Agric Res (September 2022) 11(3):506–517
https://doi.org/10.1007/s40003-021-00586-4

FULL-LENGTH RESEARCH ARTICLE

Post-harvest Constraints of Solanaceae Species Produced in Kabare Wetlands, Eastern Democratic Republic of Congo

Basimine Géant Chuma[1,2] · Byamungu Adrien Ndeko[1] · Blaise Mulalisi[2] · Bora Francine Safina[1] · Serge Shakanye Ndjadi[1] · Nachigera Gustave Mushagalusa[1]

Received: 20 August 2020 / Accepted: 3 June 2021 / Published online: 6 July 2021

Abstract The Kabare territory wetlands produced a significant quantity of solanaceous crops (potato, tomato and eggplant, etc.). One of the observations is the fact that significant losses are being observed during production and mostly after harvesting. The objective of this study was to assess the post-harvest constraints of the main solanaceous crops grown in these wetlands. A survey was carried out among 225 randomly selected households from four wetlands that lied down six districts to characterize the producers, identify the post-harvest techniques used and the constraints observed. Samples of solanaceous products were preserved for 15 days according to the local preservation techniques used to evaluate their effectiveness. The results showed that the producers face numerous post-harvest constraints of three types: structural, technical, and technological. These constraints a varied from value chain actor group to another. Most of the methods used by producers were mostly classified as moderately effective, and did not allow the quality of the products to be preserved, while quantitative losses remained very significant high. Besides, other external factors such as environmental and socio-economic factors contributed significantly also to these losses. Much losses are observed on tomato than on potato and eggplant; only a few preservation methods were classified as effective, notably tuber sorting (– 60%), the use of ice cubes (– 65%), and the use of pesticides (– 70%). Methods such as spreading out in a corner of the house (60%) and storage in the bag (50%) were classified as less effective for more than half by the farmers. Although suffering significant losses, these solanaceous crops provided important household income and thus contributed to food security in the area. Crop production and preservation have to be improved while effective production practices in Kabare and South-Kivu wetlands, eastern of DR Congo, have to be implemented.

Keywords Solanaceae · Conservation of agricultural products · Post-harvest · Kabare · Wetlands

Abbreviations

CEC	Cations Exchange Capacity
CV	Coefficient of Variation
DRC	Democratic Republic of the Congo
INERA	Institut National d'Etudes et Recherches Agronomiques
PNKB	Kahuzi Biega National Park
NGO	No Government Organization
OM	Organic Matter
GHP	Good Hygiene Practices
FC	Congolese francs
PCA	Principal Component Analysis
HAC	Hierarchical Ascending Classification
WRB	World Reference Base for soil resources

✉ Basimine Géant Chuma
geant.ch@gmail.com; geantchuma@uea.ac.cd

[1] Faculty of Agriculture and Environmental Sciences, Université Envagélique en Afrique (UEA/Bukavu), 465/ Cyangugu-Rwanda, P.O. Box: 3323, Bukavu, South Kivu, Democratic Republic of the Congo

[2] Institut Supérieur d'Études Agronomiques et Vétérinaires, ISEAV-Walungu, Walungu, South Kivu, Democratic Republic of the Congo

Introduction

Agriculture is of essential importance for feeding humanity and much more in developing countries than in developed countries as the main activity. It is a basic element for the improvement of the economy and thus for the country's development. Despite a remarkable increase in world production, almost half of the third world does not have access to sufficient food. There are many reasons for this trend, one of which is related to the post-harvest losses that occur before and after harvesting but also and above all during marketing. It seems quite true that these losses are greater in countries where food needs are most acute [11, 13, 30].

It is estimated that 30–45% of annual crop losses on the field and storage are caused by viruses, bacteria and fungi [15, 21, 36]. In Africa, the consequences of such losses result in food shortage and scarcity, especially during hostile climatic conditions. Thus, diseases can cause serious economic and social problems. In East Africa (Kenya, Malawi, and Tanzania) for example, it is estimated that losses of the national production of vegetables and fruits, especially eggplant, pepper, and tomato amount to 150–300 million dollars [6, 14, 16]. As a result, farmers who were afraid of losing their production as soon as possible sell the production fairly quickly in the field before harvest regardless of the price [4, 23]. It thus seems clear that post-harvest management must be given priority in the same order as the agricultural practices used for production to reduce these losses. It is a set of operations taking place in the post-harvest phase including the process of cleaning, washing, selection, sorting, disinfection, drying, packaging but also and above all storage.

All plants are not affected in the same way; Solanaceae and citrus fruits are the most vulnerable. Quantitative and qualitative losses of extremely variable magnitude occur at all stages from production to consumption, i.e. from harvest to final delivery to consumers, including handling, storage, treatments, and marketing [1, 19]. In the case of the eastern Democratic Republic of Congo (DRC), and more specifically in wetlands located in South-Kivu territories, three main solanaceous crops (tomato, potato, eggplant) are produced; followed by other vegetables such as cabbage, amaranths, carrots, onion, etc., grown mainly in Walungu and Kabare territories. The majority of these crops are grown in wetlands such as Muku, Mudaka, Hogola, and Chisheke known for their high production.

Firstly, these crops suffer, on the field, from disease and pests that significantly reduce production and the product's market value. In addition to these problems, there are current climatic vulnerabilities and land degradation problems due to overexploitation, soil erosion and low input [20]. Their production is sent to serve the towns, cities and villages of South Kivu Province (Bukavu, Katana, Nyangezi, etc.). However, they still face strong competition from products exported from neighboring countries (Rwanda and Burundi) or produced in other provinces (mainly North Kivu).

Secondly, post-harvest damage involving much more financial losses for producers can be observed [13, 18, 34]. Indeed, crop storage is generally also a serious problem due to their high water (80–95%) and sugar contents that are linked to a warm environment provide an ideal breeding ground for the proliferation of the pathogens responsible for stock rot. Their abundant supply on local markets during harvest periods often coincides with an almost price drop. This is because the number of pathogens affecting the solanaceous crop is particularly high and particularly in high humidity areas such as wetlands. Virtually all of them are responsible for various infections that can lead to significant crop losses [3, 29].

In Kabare territory as in the whole province, few studies have been carried out to assess these constraints, wetlands use, and ecosystem function and services. And yet, knowledge, characterization, and evaluation of these post-harvest constraints would make it possible to know where the gap in the chain lies and to think of solutions, reduce losses and thus enable the reduction of dependence on neighboring provinces and countries. The objective of this study was therefore to contribute to the knowledge of post-harvest losses of the three Solanaceae species (potato, tomato and eggplant) grown in the wetlands of Kabare territory, eastern DR Congo. Specifically, the study tries to characterize the farming households producing solanaceous crops in the Kabare territory; then, presents the different actors and the marketing circuit of these products, identify and prioritize the main post-harvest constraints of these crops at the farm household level, to quantify the qualitative and quantitative losses as well as the efficiency of the conservation methods adopted by farmers to reduce these losses.

Materials and Methods

Study Area

Location

The study was conducted in four wetlands generally located in Kabare territory, one of eight territories found in the South Kivu province, eastern DR Congo. The territory has an area of – 1690 km^2 and a population estimated to $\sim$ 535,114 habitants, with a density of $\sim$ 288 habs per km^{-2} spread over two chiefdoms: Kabare and Nindja. Kabare is

divided into 17 districts locally called "groupements". Due to time, cost, and accessibility, only six districts were randomly selected among the 17. These districts surround Bukavu town and help in its vegetable supply. These districts included Miti-Murhesa, Katana, Mumosho, Bugobe, and Cirhunga. According to pre-survey data from these areas, the villages of Kahave, Karhwa, Cifuma, Kalulu, Cibungu and Nyunda are at the top of the list in terms of vegetables and solanaceous production [9].

Soil, Climate, and Topography in Kabare Territory

Soil diversity is found throughout the province and especially in Kabare. Based on the World Reference Base (WRB) classification [12, 20], the territory of Kabare is majorly divided into five soil units: Ferralsols dominate the territory, followed by Nitisols and Cambisols. These soils are generally acidic to very acidic with low Cation Exchange Capacity (CEC), low organic matter (OM) content and limited phosphorus. Acrisols and Vertisols can be also found in some areas (Supplementary data) (Fig. 1).

According to climate, the area is characterized by humid tropical climate type tempered by the elevation. The available meteorological data from the only available station (INERA/Mulungu) show a mean annual temperature of ∼ 15 to 20 °C and a daily amplitude that reach ∼ 6 to 11 °C while the annual amplitude does not exceed ∼ 2 °C. The average annual precipitation varied between – 1300 and ∼ 1900 mm and increased with the elevation while temperature decreased. The year is divided into two seasons: wet season (9 months) and dry season (3 months) (Fig. 2).

All the Babare territory is located between ∼ 1000 and 3250 m of elevation (Supplementary data). It is dominated by mountains whose highest peaks are Kahuzi reach ∼ 3250 m and Biega with ∼ 2700 mm; these mounts are located in the Kahuzi-Biega National Park (PNKB).

Some hills and lowlands can also be seen across the territory. In analyzing the terrain slopes, they are around ∼ 16% and mostly higher than 25%. The eastern region of DR Congo is characterized by an ancient and recent tectonic movement of Central African graben that crosses the Kivu region in a north–south direction.

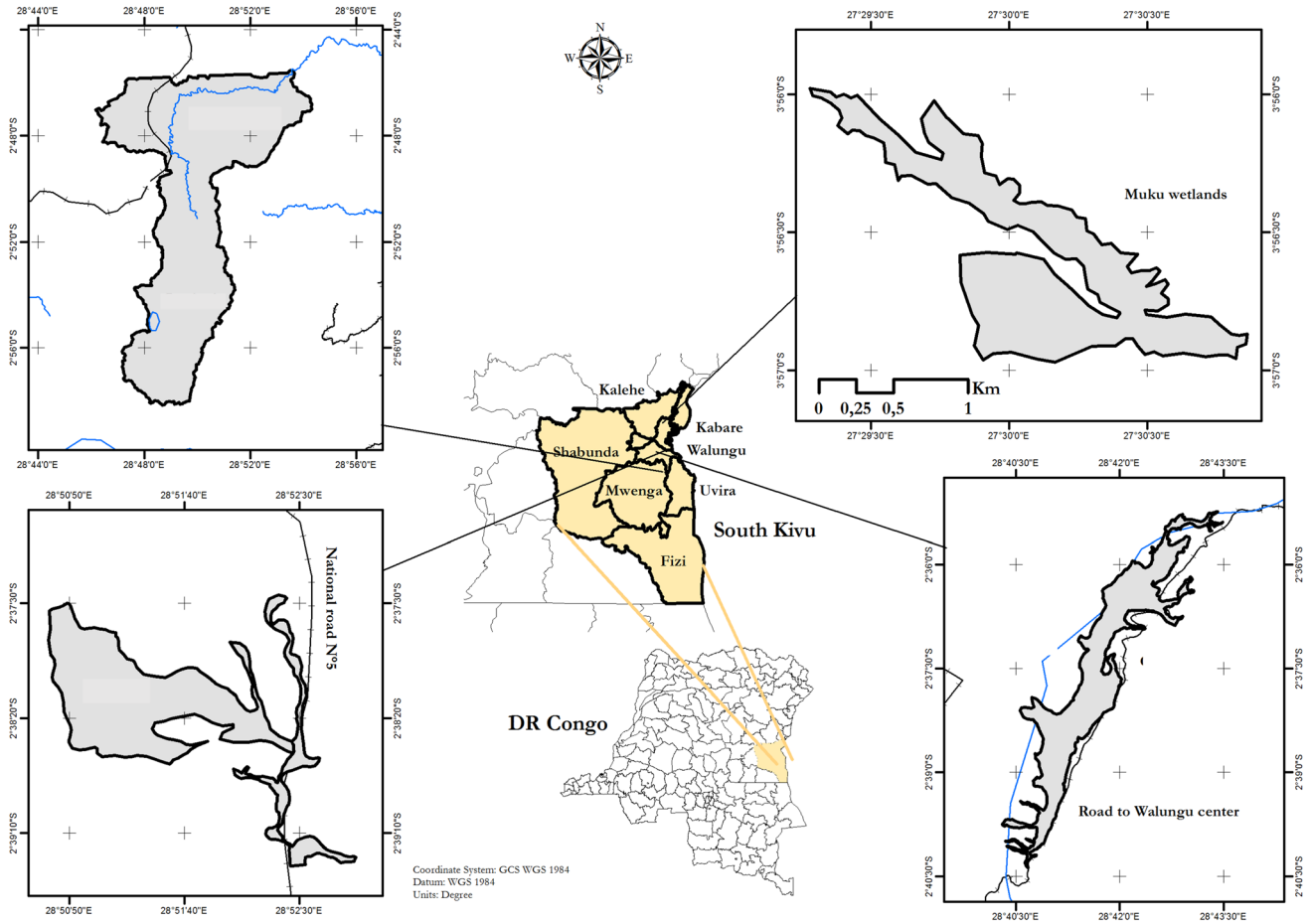

Fig. 1 Wetlands selected for the producers survey in Kabare, South-Kivu province

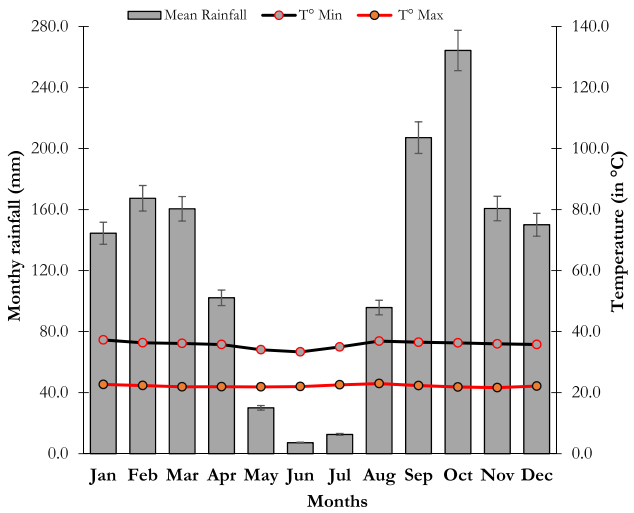

Fig. 2 Average monthly precipitation and temperatures in the Kabare territory (average of four year 2016, 2017, 2018 and 2019)

Land Cover and Land Use in Kabare

Due to its topography, the site of original vegetation was a mesophilic mountain forest with *Newitonia bachawani*. Because of the actual human occupation, this secondary forest had disappeared by the time the Europeans arrived. In the swampy valleys, one finds sedges, papyrus, and reeds. There are also a few forest galleries (on the shores of Lake Kivu) and on the banks of some rivers. Supplementary data showed the land use of the territory in 2018. It shows that the east part was dominated by villages, agricultural fields and plantations (along the lake), while the west and northwest are majorly covered with forests (specifically the PNKB). Savannah and secondary forest can be also observed in the center of the territory [24, 25].

Methods

Characterization of Solanaceous Production in Kabare Wetlands

This study was part of a formal survey conducted from April to June 2016, and that involved a field visits in the four wetlands located in the six selected districts in Kabare. The simple survey unit was the household producing solanaceous in wetlands.

The survey was conducted following individual interviews with other stakeholders (traders and consumers). A total of 225 producers were interviewed in local languages (Mashi and Kiswahili). The questions concerned consisted of closed, opened, and semi-opened questions (Cfr. Supplementary data). The questionnaire was divided into 3 components: the socio-economic characteristics of solanaceous producers, the preservation methods used, and the evaluation of their effectiveness. The other questions concerned the identification of the various constraints observed during production.

In each locality in districts, 30 household producers of at least one solanaceous crop were randomly selected; which makes a total of 180 households. To analyze the value chain of solanaceous species in Kabare, we selected and added also (45) other households composed of traders (20) and consumers (25). All the interviewed producers and traders were also taken into account as consumers in order to well design the value chain. Their choice depended on household accessibility (both availability, transport availability in terms of reaching, easy contact, and language mastery (Mashi and Swahili).

Evaluation of Control Techniques Used in Kabare for Solanaceous Preservation

To evaluate the effectiveness of the three (3) solanaceous preservation techniques, products were purchased and monitored with the help of producers.

To be effective, products from all the value chain actors (producers, traders, and consumers) were analyzed. This allowed us to know where in the value chain is the problem in term of preservation. For each one of these actors, a basket of each product was monitored to access the post-harvest damage observed from the production to consumers. These monitoring took up to half a month ($\sim$ 15 days). We were reassured that the producers and traders practiced the preservation method(s) as they always did to not be deviated from reality. At the end, tested products (tomatoes, potatoes and eggplants) were weighed and counted the respective number of the deteriorated product during the period under consideration. Efficacy was assessed by the ratio of the total number of each product before, during and at the end of storage. It was expressed as a percentage and assessed on a scale of three levels (100–70%: "*effective*", 70–50%: "*moderately effective*" and less than 50%: "*less effective*").

Data Processing and Analysis

Socio-economic characteristics were analyzed and presented in tabular form according to the three crops (tomato, potato and eggplant). For producers diversity simple producers, producer-sellers, producer-consumers, small producers, big producers, etc.), socio-economic characteristics were subjected to a Principal Component Analysis (PCA) followed by a hierarchical ascending classification (HAC) to classify surveyed households. Analyses were carried out according to the household classes obtained from HAC. They consisted of descriptive statistics (mean followed by its standard deviation) and frequency calculations. Analysis

of variance was also performed on economic characteristics (different costs, monthly income, quantity produced) according to the type of producers; separation of the means was performed using the Tukey HSD test at the 5% threshold. The XLSTAT tool 2014 was used to process and analyze data. The production of potato was expressed in the quantity of harvested bags (1 bag corresponds to ~ 100 kg), while tomato and eggplant were expressed in terms of the number of harvested baskets. The total income from solanaceous production was expressed in dollars and corresponded to the quantity sold times the market price in the Bukavu town markets. As the product was sold in Congolese Francs (CF), a conversion into dollars was made based on the total exchange rate (1$ ~ 1200 FC). Linear regression models were conducted to assess the post-harvest constraints, while the Chi^2 test was executed to assess the dependence between varietal criteria and varieties, and socioeconomic characteristics, and actors at the 5% threshold.

Results

Socio-Economic Characteristics of Potato, Tomato and Eggplant producers in Kabare Wetlands, Eastern DR Congo

The selected crops are produced by both men (58%) and women (42%); however, a dominance of men to grow tomato and potato (78 and 76%) is observed compared to eggplant which is mostly grown by women (– 80%). Since agriculture is their main activity, most of these producers are married (79%) and their age varies between 30 and 50 years (49%). More than half of them have no more than secondary education (– 69%). Other secondary activities are carried out by these producers to increase their income, such as trading (27%), teaching (10%) and mini-livestock (26%). More than half of them form farmers' associations (55%). Most of the fields are in the marshland (50% have between 0.5 and 1 ha, and 5% more than 1 ha) and others have gardens of less than 0.5 ha (45%). These solanaceous plants are generally cultivated in pure crops (~ 90%) or the association. This association is often conducted in rotation with amaranths (~ 50%), cabbage (27%), carrot (11%), or sorghum (9%) (Supplementarty Table S2).

Characteristics of the Main Varieties of Solanaceous Plants Grown in Kabare Wetlands, Eastern RD Congo

Throughout the survey period, an inventory of the varieties found in all fields was conducted. A total of nine varieties were inventoried; two varieties of eggplant: La Dourga and Black bell called at the Rwandan market as Intoryi (local name), two varieties of tomato (Valencia and Roma), and five varieties of potato (Cruza, Gahinga, Shagi, Serenya and Sangema) (Supplementarty Table S$). These varieties come either from the Institut National d'Etudes et de Recherches Agronomiques (INERA) Mulungu station, from Uganda or Rwanda. Subsequently, production materials are obtained in different ways, from the producer's seed bank via his last production, or neighboring producers, or from Non-Governmental Organizations (NGOs) intervening in the area (Action Sociale et d'Organisation Paysanne (ASOP), Mercy corps, Food for the Hunger (FHI), World Vision, etc.). Other producers close to the lNERA-Mulungu station get their supplies from it; some of these varieties have been used for a long time (1983, 2004) by the producers to the point that they already bear local names, and others were recent and bought locally on the local markets or from the INERA station.

Based on assessment, criteria based on disease resistance, size, appreciation on the local market, shelf life, consistency, production performance in the environment, differences were observed between these varieties and these criteria ($Chi^2 = 23.4$; $p < 0.001$). These criteria have therefore varied from one variety to another and from one speculation to another. Cruza is appreciated for its size (~ 70%), its appreciation on the local market (80%), and its performance (100%) while Gahinga is appreciated for its size (~ 70%), performance (~ 91.6%) and consistency (50%). Long shelf life (– 80%), and performance (~ 90%) are Shagi's assessment criteria. For both tomato varieties, the Roma variety is appreciated for three characteristics, in particular its resistance to downy mildew (60%), its long shelf life (63%) and its consistency (~ 76%). On the other hand, Valencia is appreciated for its resistance to downy mildew (50%), long shelf life (50%), consistency (50%) and performance (60%). Two varieties were found, one called "La Dourga" bought on the local market and one Black bell from Rwanda and locally called "Intoryi". The latter is appreciated for two characteristics, notably its strong resistance and its appreciation on the local market. It should be noted, however, that the production of tomato and eggplant is mixed so that the varieties are mixed at the end. Valencia and Roma are mixed and difficult to identify; the same trend was observed on eggplant.

Actors Involved in the Solanaceous Value Chain in Kabare Wetlands, Eastern DR Congo

The links between actors involved in the value chain (production, marketing and consumption) of solanaceous crops produced in the Kabare wetlands were presented in the diagram presented in Fig. 3. The diagram showed the distribution and links between different actors involved in

the production, marketing and consumption of these crops. Indeed, the producers were spread out around the city of Bukavu, which is the important evacuation point. Two types of products were found on the market: those coming from Kabare and others coming either from Rwanda or from the other province (North Kivu) or other territories (Walungu and Uvira). The latter either brought directly by traders or by consumers themselves. Some producers were themselves producers and traders. Subdivided into large producers (Type 1:4%), small producers (Type 2:15%), intermediate producers or producers-sellers, i.e. those who produced and sold their production directly (Type 3:64%) and consumer producers (Type 4:17%) who produced only for the household's subsistence. At the level of traders, two types were observed: those classified as local, i.e. sold their products on local markets or to other urban traders, and those who were urban and sold their products through towns and cities. The latter had significant capital and can rent vehicles to transport goods to market compared to other premises. There were also two local trader types: those who sold their entire products in full (and much more while the products are still on the field and even before harvest) and those were harvesting and selling weekly and/or according to the household needs. These producers also produced other market garden crops (Supplementary Table S2).

The assessment of the seasonal production of the different types of crops among the producers found (Supplementary Table S3) is as follows: Differences in production, consumption, and sales were observed between the different farm types ($p < 0.05$) and according to different produced speculations ($p < 0.05$). Of all the farm types, type 1 received more income from the production of these crops than the other; the tomato was the crop that brings more income (– $ 1240 per season) followed by potato and eggplant (– $ 300). A large part of the eggplants and amaranths was for consumption and not for sale. For type 4, a low income related to production is observed, the major part was for consumption. Only a portion of the tomato (– 1.5 basins) and eggplant (– 5 basins) production were sold. These operators (type 4) were classified as "producer–consumers". The total observed post-harvest losses were estimated as the difference between the total production and the sum of the quantity sold and consumed. The latter also varied from one speculation to another and from one type of holding to another. These losses were most observed on cabbage, tomato and eggplant. Small losses were observed in lamb's-quarters. On average per speculation, the following can be observed:

Out of 16 bags of potatoes produced by large producers (type 1), only 12 bags were sold and 2.5 bags reserved for household consumption while – 1.5 bags were lost. For type 2, from – 11.4 bags produced, 9 bags were sold, – 1.4 are consumed by the household and up to 2.5 bags lost. For tomatoes, losses varied from – 1.1 basins for type 4 to – 48 basins for type 1. The same trend was observed for eggplant, with 0.4 basins (type 4) and 2 basins (type 2) and 0.5 (type 1).

Main Post-harvest Constraints Related to the Production of solanaceous Crops in Wetlands in Kabare Territory

The constraints were classified into three categories: post-harvest constraints related to production, structural constraints, and technical and technological constraints. The supplementary materials (Tables 1, 2 and 3) presented the contribution of these constraints on the productivity of these crops. The post-harvest constraints that significantly impacted the productivity of solanaceous crops and which caused very significant losses included the presence of black heart disease, *Pythium*, *Phytophtora*, bacterial disease (*Pseudomonas solanacearum*), the persistence of *Fusarium*, soft rot, and rodent attacks (rats and mice) during the storage period. Difficulty in the product flows due to the impassability of agricultural feeder roads. A marketing circuit is classified as weak, low use of preservatives, poor knowledge of methods for preserving foodstuffs (Tables 3 and 4 in Supplementary data). There were also conservation units such as refrigeration and freezing on the market for products or preservatives. Other farmers, to maintain the quantity required by the buyer, did not carry out pre-sorting after harvest. Both healthy and already degraded products were all mixed, which accentuated the problem. Products such as tomato and eggplant also required cleaning. A lack of such a practice was also reported as accentuating post-harvest losses of these crops. A combination of these constraints was observed for the majority of producers and traders. For example, the presence of black heart disease and a lack of knowledge on the method and shelf life of products, the presence of black heart disease and fusarium, black heart disease and soft rot, coupled with a lack of use of preservatives and the difficulty in selling the product, had a very significant impact on production as they reduced the quantity and quality of the product (Supplementary Table S4).

To reduce the losses referred above, producers used several preservation methods listed in Table 1. The most common method was to store products in jerry cans. For large producers and traders, the use of ice cubes, pesticides, and large containers of daily changed water was practiced. Producers far from electrified areas used *Eucalyptus* leaves for preservation. The eggplant was preserved either by refrigeration, by simple sorting, or by spreading them below the ceilings of houses.

Table 1 Effectiveness evaluation of the preservation techniques used based on farmers' perceptions

Cultures	Used methods	Highly effective	Moderately effective	Low effectiveness
Potato	In the corner of the house	10	30	60
	Storage in bags	05	45	50
	Leave in the fields	0	70	30
	Put in boxes or baskets	20	55	25
	Cleaning and sun-drying	40	40	20
	Spread on the tarpaulin	10	55	35
	Tuber sorting	60	30	10
Tomato	In the shelves	8	54	38
	Harvest before ripening	28	64	8
	Keep in a jerrycan	20	70	10
	Put on ice	65	30	5
	Pesticide Use	70	30	0
	In water jars	10	70	20
	Uses of dry Eucalyptus leaves	55	20	25
Eggplant	Fridge	80	10	10
	Below the ceiling	70	20	10
	Sorting	30	40	30

The losses observed varied according to the practiced post-harvest methods, their efficiency and the interaction of the two. It also varied from one speculation to another, and from farm-type to another. The farmers' assessment of conservation methods showed that only a few methods were classified as effective, notably tuber sorting ($\sim$ 60%), the use of ice cubes ($\sim$ 65%), and the use of pesticides ($\sim$ 70%). Methods such as spreading out in a corner of the house (60%) and storage in the bag (50%) were classified as less effective for more than half of the farmers.

Evaluations of the Qualitative and Quantitative Losses

The representation of qualitative losses due to the observed post-harvest constraints is shown in Tables 3 and 4 in Supplementary data. Both quantitative and qualitative losses were reported. The monitoring of each product during the 15 days of preservation showed that the observed degradations affected very significantly ($p < 0.001$) the taste and aroma of the products. On the other hand, the smell and color were significantly also impacted ($p < 0.05$). The estimation of the quantitative losses observed after evaluation presented in Fig. 5 shows that after preservation, tomato suffered from high losses (– 2000 kg), followed by potato ($\sim$ 1600 kg) and finally eggplant ($\sim$ 620 kg). On the other hand, depending on the types of quality losses, color was an important sign of high losses. The products that observed degradation of the color showed an estimated loss of ($\sim$ 2050 kg) compared to those that degraded aroma and taste ($\sim$ 1500 kg) and flavor ($\sim$ 1620 kg). However, losses of nearly 730 kg were observed for the control, i.e., not lost by other processes (donation, theft, etc.) (Figs. 4a and 5). The monitoring of losses brought back to the farm level for each preservation method tested is shown in Fig. 5, Fig. 4b presents the preservation practices for solanaceous products in Kabare households and markets.

Discussion

General Characteristics of Solanaceous Farmers in the Territory of Kabare, Eastern DR Congo

Of all the solanaceous plants studied, eggplant is still much more widely used by women. In the other two species, the practice was shared between men and women. Most were married with a low educational level. This clearly shows that the practice of these crops is dual, on one hand, carried out by women for self-consumption, and on the other hand, by men exclusively for sale, thus increasing the household income [10, 27]. That is why the fields are located either in the shallows and wetlands or around the dwellings (hut garden). Half of these fields are less than 0.5–1 ha and 45% less than 1 ha. Indeed, due to the high density in the area, as in almost the whole region, the exploited fields are characterized by small areas (Supplementary Table S2. Thus, the combination of these crops is almost strategic in order not only to secure the products that will be sold but

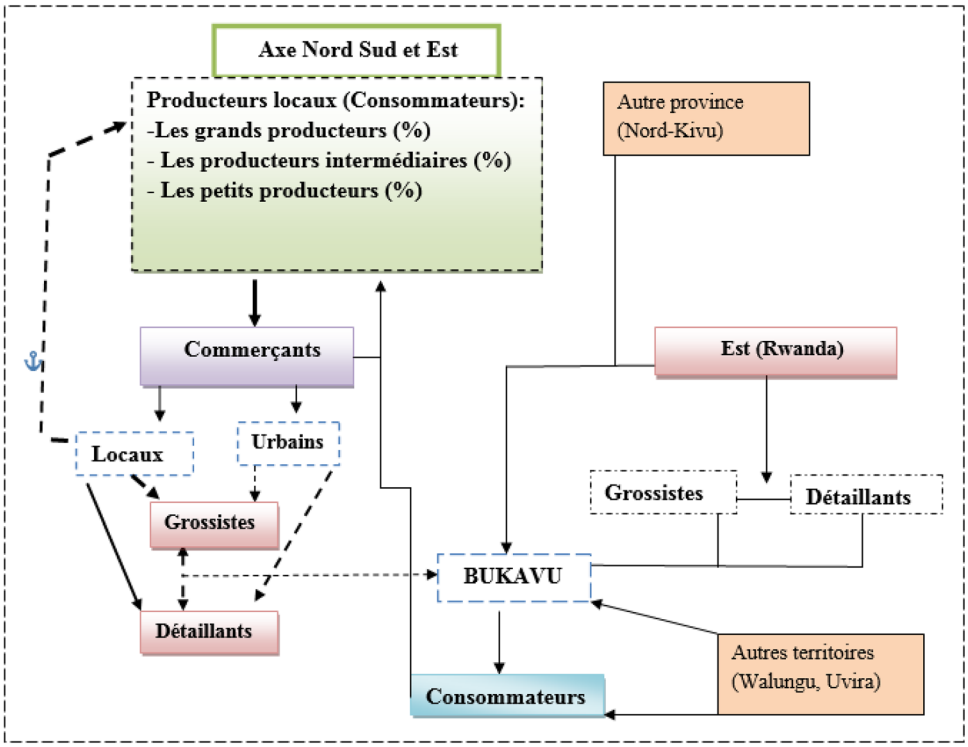

Fig. 3 Diagram of the value chain of solanaceous crops (Tomato, potato and eggplant) produced in wetlands located in the territory of Kabare, eastern RD Congo (*Actors names are given in French and translated in the supplementary data*)

also to ensure the availability of food in the household. It is also carried out to maximize the use of land and the labor force, which is mostly family-based. Young people are also more interested in these crops than older people. In the community, it is too often young people who are involved in market gardening production to meet their needs. Lamb chops and eggplants, for example, are produced by young people who sell them occasionally to pay for their post-secondary schooling, or that of their brother. This justifies the presence of almost a quarter of the producers classified as students. These crops therefore remain profitable according to the perception of producers [2, 20].

The seeds used to come either from previous harvests, from INERA, or neighboring provinces or countries. Some of these varieties are multiplied and sold by companies such as INERA, the union of seed multipliers, the Farmers' Association of BWISHA (South Kivu); however, no processing or packaging unit for these products is observed in North Kivu. The Barungu et Fils company already processes tomatoes, SYDIP (Syndicat de défense des intérêts paysans) works in potato seeds, APAV for vegetable seeds (onion, carrot, cabbage, leek, potatoes); the Maison KIVU STARS (Kivu Star Seeds) also works in vegetable seeds of all kinds [9].

The methods used are not effective, and significant losses have been observed when evaluating them. It is therefore daring to believe that certain methods promote the reduction of temperature and the increase in humidity which are the two important parameters for the development of rot in potatoes for example. Other constraints even stem from poor knowledge of how to harvest the products. Producers who do not fully master harvesting techniques in tomatoes and eggplant for example still use archaic methods such as the use of dirty knives, contaminated equipment, can cause mechanical damage on the tubers to infect the product. Growers have been classified into four types. Type 1 being considered the large producers. These growers account for only 4% of the total and yet produce the bulk of the production. These producers have very important commercial, financial and administrative means, occupy a good position to use more direct channels, have the capacity to hire and pay for technical labor and to store their products. However, they still rely on intermediaries (local wholesalers and/or retailers) to provide their services. And yet, it would be important to deliver products to the final consumer via shorter chains by signing partnerships with the city's shops and supermarkets (Kavumu, Bukavu, etc.). A greater number of intermediaries involved (rural wholesalers and retailers, urban wholesalers, small urban traders, etc.) would imply losses in profitability along the chain given the gap observed between prices at the first producer and the final consumer. Thus, producers or investors wishing to enter this activity will have to take into account the life span of the products, the cost and the commercial margin, the capacity to build their own distribution network and finally the availability of services provided by intermediaries [13, 35].

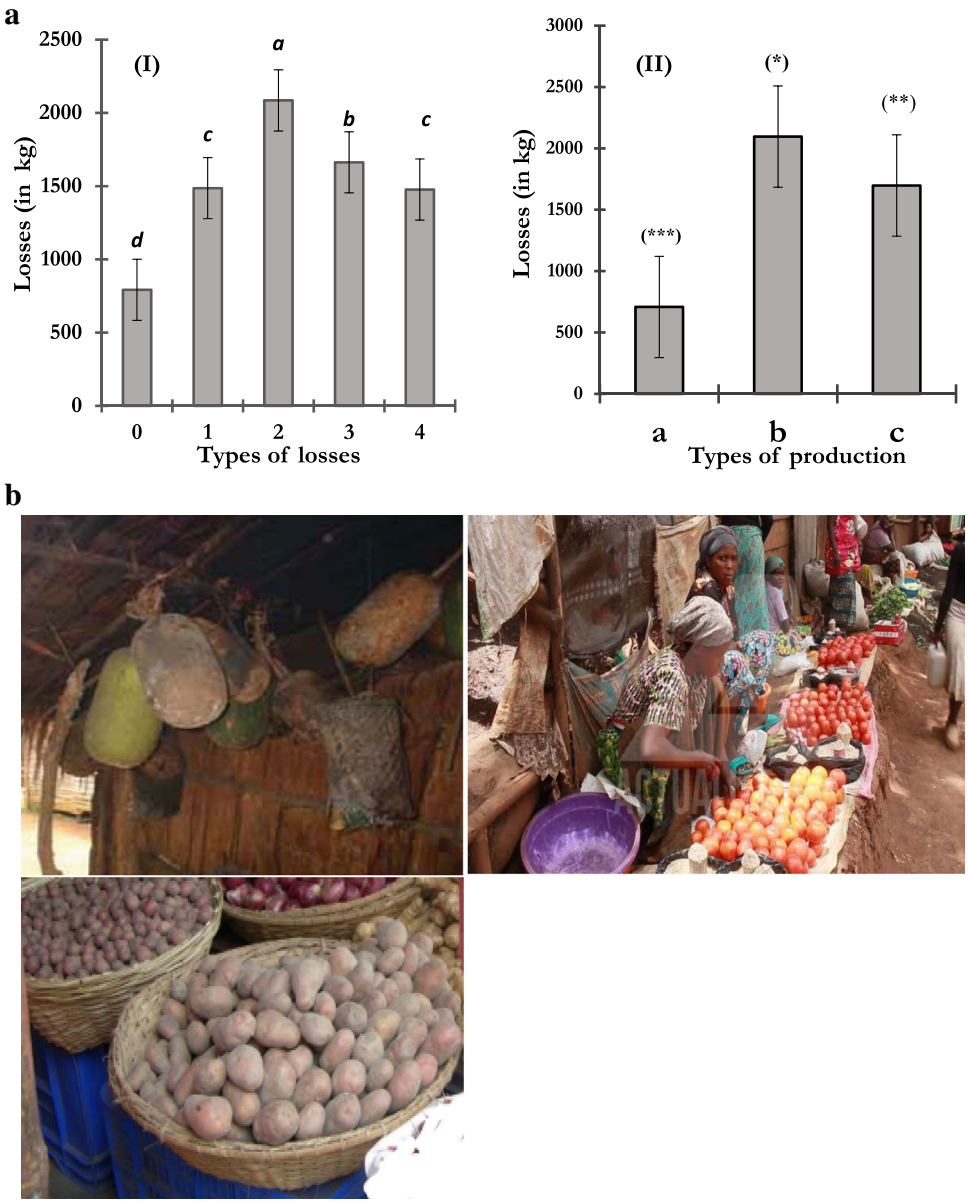

Fig. 4 **a.** Qualitative and quantitative losses related to the constraints observed (quantities were extrapolated to the hectare of each crop field). Variation of type of losses (I) and type of production (II) of solanaceous crops produced in Kabare wetlands. Legend: Types of losses: 0: no influence, 1: Aroma, 2: Color, 3: Smell, 4: Taste, and Types of production: a: Eggplant, b: Tomato, c: Potato, *: means separation using Tukey HSD test at 0.05 threshold. **b**. Figures of preservation practices for solanaceous products in Kabare households and markets

Post-harvest Constraints of the Main Solanaceous Crops Grown in Wetlands in Kabare Territory

The post-harvest sector in DR Congo in general is characterized by the non-existence of means of preservation and storage of food products such as potatoes [28]. In other regions [8], refrigerated or isothermal trucks and containers are available to conserve and transport food. This is not the case in Kabare in general and the province of South Kivu in particular. In the economic analysis (Supplementary Table S3), costs related to transport are observed and therefore producers and traders are kind enough to improve preservation and transport. However, the economic situation and the equipment available in the area do not allow them to afford such equipment on the one hand. On the other hand, the cost and mechanisms allocated by producers to preserve products remain to be questioned. A typical example, and linked for example to the situation of the territory, some households do not have the means to set up the electrification of their house, so it remains to be wondered whether they will be able to manage to pay the electricity bills in order to conserve their products. Koussoube et al. [22] point out that one of the main constraints in the marketing of agricultural products in Africa remains the lack of infrastructure to store the products harvested in the respective production areas. Support structures should therefore initiate a financing system that would enable entities to build storage warehouses adapted to the level of the production area in order to relieve the farmers and thus preserve the quality of the products [31].

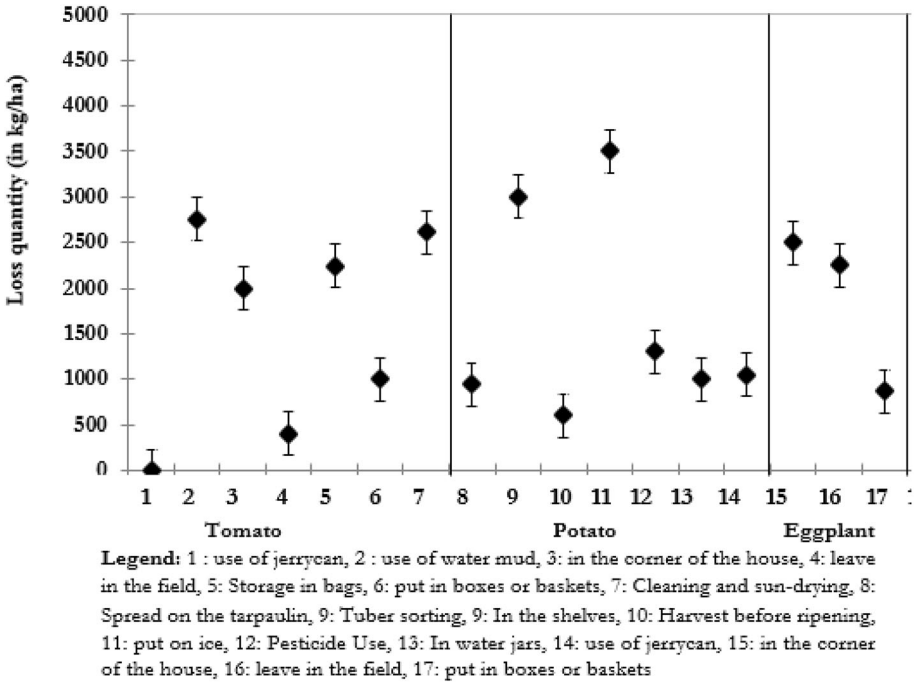

Fig. 5 Estimated losses according to the methods of preservation practiced by producers (*values have been reduced to the hectare of each solanaceous crop*)

The appearance requirements of today's markets (both local and international) cannot be clearer. If they are more advanced for fruits (pineapple, banana, apple etc.), for example for tomatoes, they range from pink to bright red in color, aroma, freedom from defects, waxing, uniform size, sold by weight or in trays of 4–6 units. Fruit appearance, color changes and color deterioration are proven to be among the crucial factors in determining products marketability during postharvest and after the cold storage period [26].

It seems therefore that one of the means is to intensify the production systems of these crops in the environment through the use of inputs in order to increase production, to protect the plants against plant pathogens. However, the intensification of market gardening in the province does not apply exclusively to other speculations, since the introduction of other crops such as biofortified varieties may be accompanied by criticism, conflicts because of the pressure and competition it may bring on water and nutritional resources, for example in the lowlands and marshlands which are exploited even in the off-season. It also raises issues related to land conflicts and even the sustainability of agricultural activities in these areas. Phytosanitary treatments to prevent the attack of fungi and insect pests remain very little used. However, compliance with storage standards is to be recommended to allow better exposure of all stored products to the required temperature and humidity conditions, and this along the entire chain from producer to consumer. Given the constraints observed, the techniques for limiting these losses remain rudimentary and do not make it possible to limit post-harvest losses, and farmers are thus obliged to sell their products very quickly, whatever the price. Aujla et al. [7] and Mpanzu [28] show that if the losses recorded at the producer level are difficult to recover financially, then the logic of traders is reflected in the selling price to the end consumer, who will see his price rise. This accentuates the problem with the strong competition on the market with products from other provinces and neighboring countries. Also, the low level of education of producers (Supplementary Table S2) would lead to poor knowledge of the uses of plant pathogenic products, their use is mainly due to the difficulty of reading how to use these products, which are generally shown on the packaging. This would lead to either under or over-use of the products, which can become a real danger [37]. This seems to be true as it is not uncommon to still find residues of plant pathogenic products on these crops at the market level. Storage conditions are not optimal, on the one hand a sensitivity to ethylene, a natural phytohormone affecting the mechanism of growth, development and especially ripening and aging of plants, normally produced in small quantities in fruits and vegetables, favoring their storage. However, eggplant is sensitive to ethylene while tomato produces a significant amount [5]. Also, for example, for tomatoes, the rate of respiration and perishable heat production during storage at different temperatures is 24.0–44.1 Mg CO_2/kg/hour and 6150–11,260 kJ/tonne/day at temperatures of 20–21 °C, while at low temperatures (4–5 °C) these values are only 5.91 Mg CO_2/kg/hour and 1508 kJ/tonne/day, respectively [13]. It is therefore clear that the conservation techniques practiced at Kabare do not allow such requirements to be met. On the other hand, the

valorization of "good hygiene practices (GHP)" which are a set of operations that are oriented to guarantee good hygiene, safety and healthiness of the products. It is in fact a set of operations whose consequences do not always seem measurable on the finished products. While on small farms their use is not necessary, on large farms (over 1 hectare), the use of these products to preserve these foodstuffs is still recommended to reduce post-harvest losses. This only in farms where the owner has a level of education and can calculate the rates to be applied. Other studies recommend the use of biopesticides which would present less severe effects. However, we are still far from this in the field.

This study therefore provides a basis for suggestion in this sense, especially since among the methods classified as effective, the use of leaves of woody species such as *Eucalyptus*, chilli pepper, *Tephrosia*, *Tagetes*, *Artemisia* [17, 32] have shown significant effects. However, these species can be found easily and at a very low cost in the environment. Their use is still very poorly known by producers and traders in the zone despite some research carried out to promote these products. [33, 38]. The establishment of small local units for the production of plant extracts and essential oils), as well as biological control (e.g. use of for example, to reduce fungal pressure would be essential actions to reduce the use of pesticides. The other constant in this work is the evaluation of the effectiveness of the conservation methods used, which are limited because they do not reduce the qualitative and quantitative losses of the products once they have been conserved. On the other hand, rising consumer awareness would encourage decision-makers in the Kabare territory to apply the laws in force regarding the use of these products.

Conclusions

The solanaceous crops (potato, tomato and eggplant) grown in Kabare wetlands are subjected to severe post-harvest constraints. These constraints are technical and technological, structural and production-related. Analysis based on the evaluation of the effectiveness of preservation methods used to reduce the losses helps to certify that these methods are not effective. However, producers continue to use them to reduce and minimize the effects. Simple sorting techniques and the use of leaves of some woody species (such as *Eucalyptus*) help to reduce these losses to some extent. The lack of a refrigeration unit (and electrification) and very low use of pesticides or preservation products accentuate the qualitative and quantitative losses. However, to improve profits, producers and traders will have to give priority to quality to differentiate themselves from imported products; this will help in reducing the strong competition observed on the market with products from neighboring countries or provinces. New information and communication techniques related to post-harvest activities and distribution channels should also be investigated in the future according to each crop separately.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s40003-021-00586-4.

Acknowledgments The authors would like to thank Université Evangélique en Afrique (UEA/Bukavu) and Pain Pour le Monde for manifold support to this work which was funded through the University project on "Improvement of research and teaching quality" (Projet A-COD-2018-0383).

Author contributions CBG, NB.A, studied and designed the research, CBG and NGA and NSN performed the analysis on all samples, interpreted the data, and wrote the manuscript. MB collected the data and did the first draft. MNG assisted in data analysis and interpretation and drafting of the manuscript. At the end, all the authors read and approved the final manuscript.

Funding Not applicable.

Declarations

Conflict of interest All authors declare that they have no conflict of interest.

References

1. ACF (Action Contre la Faim) (2014) Post-harvest losses and strategies to reduce them. Technical paper, Scientific and Technical Department. 25 p
2. ACF (Action Contre la Faim) (2009) Évaluation conjointe, ACF USA - IPAPEL - FAO Sud Kivu sur les besoins en sécurité alimentaire, Zone de Santé de Bunyakiri République Démocratique du Congo, Rapport, 30 p
3. Adeoye IB, Odeleye OMO, Babalola SO, Afolayan SO (2009) Economic analysis of tomato losses in Ibadan Metropolis, Oyo State, Nigeria. Afr J Basic Appl Sci 1(6):87–92
4. Arah IK, Ahorbo KG, Kosi KE, Kumah EK, Amaglo H (2016) Postharvest handling practices and treatment methods for tomato handlers in developing countries: a mini review. Adv Agric. https://doi.org/10.1155/2016/6436945
5. Arah IK, Kumah EK, Anku EK, Amaglo H (2015) An overview of post-harvest losses in tomato production in Africa: causes and possible prevention strategies. J Biol Agric Healthcare 5(16):78–88
6. Atanda SA, Pessu PO, Agoda S, Isong IU, Ikotun (2011) The concepts and problems of post-harvest food losses in perishable crops. African J Food Sci 5(11):603–6013
7. Aujla KM, Shah NA, Ishaq M, Fraooq A (2011) Post-harvest losses and marketing of grapes in Pakistan. Sarhad J Agric 27(3):485–490
8. Bokombola PB, Balomba PM (2019) La performance de la chaîne de commercialisation des feuilles de manioc à Kinshasa et dans son hinterland. Revue internationale des etudes du developpement 1:35–63
9. Chishesa HT (2016) Production de la tomate, contraintes et opportunités en territoire de Walungu, Sud-Kivu à l'Est de la RD Congo. Int J Innov Sci Res 23(1):15–27p

10. Chuma BG (2019) Connaissances paysannes et évaluation des techniques de conservation du sol dans les petites exploitations de Kabare nord, est de la RD Congo. *Faculté des bioingénieurs*, Université catholique de Louvain. 82 p. http://hdl.handle.net/2078.1/thesis:22507
11. CNUCED (2003) Conditions d'entrée influant sur la compétitivité et les exportations des biens et services des pays en développement: les grands réseaux de distribution, compte tenu des besoins particuliers des PMA. http://www.unctad.org/fr/docs/c1em23d2_fr.pdf
12. Dewitte O, Jones A, Spaargaren OC, Breuning-Madsen HD, Brossard ME, Dampha AF, Deckers JG, Gallali TH, Hallett SI, Jones RI, Kilasara MJ, Le Roux PK, Michéli E, Montanarella LA, Thiombiano LM, Van Ranst EN, Yemefack MO, Zougmore R (2013) Harmonization of the soil map of Africa at the continental scale. Geoderma 211–212:138–153. https://doi.org/10.1016/j.geoderma.2013.07.007
13. FAO (2010) Formation en gestion d'entreprises associatives rurales en agroalimentaire, Version adaptée pour l'Afrique francophone. Matériel de formation en gestion, commercialisation et finances agricoles de la FAO. Module 4 : Opérations de post-récolte et commercialisation, Rome, Italie. 119 p.
14. Gudila AK, Monica L, Mbwana AH, Mongi JM, Ruhembe CC (2013) Assessment of Post-harvest handling practices: knowledge and losses of fruits in bagamoyo district of Tanzania. Food Sci Quality Manag 11:2224–6088
15. Habineza MJP (2011) Essai d'utilisation d'un pesticide organique naturel et de synthèse dans la lutte contre le mildiou (*Phytophtora infestans*) chez la pomme de terre (*Solanum tuberosum*) cas des extraits de bulbes d'ail et du Dithane M45. Faculté des sciences économiques, Université de Goma, 58p
16. Hodges RJ, Buzby JC, Bennett B (2011) Postharvest losses and waste in developed and less developed countries: opportunities to improve resource use. J Agri Sci 149:37–45
17. Isman MB, Machial CM (2006) Pesticides based on plant essential oils: from traditional on lepidopterous larvae and their feeding response. Natural Pesticides from the Neem Tree (*Azadirachta indica* A. Juss) and Other Tropical Plants. In: Proceedings of the 2nd International Neem. Conference, edited by Schmutter, H., and Asher, K. R. S. Germany: German Agency for Technical Cooperation, 57
18. Kambale PD, Kambale PD, Pawar CD (2019) Effect of storage conditions and benzoic acid concentrations on quality and shelf life of Aonla Juice Cv.NA-10. J Tree Sci 38(2):92–97
19. Karim MA, Hawlader MNA (2005) Mathematical modelling and experimental investigation of tropical fruits drying. Int J Heat Mass Transf 48:4914–4925
20. Kazi H, Bielders LC (2020) Dégradation des terres cultivées au Sud-Kivu, R.D Congo: perceptions paysannes et caractéristiques des exploitations agricoles. Biotechnol Agron Soc Environ 24(2):99–116
21. Kitinoja L, Gorny JR (1999) Postharvest technology for small-scale produce marketers: economic opportunities, quality and food safety. Univ. Calif. Postharvest Hort. Series No. 21
22. Koussoube S, Traore F, Some K, Binso-Dabire S, Sanon A (2018) Perception paysanne des principales contraintes et pratiques culturales en production de patate douce au Burkina Faso. J Appl Biosci 126:12638–12647. https://doi.org/10.4314/jab.v126i1.2
23. Lopez-Camelo A (2004) Manual for the preparation and sale of fruits and vegetables-from farm to market
24. Mangambu M, Aluma K, Van Diggelen R, Rugenda-Banga R, Mushangalusa K, Chibembe S, Ntahobavuka H, Nishuli B, Robbrecht E (2015) Etudes ethnobotanique et ethnolinguistique des ressources forestières ligneuses utilisées par la population du couloir écologique du parc national de Kahuzi-Biega (R.D Congo). Eur Sci J 11(15):135–162
25. Mangambu M, Ntahobavuka H, Basinyize B, Lokumu I, Elmar Robbrecht (2018) Pteridaie: indicator of the vegetation succession and dynamics in the forests Chablis and Edges in Kahuzi-Biega National Park (Eastern DR Congo, Albertine Rift). Int J Biol Res 6(1):5–13. https://doi.org/10.14419/ijbr.v6i1.9241
26. Mohi-Alden K, Alabboud M, Soltani F, Kalantari S (2021) 'Developing a postharvest color changes identification system of melon rind using image processing, DYSONA. Appl Sci 2:13–20. https://doi.org/10.30493/das.2021.263257
27. Mondo JM, Irenge AB, Ayagirwe RBB, Dontsop-Nguezet DM, Katcho K, Njukwe E, Mapatano SM, Zamukulu MP, Chuma BG, Musungayi EM, Mbusa HK, Kazamwali KL, Civava R, Mushagalusa NG (2019) Determinants of adoption and farmers' preferences for cassava varieties in Kabare Territory, Eastern Democratic Republic of Congo. Am J Rural Dev 7(2):44–52. https://doi.org/10.12691/ajrd-7-2-1
28. Mpanzu P (2012) Commercialisation des produits vivriers paysans dans le Bas-Congo (RD Congo): contraintes et stratégies des acteurs. Thèse de doctorat, Gembloux Agro-Bio Tech
29. Nasrin TAA, Molla MM, Hossaen AM, Alam MS, Yasmin L (2008) Effect of post-harvest treatments on shelf life and quality of tomato. Bangladesh J Agric Res 33(3):579–585
30. The World Bank, NRI and FAO (2011) Missing food: the case of postharvest grain Losses in Sub-saharan Africa. Report No. 60371-AFR
31. PADDAFAC et PASAOC (2011) Projets PADDAFAC & PASAOC - RD Congo Appui au développement durable des activités et des filières agricoles Province du Bas Congo. Agrisud International
32. Parekh J, Chanda S (2007) Antibacterial and phytochemical studies on twelve species of indian medicinal plants. Afr J Biomed Res 10:175–181
33. Rehema ME, Hezron NE, Gaymary BG, Nabintu N, Maulid MW, Maerere AP (2019) Controlling *Tuta absoluta* (Meyrick) by Selected Crude Plant Extracts in the Laboratory and in the Screen House. J Agric Sci Technol A 9:227–239. https://doi.org/10.17265/2161-6256/2019.04.003
34. Renou C, Lindiro R, Kambale-Kamale JM (2015) Manuel-Production de semences de riz. Centre for Development Innovation, Wageningen
35. Rushigira C (2017) Analyse technico-économique de la production maraîchère à Kamanyola dans la plaine de la Ruzizi/RDC : Contraintes et stratégies d'acteurs. Faculté des sciences économiques, sociales, politiques et de communication, *Msc thesis*, *Université catholique de Louvain,* http://hdl.handle.net/2078.1/thesis:11436
36. Sidikou R (2002) Contribution de biotechnologie végétale à l'adaptation de la pomme de terre (*Solanum tuberosum*) au Niger, *Thèse d'état Niamey*, 354 p
37. Son D, Somda I, Legrève A, Schiffers B (2017) Pratiques phytosanitaires des producteurs de tomates du Burkina Faso et risques pour la santé et l'environnement. Cahiers Agric 26:25005. https://doi.org/10.1051/cagri/2017010
38. Zihalirwa KP, Chuma BG, Mushagalusa NG, Philippe T, Ongena M (2017) Efficacy of *Bacillus amyloliquefaciens* as biocontrol agent to fight fungal diseases of maize under tropical climates: from lab to field assays in South-Kivu, chemistry, activity and impact of plant biocontrol products. Chem Activity Impact Plant Biocontrol Prod. https://doi.org/10.1007/s11356-017-9314-9