild grass and forest (the Kahuzi-Biega National Park), bamboos forest, some trees and grass from primary forest. Some small wetlands are also found across the study area [38,39]. In these areas, *Carex* spp., *Papyrus* spp. and other marsh grasses can be observed. Ten administrative zones, referred to as “groupements” were covered in this study and were selected based on their high horticultural production's reputations: Karhongo, Ibona, Walungu-Centre, Nduba and Izege for Walungu territory, and Bugorhe, Mudaka, Kagabi, Mumosho, and Mudusa for Kabare territory.

These two territories are among the most densely populated of the country (>300 persons km^2) and inhabited by two major ethnic groups: Bashi and Bahavu [23,35]. These areas' populations rely mostly on agriculture, livestock farming, fishing and small business for income. Of the staple crops, cassava, maize, sweet potato, sorghum, banana, and beans are the most cultivated, while plantations of coffee, tea and sugar cane are found across areas as the major cash crops [23,35]. Most of the production is either locally consumed or sold to nearby agglomerations. It is noteworthy that geographic locations of these regions have made them direct food suppliers to the Bukavu City, the regional capital of South-Kivu province (Fig. 1).

2.2. Methods

2.2.1. Inventory, use, production system and marketing of neglected and underutilized crop species in Walungu and Kabare

Pre-surveys were conducted in Kabare and Walungu territories prior

Table 1
Socioeconomic characteristics of households growing NUCS in Walungu and Kabare territories, eastern DR Congo.

Variables	Modalities	Territories		Mean (%)	χ^2	*p*-value
		Kabare	Walungu			
Age (years)	<30	36.7	45.3	41.0	8.82	*0.134*
	30–50	44.7	38.0	41.4		
	>50	18.7	16.7	17.6		
Gender	Female	67.3	67.3	67.3	5.09	*0.75*
	Male	32.7	32.7	32.7		
Marital status	Married	88.0	77.0	82.5	10.60	*0.023*
	Widow	6.0	2.3	4.2		
	Single	6.0	20.7	13.3		
Education level	No formal education	70.0	28.6	49.2	7.82	*0.80*
	Primary	19.3	32.7	26.0		
	Secondary	7.3	35.3	21.3		
	University	3.3	3.3	3.3		
Main activity	Farming	81.4	88.5	84.9	44.32	*0.02*
	Trade	4.7	5.6	5.2		
	Teaching	11.4	4.6	8.2		
Household size	<5	42.7	43.3	43.0	3.53	*0.47*
	>5	57.3	56.7	57.0		
Association membership	Yes	6.7	83.3	45.0	15.84	*0.003*
	No	93.3	16.7	55.0		
Major associations	AVEC	30.0	12.0	21.0		
	Mercy Corps	40.0	–	20.0		
	FH	–	60.0	30.0		
	CLIP	10.0	–	5.0		
	MUZIRHE-ZUSAYI	–	12.0	6.0		
	MUSO	20.0	4.0	12.0		

AVEC: Association Villageoise d'Epargne et de Crédit, CLIP: Crop Livestock Integration Project, FH: Food for the Hungry, MUSO: Mutualité de Solidarité.

to data collection for mainly identifying administrative zones to include in the study. These pre-surveys consisted in focus-group meetings with resource-persons such as farmer associations' representatives, extension officers, non-governmental organizations operating in the two territories, etc. Discussions were mainly on the importance of NUCS production and trade in different zones of target territories and identification of major stakeholders. The questionnaire was also discussed with those major stakeholders to evaluate the relevance of questions to target survey populations. Selected zones (referred to as "groupement") were Bugorhe, Mudaka, Mudusa, Mumosho and Kagabi for Kabare territory while Karhongo, Ibona, Izege, Walungu-centre and Nduba were selected for survey in Walungu territory. After selecting 10 administrative zones, a household survey based on individual interviews was conducted in 300 households (150 per territory) using a semi-structured survey questionnaire. In each of the 10 zones, 30 households were randomly selected. In households where NUCS are grown or traded, target persons were those directly involved in NUCS production and trade while for non-involved households, general questions on the mode of acquisition, uses and consumption were addressed to household head or any adult member found at the time of the survey.

For both groups (involved and non-involved households), collected information was related to the respondent's socioeconomic characteristics such as the age, gender, marital status, education level, main activity, main crop, household size, membership to farmer associations and questions related to the mode of acquisition, consumption frequency (rate of utilization), target plant parts (root, leaves, grains, stem, …), common uses, medicinal virtues (if any), etc. of NUCS products. For NUCS producers and/or traders, information was collected on grown varieties, surface area allocated to NUCS production, cropping systems, seed origin, crop species types, income from NUCS production, crop seasonality, and marketing. Besides, we sought to understand the age and the gender involvement in NUCS production and trade in Kabare and Walungu. It is noteworthy that surveys were coupled with seed collection for further characterization to elucidate genetic diversity among NUCS morphotypes from the study area. Surveys were carried out during the 2019 short rainy season, from February to June.

2.2.2. Morphological characterization of morphotypes of the two major NUCS of Kabare and Walungu

After the survey and the seed collection across territories, a greenhouse experiment was conducted to morphologically characterize 17 amaranth (*Amaranthus* spp.) and 11 African nightshade (*Solanum* spp.) morphotypes. These two species were the most widely distributed and produced in the study area and thus they hold potential for commercialization. Besides, the region experiences a huge diversity for these crops, whether cultivated or picked from wild environments. The greenhouse was located at the Faculty of Agriculture and Environmental Sciences of the Université Evangélique en Afrique (UEA), Bukavu City, eastern DRC (2°32′30″S, 28°51′46″E, 1588 masl) [40]. Trials were conducted using completely randomized design (CRD) with three replications. Plots were represented by pots (19 cm height × 17 cm diameter). The pots were filled with growing media composed of soil, sand and cow manure at the ratio of 3:1:1. The 10 surveyed regions had the same ethnic language and little information was available on variety names such that farmers were attributing a same name to multiple morphotypes. In the characterization experiment, each morphotype was labeled based on its origin (using territory initials) and the objective was to ascertain which of them were actually different based on morphological features. The used greenhouse had 9 m length, 4 m width and 3 m height.

Trials were conducted from June to August 2019 for both species. An amount of 2–3 g of seed per morphotype was sown across pots (since we had no idea on the germination capacity of collected seeds), and after thinning, we left 11 plants per pot. Management involved regular weeding and daily watering. The germination rate (in %) was evaluated one week after sowing. Data collection on plant growth parameters such as the plant height, stem diameter, number of leaves per plant, flower color and types, and leaf area, was conducted 30 and 30–50 days after sowing for the amaranth and the African nightshade, respectively, when they reached 50% flowering stage. As the economical part for both species is the aerial biomass (mainly leaves and stems), the yield parameters assessment focused on total biomass, aerial biomass, and weight of consumed parts. These data were also collected at the 50% flowering stage. It is noteworthy that leafy vegetables are commonly harvested before the flowering stage (from three weeks after planting for

Table 2
NUCS diversity and usage in Walungu and Kabare territories, eastern DR Congo.

	Species	Family	Local name	English name	Producers (%)	Types	Use	Used part	Seed origins	Selling unit
Kabare	*Allium sativum*	Alliaceae	Tungulusumu (sw)	Garlic	0.08	Herb	Nutritional	Bulb	Farm and market	1
	Amaranthus spp.	Amarantaceae	Lengalenga (sw)	Amaranth	3.53	Herb	Nutritional	Leaves and stem	Farm and market	1
	Anona muricata	Anonaceae	Mustafere (sw)	Soursop	0.07	Tree	Nutritional	Fruit	Farm and market	1
	Colocasia esculenta	Araceae	Bifunu (ma)	Taro	0.53	Herb	Nutritional	Rhizome/tuber	Farm, market and gift	1
	Canarium album	Burseraceae	Muzeituni (sw)	Chinese white olive	0.00	Shrub	Nutritional	Fruit	Farm	1, 2
	Carica papaya	Caricaceae	Papayi (sw)	Papaya	0.16	Shrub	Nutritional	Fruit and leaves	Farm, market and gift	2,1
	Cucurbita pepo	Cucurbitaceae	Mabogi (sw)	Pumpkin	0.36	Herb	Nutritional and medicinal	Fruit and leaves	Farm and market	1
	Dioscorea spp.	Dioscoreaceae	Maliga (ma)	Yam	0.00	Herb/vine	Nutritional	Rhizome	Farm and market	3
	Mucuna pruriens	Fabaceae	Mukuna (ma)	Velvet bean	0.00	Herb	Nutritional and medicinal	Grains	Farm	3
	Vigna unguiculata	Fabaceae	Kunde (ma)	Cowpea	0.00	Herb	Nutritional	Grains	Farm and market	2
	Persea americana	Lauraceae	Voka (ma)	Avocado	3.99	Tree	Nutritional and medicinal	Fruit and all the tree (for wood and statue making)	Farm, market and gift	3
	Hibiscus sabdariffa	Malvaceae	Ngaingai (ma, sw)	Roselle	0.00	Shrub	Nutritional	Fruit	Farm	1
	Moringa oleifera	Moringaceae	Moringa (sw)	Moringa/horseradish tree	0.08	Shrub	Medicinal	All the plant	Farm and market	1
	Psidium guajava	Myrtaceae	Pera (sw)	Guava	1.15	Tree	Nutritional and medicinal	Fruit and all the plant (for wood and statue making)	Farm, market and gift	2,1
	Passiflora edulis	Passifloraceae	Marakuja (sw)	Passion fruit	0.00	Vine/shrub	Nutritional	Fruit	Farm and market	2,1
	Duchesmnea indica	Rosaceae	Mafrenze (sw)	Mock strawberry	0.35	Herb	Nutritional	Fruit	Farm	1
	Citrus reticulata	Rutaceae	Mandarina (sw)	Mandarin orange	0.00	Shrub/thorn	Nutritional	Fruit	Farm and market	1
	Solanum macrocarpon	Solanaceae	Nyanya (sw)	African eggplant	0.39	Herb	Nutritional and medicinal	Fruit and leaves	Farm and market	1
	Solanum indicum	Solanaceae	Kashongo (sw)	Blackberry nightshade	0.18	Herb	Nutritional	Leaves	Farm	1
	Physalis peruviana	Solanaceae	Mbuma (sw)	Cape gooseberry	0.16	Herb	Nutritional and medicinal	Fruit and leaves	Farm, market and gift	1
	Solanum nigrum	Solanaceae	Mbogabuchungu (sw)	African black nightshade	0.07	Herb	Nutritional	Leaves	Farm and market	1
	Zingiber officinale	Zingiberaceae	Tangawizi (sw)	Canton Ginger	0.00	Herb	Nutritional and medicinal	Rhizome	Farm and market	1
	Amaranthus spp.	Amarantaceae	Lengalenga (sw)	Amaranth	4.17	Herb	Nutritional	Leaves and stem	Farm and market	1
	Salanum aethiopicum	Solanaceae	Ntolya (ma)	Ethiopian eggplant	0.83	Herb	Nutritional	Fruit	Farm and market	1
	Persea americana	Lauraceae	Voka (ma)	Avocado	1.67	Tree	Nutritional and medicinal	Fruit and all the plant (for wood and statue making)	Farm and market	2
Walungu	*Colocassia esculenta*	Araceae	Bifunu (ma)	Taro	4.04	Herb	Nutritional	Rhizome/tuber	Farm and market	1
	Cucurbita pepo	Cucurbitaceae	Bishusha (sw), Cungulira (ma), mabogi (sw)	Pumpkin	2.56	Herb	Nutritional and medicinal	Leaves, fruit and flower	Farm and market	1
	Dioscorea spp.	Dioscoreaceae	Masunga (sw)	Yam	3.97	Herb/vine	Nutritional	Rhizome	Farm and market	1
	Duchesmnea indica	Rosaceae	Mafrenze (sw)	Mock strawberry	0.51	Herb	Nutritional	Fruit	Farm and market	1

(continued on next page)

Table 2 (*continued*)

Species	Family	Local name	English name	Producers (%)	Types	Use	Used part	Seed origins	Selling unit
Zingiber officinale	Zingiberaceae	Tangawizi (sw)	Canton Ginger	0.10	Herb	Medicinal	Rhizome	Farm and market	1
Physalis peruviana	Solanaceae	Mbuma (sw)	Cape gooseberry	1.47	Herb	Nutritional and medicinal	Fruit and leaves	Farm and market	1
Solanum indicum	Solanaceae	Kashongo (sw)	Blackberry nightshade	0.51	Herb	Nutritional	Fruit	Farm and market	1
Citrus reticulata	Rutaceae	Mandarini (sw)	Mandarin orange	0.10	Thorn/ shrub	Nutritional	Fruit	Farm and market	1
Passiflora edulis	Passifloraceae	Marakuja (sw)	Passion fruit	0.58	Vine/ shrub	Nutritional	Fruit	Farm and market	2
Panicum milliaceum	Poaceae	Bulezi (sw)	Millet	0.45	Grass	Nutritional	Grain	Farm and market	3
Solanum nigrum	Solanaceae	Mboga buchungu (sw), Mulunda (ma)	African nightshade	0.64	Herb	Nutritional and medicinal	Leaves and fruit	Farm and market	1
Moringa oleifera	Moringaceae	Moringa (sw)	Moringa/ horseradish tree	0.06	Shrub	Medicinal	All the plant	Farm and market	1
Anona reticulata	Anonaceae	Mustafere (sw)	Soursop	0.48	Tree	Nutritional	Fruit	Farm and market	1
Mucuna pruriens	Fabaceae	Mukuna (sw)	Velvet bean	0.13	Herb	Nutritional and medicinal	Grain	Farm and market	3
Hibiscus sabdariffa	Malvaceae	Ngaingai (ma, sw)	Roselle	0.45	Herb	Nutritional	Fruit	Farm and market	1
Vigna unguiculata	Fabaceae	Kunde (ma)	Cowpea	2.63	Herb	Nutritional	Grain	Farm and market	3
Canarium album	Burseraceae	Muzeituni (sw)	Chinese white olive	0.48	Tree/ shrub	Nutritional	Fruit	Farm and market	1,2
Carica papaya	Caricaceae	Papayi (sw)	Papaya	0.54	Shrub	Nutritional and medicinal	Fruit and all the plant	Farm and market	2,1
Psidium guajava	Myrtaceae	Pera (sw)	Guava tree	0.60	Tree	Nutritional and medicinal	Fruit and all the plant (for wood and statue making)	Farm and market	2,1
Allium sativum	Alliaceae	Tungulusumu (sw)	Garlic	0.58	Herb	Nutritional and medicinal	Bulb	Farm and market	1

sw: Swahili, **ma**: Mashi, **selling unit**: **1**: pile (mass), **2:** piece, **3:** kg.

amaranths, for example) but since flowering ability, flower color and types are major descriptors in breeding and botany characterizations, we had to delay harvesting until 50% flowering stage. In experiments, commercial checks were involved in the characterization to determine whether local NUCS had potential to improve the genetic background of commercial varieties. For amaranths, the variety Inca, widely grown in the study area was used as check while varieties Managu and Jjobyo served as commercial checks for the African nightshade. All the commercial varieties were bought from Bukavu city seed suppliers.

2.3. Data analysis

Collected data from the survey were recorded in Microsoft Excel 2016. Analysis consisted of summarizing survey qualitative information in frequencies and the dependency/independency between parameters and territories was assessed using Chi^2 test. Survey quantitative data were represented by means and standard deviations. For experimental trials, data normality was first evaluated using the Shapiro-Wilk test. Data without normal distribution were transformed prior the statistical analysis. Analysis of variance (ANOVA) and the least significant difference (LSD) tests were performed at 5% probability threshold ($p = 0.05$) to assess differences among morphotypes for collected quantitative parameters. All analyses were performed using Microsoft Excel 2016 and R 3.4.3 software packages.

3. Results

3.1. Socioeconomic characteristics of NUCS producers in Walungu and Kabare

NUCS producers in the study area were young- and middle-aged adults with ~80% being below 50 years old, irrespective of the location (Table 1). In both territories, NUCS were women crops (~67.3%, Table S4) and grown mostly by married persons (~82.5%). The main economic activity among NUCS producers varied with location ($p < 0.05$), although agriculture (84.9%) was the most predominant activity in both territories. The education level was low among NUCS farmers (49.2% had no formal education and 26% had primary school level). NUCS producers had households with more than 5 members (57.0%) (Table 1).

Significant differences ($p < 0.01$) existed between territories for NUCS producers' participation in farmer associations. Only 6.7% Kabare producers were members of associations while ~83.3% Walungu producers belonged to associations. Food for Hungry (60%) was the most popular farmer-support structure in Walungu while Mercy Corps (40%) and AVEC (30%) were the most active in Kabare. Some of these associations (NGOs), Food for Hungry, CLIP, and Mercy Corps, intervened in NUCS promotion in the study area.

3.2. Diversity and use of NUCS in Walungu and Kabare

Inventoried NUCS of the Walungu and Kabare territories, eastern

Fig. 2. Images of some NUCS grown in Kabare and Walungu territories, eastern DR Congo (Pictures of some NUCS were taken during field work: *Physalis peruviana (a), Carica papaya (c), Amaranthus* spp.(d), *Solanum nigrum (e), Citrus* sp. *(f), Zingiber officinale (g), Passiflora edulis (h), Colocassia esculenta (i), Prunus* sp. *(j), Moringa oleifera (k), Solanum* spp. (l)).

DRC are presented in Table 2 and Fig. 2. Table 2 provides the species names, families, types and uses and other related farming and marketing practices. In Walungu, 23 NUCS (from 18 botanical families) were inventoried while Kabare had 22 NUCS (grouped into 17 botanical families). Only *Panicum milliaceum* (Poaceae), locally known as *Bulezi* in Swahili (and Mashi, the local language), was found in Walungu but not in surveyed areas of Kabare. In Walungu, these NUCS were mostly under *Solanaceae* (~24%), *Fabaceae* (~8%), and *Zingiberaceae* (8%) botanical families. All the other families represented 4% of inventoried species (Fig. 3a). On the other hand, Kabare NUCS were mostly from *Solanaceae* (~11%) and *Fabaceae* (~11%); other families contributed ~5% each (Fig. 3b). Most of the NUCS from these two territories were used as nutritional leafy vegetables or fruits; both produced on family farms and bought from local markets. The seed exchange among farmers and farmer-saved seed were the most dominant means of acquiring NUCS seeds. When traded, pile/bunch (mass), piece, or weight in kg served as selling units (Table 2, Tables S1 and S2). Comparing NUCS producers to

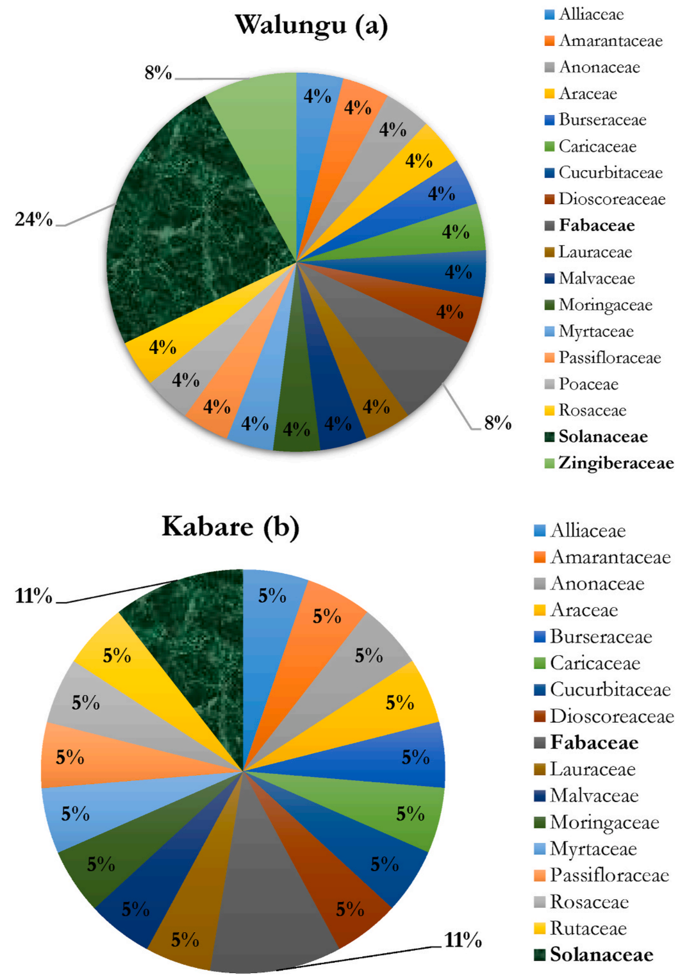

Fig. 3. Botanical families of NUC species found in Walungu (**a**) and Kabare (**b**) territories in South-Kivu, eastern DR Congo.

the entire population, 11.1% Kabare farmers and 27.5% Walungu farmers were involved in farming of at least one of the NUCS, making a mean of 19.3% of the entire study area's population.

Fig. 4 presents NUCS types in the two territories (Fig. 4a), the types of use (Fig. 4b), and the target plant parts (Fig. 4c). Most of these NUCS species were grasses and herbs (62%), trees (16%) and shrubs (20%) (Fig. 4a). Most of the shrubs (56%) were grown in Kabare. Grasses and herbs (64%) and trees (57%) were mostly used in Walungu.

Fig. 4b and Table 1 show that thorn species were commonly used for nutritional purpose while trees were either for nutritional (43%) or nutritional and medicinal purposes (57%). Grass and herbaceous species were mostly used for nutritional purposes (61%), medicinal (4%) or both nutritional and medicinal purposes (36%). A similar trend was observed for shrubs (nutritional: 67%, nutritional and medicinal: 36%, and medicinal purposes only: 4%) (Fig. 4c).

The species for which all plant parts were used are mostly medicinal, while species for which flowers, fruits, leaves, or leaves and stems were used are mainly nutritional. NUCS for which rhizomes are the target plant parts are often multipurpose: medicinal (17%), nutritional (67%) or both medicinal and nutritional (17%) (Fig. 4c).

Diseases treated by NUCS are presented in Table 3. These diseases included hypoglycemia, hypertension, ascariasis, flu, hernia, intestine worms, prostate diseases, inflammations, urinary complications, cutaneous diseases, poison or food intoxication, intestine troubles, liver disease, etc. Medicinal uses vary with NUCS: some NUCS are used for several diseases, and in some cases, one disease is treatable by several NUCS. According to producers and users, it sometimes requires

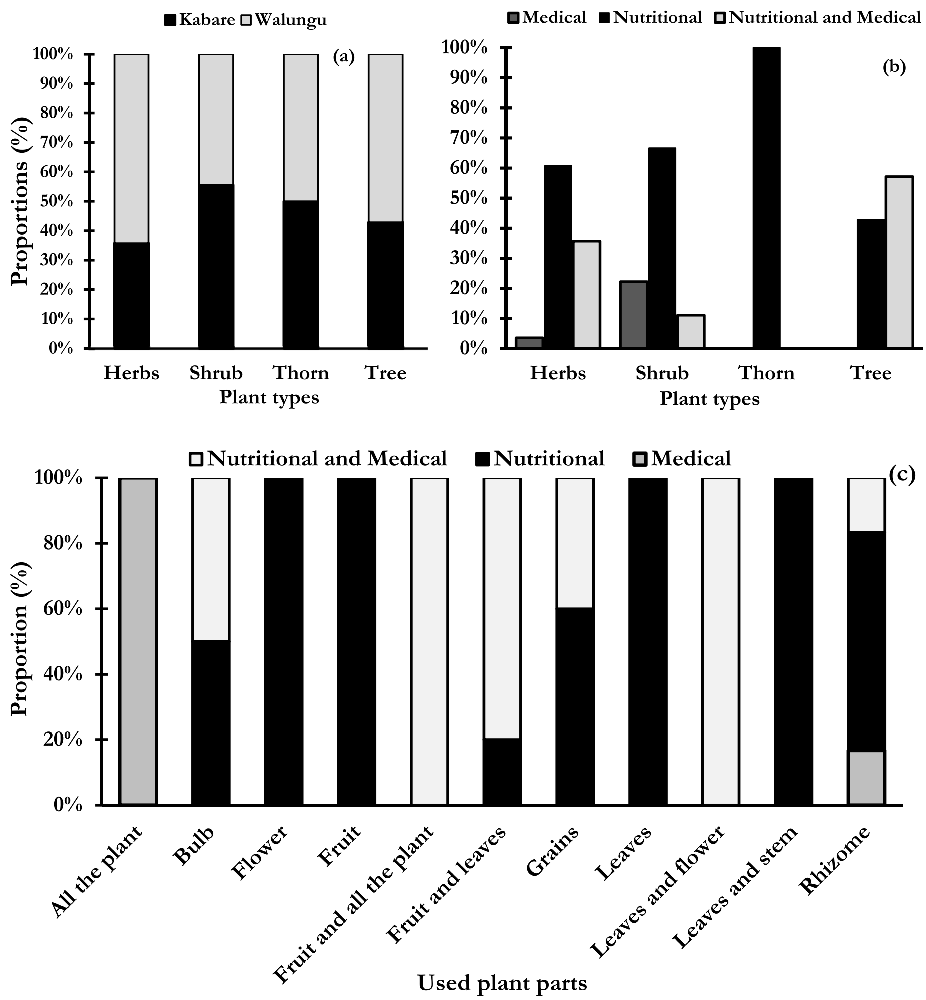

Fig. 4. Plant types (**a**), uses (**b**) and target plant parts (**c**) of NUCS in Kabare and Walungu, eastern DR Congo.

Table 3
Diseases treated by the NUCS in Walungu and Kabare territories, eastern DR Congo.

Species	Treated diseases
Allium sativum	Hypoglycemia, hypertension, ascariasis, flu, hernia
Carica papaya	Intestine worms
Cucurbita pepo	Prostate diseases, inflammations, urinary complications
Moringa oleifera	Cutaneous diseases, poison, intestine troubles
Mucuna pruriens	Liver diseases
Persea americana	Circulatory system, reproduction abnormalities, teeth issues
Physalis peruvianna	Circulatory and digestive systems, cutaneous issues
Psidium guajava	Digestive system, ascites, diarrhea
Solanum nigrum	Stomachache
Zingiber officinalis	Nervous system, vitality
Musa sp.	Cutaneous, nervous, infections, digestive system issues

combining several NUCS for a better treatment result. Some of the inventoried NUCS are presented by Fig. 2.

NUCS were mostly produced on small plots (<0.25 ha) irrespective of the administrative zone and territory. These crops were mainly practiced by women (58%). The seed system was mainly informal with most planting materials originating from farmer exchanges (50%) and farmer-saved seeds from previous harvests (19%). Contributions from farmer-support structures such as NGOs were low (1%) while seed bought from the local market represented 21%. Domestication process of NUCS was also reported since 8.4% of seed were from wild environments. This was particularly the case for trees and shrubs. Farmers had no particular cropping system for NUCS (89%) which were mostly grown as an intercrop with common beans (60%), cassava (16%) and sweet potato (8.1%), the major staple crops in the study area (Table 4).

3.3. Market value, consumption and number of harvests per year for inventoried NUCS

Across species, the mean number of harvests was once a year with a huge disparity among species (Fig. 5). Disparities were also high among species for the mean number of monthly consumptions (Fig. 6, once for *Solanum indicum* (Kashongo) to 7 times for amaranths) and the market value: 549.61–1104.33 CF (0.34–0.69$) (Fig. 7; Tables S1 and S2). When comparing territories, NUCS products had a high market value (Fig. 8) in Kabare territory (1024.87 CF = 0.64$) than Walungu (722.62 CF = 0.45$), although the harvest frequency and number of monthly consumptions were high in Walungu (three times) than Kabare (twice). These NUCS were either sold by bunch, piece or kilogram (Tables S1 and S2).

3.4. Morphological characterization of collected African nightshade and amaranth morphotypes from Walungu and Kabare

Based on the Shapiro-Wilk test, characterization data were normally distributed, and therefore, parametric tests such as ANOVA and LSD were used for means' comparison and separation. There were significant differences among amaranth morphoptypes for all the assessed traits ($p < 0.05$) (Table 5). The plant height varied from 15.7 cm on WWA6 to

Table 4
NUCS Production system's characteristics in Walungu and Kabare territories, eastern DR Congo.

Variables	Modalities	Walungu	Kabare	Mean (%)	χ^2	p-value
Area allocated to NUCS	<0.25 ha	87.3	92.1	89.7	-	-
	0.25–0.5 ha	4.3	6.8	5.6		
	>0.5 ha	8.4	1.1	4.7		
Family member involved	Men	9.8	58.7	34.2	12.7	*0.45*
	Women	90.2	25.3	57.7		
	Both	–	16.0	8.0		
Sources of NUCS seeds	Market	22.9	19.4	21.2	17.3	*0.032*
	NGOs	0.5	1.5	1.0		
	Previous harvest	36.4	1.9	19.2		
	Other farmers	28.2	72.3	50.3		
	Forest	11.9	4.8	8.4		
Cropping system with NUCS	No	85.2	93.3	89.3	23.2	*0.001*
	Yes	14.8	6.7	10.7		
Crops intercropped with NUCS	Banana	10.8	1.3	6.1	9.4	*0.053*
	Common bean	52.7	68.0	60.4		
	Maize	5.4	6.0	5.7		
	Cassava	13.5	18.7	16.1		
	Soybean	6.8	0.7	3.7		
	Potato	10.8	5.3	8.1		

45.2 cm on WWA7. Six of 16 amaranth morphotypes had height superior to the commercial check. The number of leaves per plant ranged from 8 to 20 with 10 of the 16 morphotypes having more leaves than the commercial check. The leaf length varied from 3.4 to 9.3 cm, eight morphotypes producing longer leaves than the commercial checks. Leaf width oscillated from 1.7 to 5.9 cm with 13 of the 16 amaranth morphotypes scoring higher than the commercial check. Regarding the collar diameter, values ranged from 0.4 to 1.1 cm. Of the 16 morphotypes, only three had larger collar diameter than the commercial check. Total biomass, aerial biomass and foliar biomass followed the same trends such that the correlations among them were positive. Total biomass fluctuated from 16 to 1445.7 g per plant, with 5 out the 16 morphotypes outperforming the commercial check. Aerial biomass values varied from 13.9 to 144.2 g per plant, the same five genotypes being superior to the commercial check performance. The foliar biomass ranged from 2.6 to 17.6 g, with almost of all the morphotypes (15 over 16) yielding higher foliar biomass than the commercial check (Table 5).

Seven of nine collected traits showed significant differences among the African nightshade morphotypes ($p < 0.05$). Only the aerial biomass and total biomass did not differ among collected morphotypes (Table 6). The collar diameter varied from 4 to 8 mm, three of the 9 collected morphotypes being larger than the two commercial checks. The plant height ranged from 38.7 to 95.4 cm with only one taller than the two checks. Morphotypes varied from no secondary branching to 8.7 secondary branches per plant. Of them, four had more secondary branches than the two checks. On the other hand, the number of leaves per plant ranged from 7 to 33 per plant, with only three morphotypes having more leaves than commercial checks. Leaf length and leaf width varied from 3.3 to 14 cm and between 1.7 and 9.7 cm, respectively. Only one and three morphotypes had longer and larger leaves than commercial checks, respectively. Like for amaranths, African nightshade's aerial biomass, leaf biomass, and total biomass were interconnected such that high total biomass was recorded on genotypes with high aerial and leaf

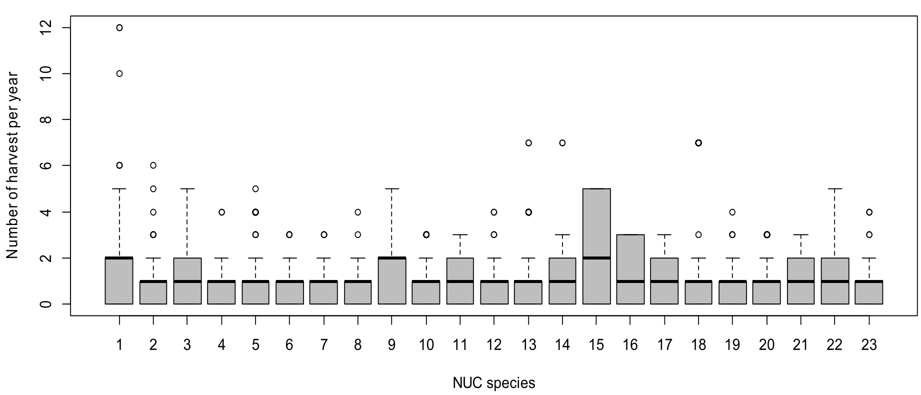

Fig. 5. Number of harvests per year for inventoried NUCS in Walungu and Kabare, eastern DR Congo. 1 = *Amaranthus* spp., 2 = *Solanum* spp. (eggplant), 3 = *Persea americana*, 4 = *Colocassia esculenta*, 5 = *Cucurbita pepo*, 6 = *Dioscorea* spp., 7 = *Duchesmnea indica*, 8 = *Zingiber officinale*, 9 = *Physalis peruviana*, 10 = *Solanum indicum*, 11 = *Citrus reticulata*, 12 = *Passiflora edulis*, 13 = *Panicum milliaceum*, 14 = *Solanum* spp. (morel), 15 = *Moringa oleifera*, 16 = *Anona muricata*, 17 = *Mucuna* spp., 18 = *Hibiscus sabdariffa*, 19 = *Vigna unguiculata*, 20 = *Canarium album*, 21 = *Carica papaya*, 22 = *Psidium guajava*, 23 = *Allium sativum.*

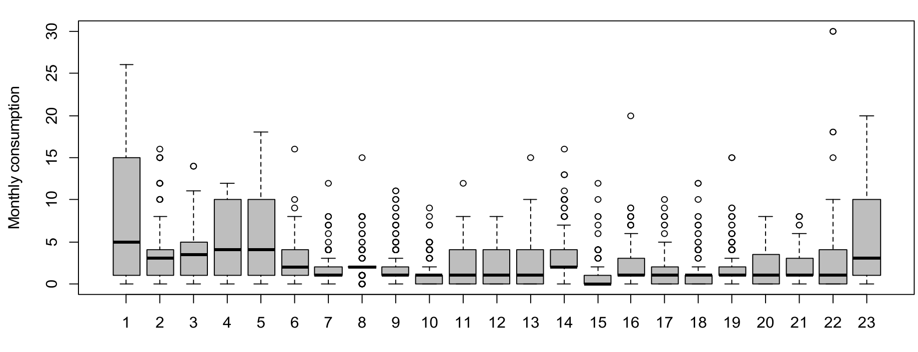

Fig. 6. Number of consumptions per month for inventoried NUCS in Walungu and Kabare, eastern DR Congo. 1 = *Amaranthus* spp., 2 = *Solanum* spp. (eggplant), 3 = *Persea americana*, 4 = *Colocassia esculenta*, 5 = *Cucurbita pepo*, 6 = *Dioscorea* spp., 7 = *Duchesmnea indica*, 8 = *Zingiber officinale*, 9 = *Physalis peruviana*, 10 = *Solanum indicum*, 11 = *Citrus reticulata*, 12 = *Passiflora edulis*, 13 = *Panicum milliaceum*, 14 = *Solanum* spp. (morel), 15 = *Moringa oleifera*, 16 = *Anona muricata*, 17 = *Mucuna* spp., 18 = *Hibiscus sabdariffa*, 19 = *Vigna unguiculata*, 20 = *Canarium album*, 21 = *Carica papaya*, 22 = *Psidium guajava*, 23 = *Allium sativum.*

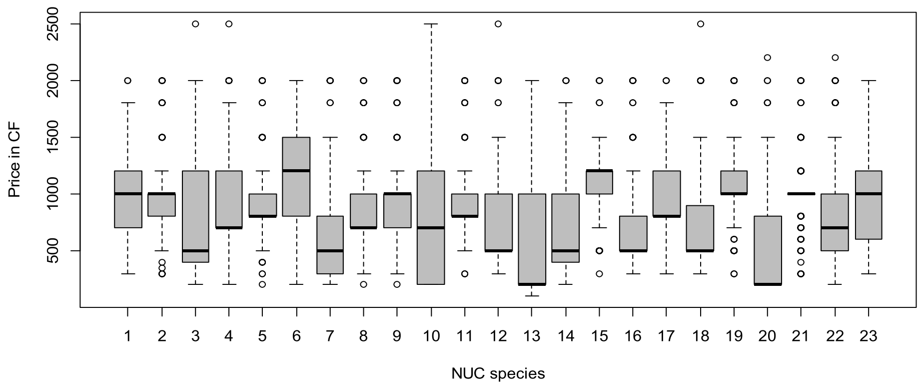

Fig. 7. Market value (in CF: Congolese francs) of inventoried NUCS in Walungu and Kabare, eastern DR Congo. At the survey period (2019 short rainy season: February to June), 1 US$ was 1600 Congolese francs. 1 = *Amaranthus* spp., 2 = *Solanum* spp. (eggplant), 3 = *Persea americana*, 4 = *Colocassia esculenta*, 5 = *Cucurbita pepo*, 6 = *Dioscorea* spp., 7 = *Duchesmnea indica*, 8 = *Zingiber officinale*, 9 = *Physalis peruviana*, 10 = *Solanum indicum*, 11 = *Citrus reticulata*, 12 = *Passiflora edulis*, 13 = *Panicum milliaceum*, 14 = *Solanum* spp. (morel), 15 = *Moringa oleifera*, 16 = *Anona muricata*, 17 = *Mucuna* spp., 18 = *Hibiscus sabdariffa*, 19 = *Vigna unguiculata*, 20 = *Canarium album*, 21 = *Carica papaya*, 22 = *Psidium guajava*, 23 = *Allium sativum*.

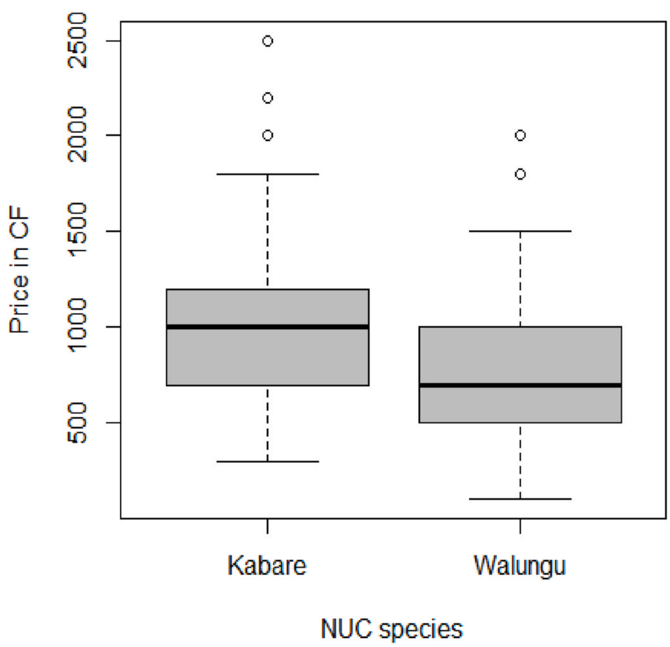

Fig. 8. NUCS market value across Kabare and Walungu, eastern DR Congo. CF=Congolese francs. At the survey period (2019 short rainy season: February to June), 1 US$ was 1600 Congolese francs.

biomasses. Leaf and total biomasses ranged from 1.7 to 19.7 g per plant and 10.3–41 g per plant, respectively. Of the nine morphotypes, only two and one had higher leaf and aerial biomasses than the two commercial checks, respectively (Table 6). Some genotypes had comparable morphology but differentiated by the flower color (Table S5).

4. Discussion

This study inventoried NUCS from two territories of South-Kivu province, eastern DRC. About one fifth of farmers of the entire study area's population were involved in NUCS production. A total of 23 species were inventoried and classified in 18 botanical families. These included a range of fruits, vegetables, legumes, grains, and roots and tubers. From this study, NUCS are not only used as food but also as source of income and medicine. Thus, NUCS contribute in diversifying food and income of rural households in eastern DRC. Food diversification has been regarded as a strategy to improve dietary quality along with food biofortification in low- and medium-income countries [4,20,22,33,41]. Crop diversification also minimizes adverse effects and risks related to weather changes as well as it favors synergies in production through crop nutrient cycling to help deal with and reverse environmental degradation [15,16,42]. Their promotion not only could help diversifying food production but also maintaining health of consumers. Some of the diseases cured by NUCS in the study area are hypoglycemia, hypertension, ascariasis, flu, hernia, intestine worms, prostate diseases, inflammations, urinary complications, cutaneous diseases, poison/food intoxication, intestine troubles, liver disease, etc. Besides, some of the NUCS such as yam, millet, etc. possess low glycemic index and slow digestion, have anticancer properties, etc., and thus, recommended to patients with diabetes and heart diseases [16,33]. Hendre et al. [43] showed that foods from NUCS are rich in minerals, vitamins, and antioxidant and thus hold potential in alleviating malnutrition in Africa where they are already part of the socio-cultural, economic, and religious belief systems.

This study showed that NUCS were secondary item crops in the study area and mostly associated with married women. Besides, these crops were grown on less than 0.25 ha regardless of the administrative zones. As previously shown by Refs. [23,35,44]; South-Kivu women are mostly practicing subsistence crops while the men counterparts are most interested in cash crops. Besides, land resources are mostly attributed to men and thus crops practiced by women are mainly on small plots as supported by this study. Promoting these crops could, therefore, be regarded as a mean of empowering rural women and hence to enable them to improve livelihoods of their households (Table S4).

We found that there is no formal seed delivery system for NUCS in rural South-Kivu. Most of the seed was acquired either through seed exchanges among farmers or farmer-saved seed from previous harvests. Contributions from farmer-support structures such as NGOs in seed supply were low. The absence of functional seed system and low institutional support could be perceived as key factors for low productivity and attractiveness of the NUCS in rural eastern DRC as supported by Refs. [13,15]. Besides, no research institution has included NUCS in their priority items, explaining the poor quality of seed grown by farmers. For some crops such as amaranths or African nightshade, seeds are imported from neighboring countries like Rwanda, Uganda, and Kenya, but are often expensive. In addition, the delivered seed is often no longer viable (poor germination or poor seed/propagule health) due to poor conservation and transportation practices and the time it takes to reach end-users. Some of the introduced varieties sometimes do not meet farmers' expectations, leading to low market penetration. Similar issues were raised by several other researchers in Sub-Saharan Africa (see review by Ref. [15]).

A supply of quality seed of improved and more adapted varieties, training farmers on most appropriate cultural techniques, processing to fit urban populations' preferences, promotion of NUCS health virtues to increase consumer awareness, linking research to policy, and increase of market opportunities for smallholder farmers have been regarded as strategies of promoting wide use of these crops in other parts of Africa [13,20,41,45]. Similar approaches should be implemented in eastern DRC to allow smallholder farmers yield maximum results from growing

Table 5
Growth and yield related parameters of amaranth morphotypes from Kabare and Walungu, eastern DR Congo.

Morphotype code	Plant height (cm)	Number of leaves	Leaf length (cm)	Leaf width (cm)	Collar diameter (cm)	Total biomass (g/plant)	Aerial biomass (g/plant)	Foliar biomass (g/plant)
KKA1	19.0 ± 0.5^{h}	8.4 ± 0.7^{f}	4.5 ± 0.3^{c}	3.3 ± 0.3^{d}	0.5 ± 0.2^{b}	36.3 ± 2.1^{g}	31.2 ± 5.3^{e}	4.0 ± 1.5^{c}
KKA2	26.2 ± 7.7^{f}	9.6 ± 0.6^{d}	4.3 ± 1.3^{d}	1.9 ± 0.2^{e}	0.4 ± 0.1^{bc}	51.0 ± 3.0^{d}	39.8 ± 1.3^{cd}	6.0 ± 0.4^{b}
KKA3	32.1 ± 1.7^{d}	8.1 ± 0.3^{f}	7.6 ± 0.5^{b}	4.3 ± 0.4^{b}	0.6 ± 0.1^{b}	56.0 ± 1.7^{d}	46.6 ± 1.0^{c}	5.4 ± 0.6^{c}
KKA4	35.9 ± 2.2^{c}	8.8 ± 0.2^{e}	9.3 ± 0.6^{a}	5.6 ± 0.2^{a}	0.5 ± 0.1^{b}	18.7 ± 2.5^{ij}	13.9 ± 2.2^{h}	3.0 ± 1.4^{d}
KKA5	30.0 ± 1.2^{d}	10.8 ± 0.7^{c}	8.7 ± 0.5^{a}	5.7 ± 0.6^{a}	0.5 ± 0.1^{b}	30.7 ± 1.5^{gh}	25.9 ± 3.2^{f}	3.1 ± 0.3^{d}
KKA6	26.3 ± 0.5^{f}	12.4 ± 0.6^{b}	6.9 ± 0.4^{b}	3.5 ± 0.3^{c}	0.5 ± 0.2^{b}	28.8 ± 1.1^{h}	24.2 ± 2.2^{f}	3.5 ± 0.6^{d}
KKA7	40.5 ± 0.9^{b}	11.8 ± 0.4^{bc}	7.7 ± 1.3^{a}	4.1 ± 0.6^{c}	0.6 ± 0.0^{b}	16.0 ± 1.7^{j}	16.0 ± 4.9^{g}	2.6 ± 0.9^{d}
KKA8	29.8 ± 0.6^{e}	10.5 ± 0.6^{c}	4.0 ± 0.5^{d}	3.3 ± 0.4^{d}	0.8 ± 0.1^{a}	17.2 ± 4.3^{j}	18.1 ± 1.9^{g}	3.6 ± 0.6^{d}
WWA1	20.0 ± 1.7^{g}	8.2 ± 0.3^{f}	4.1 ± 0.6^{d}	2.9 ± 0.6^{d}	0.8 ± 0.3^{a}	27.0 ± 2.0^{h}	23.3 ± 7.6^{f}	3.8 ± 0.2^{c}
WWA2	30.7 ± 1.7^{d}	10.4 ± 0.9^{c}	3.7 ± 0.1^{d}	2.4 ± 0.3^{e}	0.6 ± 0.0^{b}	42.7 ± 1.2^{f}	34.7 ± 2.3^{de}	5.7 ± 2.0^{b}
WWA3	26.1 ± 0.2^{f}	10.3 ± 0.7^{c}	4.7 ± 0.4^{c}	2.8 ± 0.4^{d}	0.6 ± 0.2^{b}	31.7 ± 1.2^{g}	25.7 ± 7.6^{f}	5.1 ± 0.6^{c}
WWA4	42.7 ± 1.7^{ab}	12.0 ± 0.2^{b}	7.4 ± 0.6^{b}	3.7 ± 0.2^{c}	1.1 ± 0.1^{a}	63.7 ± 2.5^{c}	45.7 ± 1.2^{c}	7.1 ± 2.0^{b}
WWA5	29.8 ± 0.6^{e}	11.1 ± 0.2^{c}	3.4 ± 0.5^{d}	1.7 ± 0.4^{f}	0.7 ± 0.2^{b}	71.3 ± 2.5^{b}	55.8 ± 2.3^{b}	6.3 ± 0.9^{b}
WWA6	15.7 ± 1.4^{h}	9.8 ± 0.7^{d}	6.5 ± 0.6^{b}	2.9 ± 0.1^{d}	0.5 ± 0.1^{b}	24.3 ± 1.1^{i}	21.1 ± 2.6^{g}	4.1 ± 0.5^{c}
WWA7	45.2 ± 1.6^{a}	9.1 ± 0.2^{e}	8.0 ± 3.0^{a}	5.9 ± 1.2^{a}	1.1 ± 0.0^{a}	145.7 ± 12.7^{a}	144.2 ± 3.0^{a}	17.6 ± 2.0^{a}
WWA8	38.1 ± 1.2^{b}	19.9 ± 0.6^{a}	4.9 ± 0.2^{c}	3.4 ± 0.3^{d}	0.7 ± 0.4^{b}	43.0 ± 2.0^{f}	31.6 ± 6.5^{e}	4.0 ± 0.4^{c}
Commercial check	31.2 ± 0.7^{d}	9.2 ± 0.3^{e}	4.9 ± 0.2^{c}	2.6 ± 0.6^{e}	0.7 ± 0.4^{b}	46.0 ± 2.6^{ef}	37.2 ± 2.3^{d}	2.7 ± 0.4^{d}
Means	**30.5 ± 8.2**	**10.6 ± 2.0**	**5.9 ± 2.0**	**3.5 ± 1.3**	**0.7 ± 0.2**	**44.1 ± 30.3**	**37.3 ± 29.4**	**5.1 ± 3.5**
CV (%)	*7.3*	*4.8*	*15.2*	*13.7*	*29.0*	*8.5*	*9.5*	*19.0*
p-value	*<0.001*	*<0.001*	*<0.001*	*<0.001*	*0.003*	*<0.001*	*<0.001*	*<0.001*
$LSD_{0.05}$	*3.7*	*0.8*	*1.6*	*0.8*	*0.3*	*6.3*	*5.9*	*1.6*
Nb. HG	*8*	*8*	*4*	*6*	*3*	*11*	*12*	*4*

KKA, WWA = codes referring to amaranth morphotypes collected from Kabare and Walungu, respectively. **CV** = coefficient of variation, **$LSD_{0.05}$** = least significant difference test at 5% *p*-value threshold. Nb. HG: Number of homogeneous groups. Means followed by the same letter are not statistically different at 5% *p*-value threshold.

Table 6
Growth and yield related parameters for the African nightshade morphotypes from Kabare and Walungu, eastern DR Congo.

Strains	Collar diameter (mm)	Plant height (cm)	Secondary branches	Number of leaves	Leaf length (cm)	Leaf width (cm)	Aerial biomass (g/plant)	Leaf biomass (g/plant)	Total biomass (g/plant)
KKN1	6.0^{ab}	53.0^{b}	0.0^{b}	10.5^{bc}	8.5^{b}	6.0^{b}	14.0	11.5^{b}	15.0
KKN2	5.0^{b}	38.7^{b}	0.0^{b}	11.7^{bc}	8.7^{b}	5.7^{b}	8.3	5.7^{bc}	10.3
KKN3	4.0^{b}	44.7^{b}	0.0^{b}	9.0^{cd}	7.3^{bc}	5.3^{c}	10.7	7.3^{b}	12.7
WWN1	8.0^{a}	95.3^{a}	8.7^{a}	18.3^{b}	4.7^{c}	1.7^{d}	27.0	3.7^{bc}	32.3
WWN2	5.3^{ab}	51.0^{b}	0.7^{b}	12.0^{bc}	9.0^{b}	6.3^{b}	12.0	5.3^{bc}	14.0
WWN3	6.0^{ab}	82.3^{a}	7.3^{a}	7.0^{cd}	3.3^{c}	1.7^{d}	14.7	1.7^{c}	17.3
WWN4	5.3^{ab}	46.7^{b}	0.3^{c}	10.3^{cd}	10.0^{b}	6.0^{b}	13.3	7.0^{b}	15.3
WWN5	6.3^{ab}	53.0^{b}	6.0^{a}	33.0^{a}	10.3^{b}	5.0^{c}	24.7	18.7^{a}	30.0
WWN6	8.0^{a}	49.0^{b}	1.7^{b}	14.7^{b}	14.0^{a}	9.7^{a}	35.0	19.7^{a}	41.0
Commercial check 1	4.7^{b}	47.7^{b}	0.0^{b}	13.7^{bc}	9.3^{b}	6.7^{b}	16.0	13.7^{ab}	18.0
Commercial check 2	6.0^{ab}	89.3^{a}	2.7^{ab}	13.0^{bc}	4.0^{c}	1.7^{d}	19.7	13.0^{b}	35.3
Mean	**5.8**	**58.5**	**2.5**	**14.1**	**8.1**	**5.1**	**17.6**	**9.6**	**21.8**
***p*-value**	*0.04*	*<0.001*	*<0.001*	*0.005*	*<0.001*	*<0.001*	*0.18*	*<0.001*	*0.06*
$LSD_{0.05}$	*2.1 (2)*	*22.1 (2)*	*4.3 (2)*	*4.3 (3)*	*3.7 (4)*	*2.1 (3)*	-	*6.5 (4)*	-
Nber of HG	*3*	*2*	*3*	*4*	*4*	*4*	-	*5*	-

KKN, WWN = codes referring to African nightshade morphotypes collected from Kabare and Walungu, respectively. **$LSD_{0.05}$** = least significant difference test at 5% *p*-value threshold. Nber of HG: number of homogeneous groups. Means followed by the same letter are not statistically different at 5% *p*-value threshold.

NUCS since major factors of neglect of these crops among South-Kivu farmers included low market competitiveness and lack of awareness (Table S3).

For the environment and population welfare, seeds of target crops should be provided to local people in the vicinity of forest and protected areas to reduce pressure on natural resources as the population would be able to produce their own food instead of invading the forest. This promotion would also help in reducing abuse on women as they will be empowered by economically producing and marketing these indigenous crops. Our recommendation is, therefore, in agreement with the Malabo declaration [1], which seeks to diversify the African continent's food systems to support human nutrition and resilient food supply.

There were significant differences among amaranth and African nightshade morphoptypes for almost of all the assessed traits. For all the traits and mainly biomasses, there were outstanding morphotypes compared to already commercialized varieties. It is, therefore, essential to conduct a selection among existing morphotypes, increase seed, and ensure distribution among farmers instead of importing seed as it is currently the practice in eastern DRC. It is noteworthy that the neglect is partly due to the NUCS's low competitiveness with modern crops such as rice, maize, and wheat which are highly improved to meet food and processing requirements ([11]; Table S3). Therefore, it is essential to implement a NUCS breeding program with purpose of promoting economically viable and highly nutritious indigenous crops by developing, multiplying, conditioning, and distributing quality seed to farmers in eastern DRC. In South Africa, for example [24], reports showed that the use of improved cropping systems and productive varieties could lead to high fresh leaves productivity in amaranth fields (40 t ha^{-1}), and thus help tackling hidden hunger and poverty among growers.

As recommended by Ref. [46] for the semi-domesticated bush yam (*Dioscorea praehensilis*) in Ghana, direct implementation of a breeding program may not be cost-effective since the market value of most NUCS is low. Therefore, selection and multiplication of more nutritious and productive varieties should be the starting point in genetic improvement and only when the market is fully developed, breeding activities can be implemented. To increase uptake rates of selected or introduced varieties by farmers, field demonstrations in farmers' or cooperative fields would be necessary. Preferred varieties would then be made available in farmer cooperatives' shops, to retailers, and seed companies in the farmers' vicinity. These varieties' seeds should be packaged in quantities as small as 5 g to 1 kg to increase access to resource-poor farmers, and thus, gain a large market share and wide use. Increased awareness of the benefits of NUCS and research geared towards agronomic improvement, social and economic acceptance will also be needed to yield maximum results from NUCS cultivation [24,33].

Local stakeholders from eastern DRC should seek to partner with the African Orphan Crops Consortium (AOCC) and other international organizations, which had already made tremendous advances in modernizing breeding of NUCS by generating genomic resources of three types, i.e., reference genome sequence, transcriptome sequence, and re-sequencing 100 accessions/species, using next-generation sequencing (NGS) technology [17,29,33,43]. These tools could facilitate speeding up breeding cycle and ensure quick delivery of improved varieties to farmers.

5. Conclusions and prospective

This study showed that one fifth of the eastern DRC rural population is involved in NUCS production. These species are associated with women and mainly practiced on small plots. Their promotion could, therefore, serve as a mean of financially empowering rural women in eastern DRC. Furthermore, these crops not only contribute to food security but also provide income and medicine to rural households. However, the NUCS market value is low compared to grains and cereals and other staple crops, which is limiting their competitiveness and thus relegating them to a subsistence crop status. Besides, the seed delivery system is absent and the institutional support from governmental and non-governmental organizations is low. The existence of morphotypes with high agronomic performance, among NUCS with potential for commercialization, opens an avenue for varietal selection and further for genetic improvement to increase productivity and profitability of these crops in eastern DRC. Improved varieties coupled with a robust seed delivery system and institutional supports could provide a mean raising productivity and attractiveness of these crops, and therefore, to improve nutritional and financial statuses of the one fifth of the population directly involved in their production and trade.

This work will serve as a baseline study for in-depth investigations for refined diversity and promotion initiatives for individual NUCS in eastern DRC. Due to synonymy in farmers' nomenclature such that a genotype may be attributed several names or several morphotypes called with single name across areas, we suggest that future diversity studies include molecular characterization to detect duplicates. Diversity studies could be coupled with identification of sources of genes for desirable traits and devise mean of introgressing them into commercial varieties. Future studies should also assess the level of genetic erosion within species to determine which of the NUCS are at risk of extinction and for which urgent conservation means should be devised. Besides, attention should be oriented at analyzing the nutritional values of identified species to determine their potential in supporting food security and fight against hidden hunger among local populations in eastern DRC. Efforts will also be necessary toward processing and value addition initiatives to meet the demand of the elites and increasing urbanized populations.

Declaration of competing interest

No conflict of interest.

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Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jafr.2021.100234.

Ethical clearance/statement

The study protocol was approved by the Interdisciplinary Centre of Ethical Research (CIRE) of the Université Evangélique en Afrique (UEA), Ref: CNES 002/DPSK/118PP/2021. We obtained consent from all resource-persons and households prior focus group discussions and data collection after ensuring the participants of the confidentiality in use of data collected.

Finding

Not applicable.

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