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Smallholder farmers' perception and challenges toward the use of crop residues and agro-industrial byproducts in livestock feeding systems in Eastern DR Congo

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ABSTRACT

The extent of crop residues and agricultural byproducts utilization for their integration in feeding systems in Eastern DR Congo was assessed in South-Kivu (Walungu *territoire*) and two *territoires* in the Tanganyika province (Kalemie and Moba *territoires*). Data were collected through 21 focus group discussions in which 273 farmers participated including respectively 116 (42%) from South Kivu and 157 (58%) from Tanganyika province. A logistic regression model was used to determine factors influencing the adoption of crop residues and agro-industrial byproducts as livestock feeds. Results revealed that all the respondents keep goats and chicken as major livestock. In all the *territoires*, crop residues (26.9%) were utilized more than agro-industrial byproducts (6.4%). Both crop residues and agro-industrial byproducts were most utilized in Walungu (39%, 10.3%), compared to Moba (18.3%, 6.2%) and Kalemie (23.4%, 2.7%). Sixteen types of crop residues and eight agro-industrial byproducts were identified and categorized into cereal crop residues (4), legume crop residues (4), root crop residues (3), fruit crop residues (3) and other crop residues (2). These crop residues and agro-industrial byproducts were generally sourced from around the homesteads and available and utilized throughout the year. They were often fed to livestock twice daily. The main constraints affecting adoption of crop residues and agro-industrial byproducts were access to information, lack of knowledge, poor infrastructures, high cost of transportation of material, storage and conservation facilities, the toxicity of material and plant diseases, high cost of products, microbial infestation and the insufficient supply of the material. Improving the utilization of crop residues and agro-industrial byproducts in the livestock feeding system in these *territoires* should tackle the above mentioned factors for sufficient utilization.

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Introduction

In sub-Saharan Africa (SSA), livestock is central to the livelihoods of a large percentage of poor rural households [1]. It plays an important function to people by supplying protein in the form of meat, milk and skin [2] and therefore contributes to improving the nutritional status and the economic growth of smallholder farmers [3]. However, livestock production is facing several challenges in SSA, including poor management, inadequate biosecurity practices, diseases with little or no veterinary attention, low genetic potential of native livestock, looting of resources in rural areas, inadequate nutrition, low feed quality and high costs of commercial feed [4–6,39].

In DR Congo, livestock contributes up to 9.2% of the gross domestic product and plays an important function in the income and livelihood of the rural population (SNSA [7]). Unfortunately, for about three decades, repeated political unrest in the eastern part of DR Congo have significantly affected the socio-economic situation of the rural population [8]. This situation has created a massive movement of the population with their livestock to the most secured villages, leading to demographic pressure [9] and scarcity of collectable forages, as well as a restriction to reaching faraway grazing lands due to existing militia and armed groups [8]. Therefore, feed shortage in Eastern DR Congo is considered amongst the major challenges constraining livestock production, especially during the dry season [10–12]. This situation has led to price fluctuations and a scarcity of feed concentrates and improved fodder adapted to marginal conditions, making them uncompetitive with food crops, which further aggravates the livestock feeding situation [4]. Addressing the issue of limited livestock feed would alleviate the abovementioned constraints.

Integrated crop–livestock production systems constitute an important source of livelihoods to the majority of smallholder farmers involved in agricultural production in Eastern DR Congo [13] as it diversifies smallholder farmers' sources of income and employment [14]. amongst other benefits, this system provides crop residues as an important low-cost feed resource [15], supplying over 20% of animals' energy requirements [16] as well as contributing between 40 and 60% of the total dry matter intake in many tropical countries [14].

Crop residues and agricultural byproducts are now widely used around the world as animal feed. The trend has changed from the situation in which crop residues and byproducts were burnt because they were considered as wastes and pollutants, to now being converted to animal protein for human consumption (Iyeghe-Erakpotobor et al. [17]). They are being used in many developing countries as the principal component of livestock diets because they are locally available and relatively cheaper feed resources. However, the use of most of them has been reported to be very low over the years [44] and is therefore wasted year after year, unused, burnt, undeveloped or poorly utilized [18,19].

Several factors including availability, quality, price, labour costs and capital investment in processing have been mentioned to influence the adoption and utilization of these crop residues and agricultural byproducts in different countries [19,20]. Understanding the socio-economic factors limiting the utilization of crop residues and adoption of new feeding systems are amongst the most fundamental principles in assessing the need for additional and alternative feeding systems or improving on the existing feeds and feeding systems for improved adoption and utilization by farmers [15,20]. Yet, numerous ways of crop by-product utilization exist amongst smallholder farmers [21]. These may have a strong cultural and economic basis and may vary from one society to another depending on the type of available residues [15].

Based on the above background, this study assessed perception and challenges faced by smallholder farmers on the use of crop residues and agro-industrial byproducts in livestock feeds and feeding systems of Tanganyika and South-Kivu provinces, Eastern DR Congo to provide a basis for future research on improving the nutritional value and development of appropriate feeding strategies based crop residues and agro-industrial byproducts.

Materials and method

Study area

This study was conducted in two *territoires* of the Tanganyika province including Moba and Kalemie and one *territoire* of South Kivu province (Walungu) as presented in Fig. 1. Moba is located within 7°02′S latitude and 29° 46′E longitude, receives mean rainfall of about 836 mm per annum and 26 °C mean temperature per annum and Kalemie within 5°56′S latitude, 29° 11′E longitude, rainfall of about 1090 mm per annum and 28 °C mean temperature per annum while Walungu is located within 2°37′S latitude and 28° 40′E longitude, receives rainfall of about 1500 mm per annum and 22 °C mean temperature per annum (Data retrieved from NASA for 01/01/2017–31/12/2019).

Sampling strategy and data collection

A total of 273 farmers were selected from 21 villages including 62 farmers from 4 villages of Moba *territoire* (Kiluya, Maseba, Katonge and Lukalanga), 95 farmers from 7 villages of Kalemie *territoire* (Tabac, Mtoa, Kabimba, Mulange, Tundwa, Kisondja and Rugumba) and 116 farmers in 10 villages of Walungu *territoire* (Lurhala, Ibanda, Burhale, Butuza, Ibinza, Kaziba, Cihusi, Irongo, Lubona and Ngali). Farmers were selected to participate in the discussion with the help of local extension officers and staffs from existing NGOs promoting crop-livestock integration. Applied criteria of farmer selection included: i) their involvement in crop-livestock systems development activities, ii) their experience in on-farm livestock feeding and iii) their willingness to participate. An informed consent form translated into local languages was presented and signed by the farmers prior to the survey.

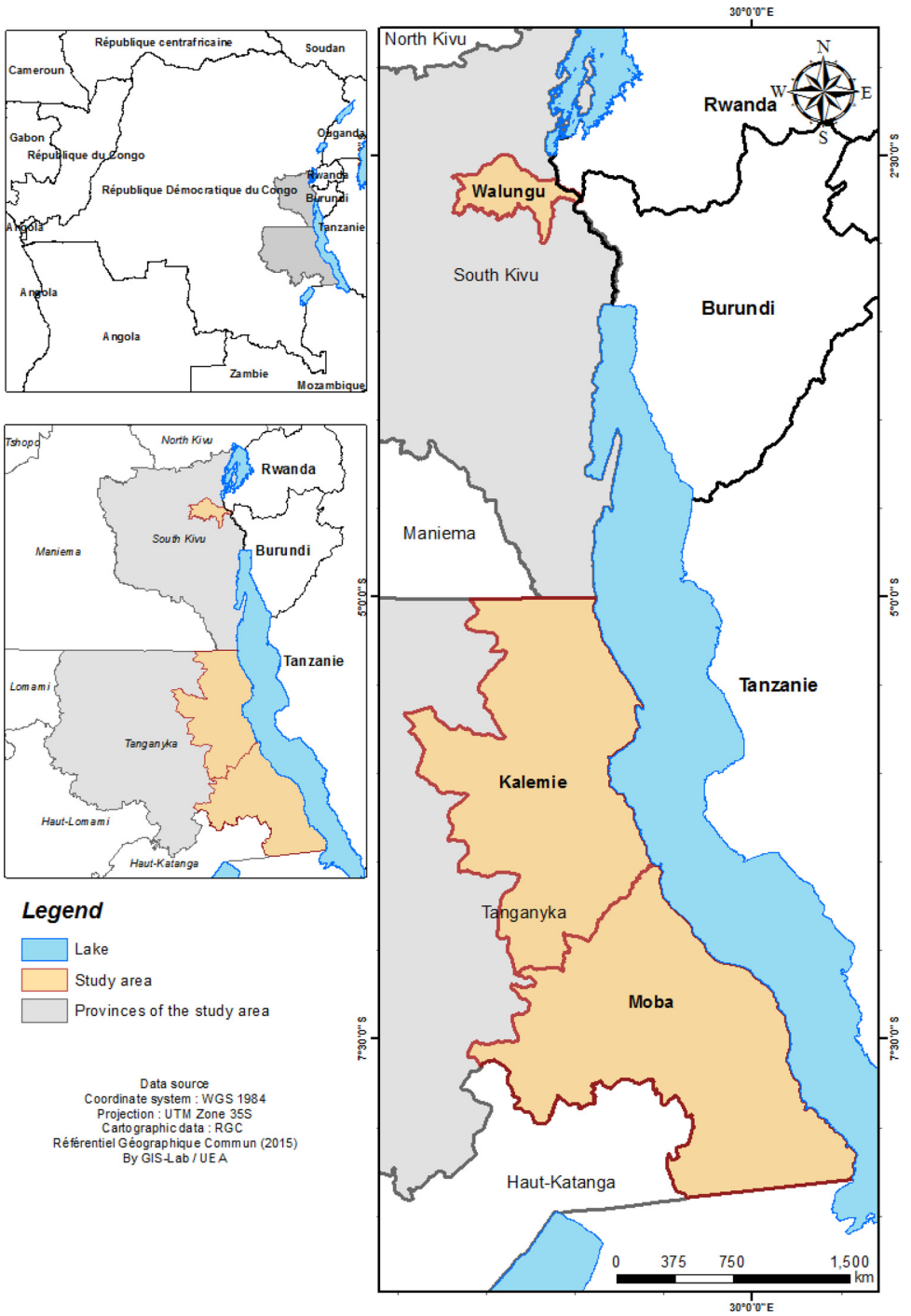

Fig. 1. Map of study area, South Kivu and Tanganyika Provinces: Map made using shapefiles from the RGC (Référentiel Géographique Commun).

The field work was done in collaboration with FH field staff and local extension officers to hold focus group discussions (FGDs) with Farmer Leader Groups (FLGs). The study design was cross sectional and both qualitative and quantitative data were collected to have an in-depth understanding of the extent of utilization of crop residues and agro-industrial byproducts by farmers as well as the related challenges for their utilization.

Data were collected using a structured questionnaire that involved the biodata and some background information of the farmer, livestock inventory, the use of crop residues and agro-industrial byproducts and the major challenges related to collection and feeding crop residues and agro-industrial byproducts. The availability rating was determined on mean scores

Table 1
Inventory of crop residues and agro-industrial byproducts.

	Kalemie (n = 95)	Moba (n = 62)	Walungu (n = 116)
CROP RESIDUES			
Cereal crop residues (%)			
Maize cob	23.2	–	35.3
Maize stalks	28.9	25.7	38.6
Maize husk	10.9	–	29.8
Rice stove	–	–	6.1
Leguminous crop residues (%)			
Bean haulms	8.6	–	41.1
Soybean haulms	–	–	9.6
Groundnut haulms	6.2	–	3.1
Pea haulms	–	–	2.2
Root crop residues (%)			
Cassava peels	9.4	11.3	49.8
Potatoes peels	15.9	–	27.1
Taro peels	–	–	1.0
Fruits crop residues (%)			
Banana peels	18.6	24.1	34.0
Banana stem	–	–	26.2
Avocado kernel	15.01	19.7	22.7
Other crops (%)			
Coffee pulp	–	–	0.3
Cabbage leaves	1.0	–	16.7
AGRO-INDUSTRIAL BYPRODUCTS (%)			
Rice bran	23.9	–	11.4
Rice brewery grain	–	–	12.9
Maize bran	46.3	41.8	21.0
Maize flour residues	5.1	7.7	9.0
Cassava flour residues	–	2.1	5.5
Palm kernel cake	18.5	–	24.9
Banana local brewery residue	–	–	18.9
Maize local brewery residue	21.7	33.0	–
Boiled bean sauce	–	–	25.6

Note: "n" represents the sample size.

to the nearest whole number as described by Onyeonagu and Njoku [40] while the most frequently used crop residues and agro-industrial byproducts were determined as those with mean usage of greater or equal to 15% as reported by Onyeonagu and Njoku [40]. The choice of independent variables summarized in Table 1 was based on literature review, and socio-economic theory governing the adoption of the use of crop residues and agro-industrial byproducts [20,22,40]. This study assumed that the constraints affecting positively the adoption of crop residues and agro-industrial byproducts had a positive impact on their use by farmers and vice versa.

Data analysis

All the data collected from the study were submitted to descriptive analysis, such as simple means, percentages, graphs and cross tabulation tables. In these graphs and pivot tables, the analysis was done with a corresponding percentage. A logistic regression model was used for the determination of factors influencing the adoption of crop residues and agro-industrial byproducts as livestock feeds. Farmers' decision to adopt the use of agricultural byproducts or crop residues was captured as a binary choice: 1 if the farmer adopted and 0 otherwise. Empirical evidences support that a farmer adopts agricultural byproducts or crop residues if the utility gained from adopting it is greater than the utility from not adopting ($\boldsymbol{U_i^* = U_{iA} - U_{iN} > 0}$) [23]. However, since the utility is unobservable, it was expressed as a function of observable variables in the following equation:

$$U_i^* = X_i'\gamma + \varepsilon_i$$

$$\text{with } U_i = \begin{cases} 1 \; if \; U_i^* > 0 \\ 0 \; otherwise \end{cases}$$

Where, U_i^* is the latent variable, representing the farmer adoption likelihood: 1 if the farmer adopts and 0 otherwise. The term X_i' represented explanatory variables associated to adoption decision, γ is a vector of estimated parameters, and ε_i is the error term (assuming it was independent and normally distributed as $\varepsilon_i \sim N(0, 1)$).

From the econometric literature, identifying factors affecting adoption decision is modelled through a binary model such as logit or probit, with little consideration on the choice between the two models [24,38]. To identify the factors affecting

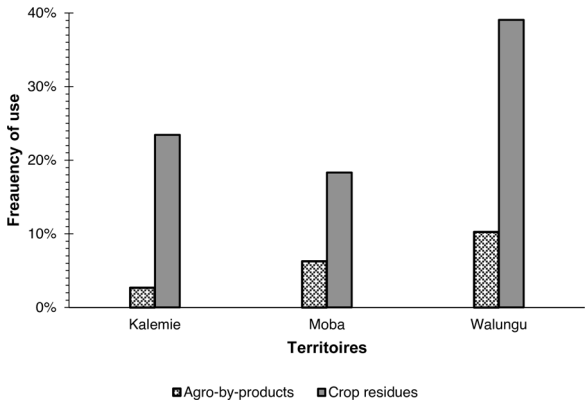

Fig. 2. Distribution of crop residues and agro-industrial by-products.

adoption decisions of agricultural byproducts or crop residues, we fitted a logit model [38]. That fitted logistic distribution function is specified as by Greene [25]:

$$P_i = \frac{1}{1 + \exp\left(-U_i^*\right)}$$

Where Pi is the i^{th} farmer's uptake probability, it ranges from 0 to 1. For the two models, independent variables presented in Table 1 were used. All the statistical analyses were performed under R software, version 3.6.

Results

Demographic information of participants

The results indicated that most of farmers were men, married, with a primary school as level of education and had average age comprised between 41 and 60 years or 26 to 40 years depending on *territoire*, and therefore sufficiently experienced to provide reliable information. All the respondents were livestock farmers and have the natural grazeland as the main source of feed for their animals.

Livestock holding by farmers

According to farmer's responses, chicken and goats are the most reared livestock and are owned respectively by 93% and 89% of farmers. Cattle are mostly present in Walungu farms compared to other sites, while sheep are scarce in the study area. Rabbits and cavies (guinea pigs) are very scarce in Kalemie and Moba *territoires* but owned by more than half of farmers interviewed in Walungu *territoire*.

Distribution of crop residues and agro-industrial by-products

The use of crop residues and agro-industrial by-products in the 3 *territoires* is presented in Fig. 2.

The results show that crop residues and agro-industrial by-products are mostly used in Walungu *territoire*. However, agro-industrial by-products are little used in all the *territoires* compared to crop residues.

Crop residues and agro-industrial by-products main types

The main types of crop residues and agro-industrial by-products used as animal feed in Kalemie, Moba and Walungu *territoires* are given in Fig. 3.

The study identified 5 groups of crops residues (cereal crops, fruit crops, leguminous crops, root crops and other crops including cabbage leaves and coffee pulp) and 5 groups of agro-industrial byproducts (cereal crops, fruit crops, leguminous crops, root crops and other crops including oil palm). However, in the 3 *territoires*, residues and agro-industrial by-products of cereals were most widely used, followed by crop resides from root crops and agro-industrial by-products from oil palm and root crops.

Crop residues and agro-industrial by-products availability

The availability of different crop residues and agro-industrial byproducts in Kalemie, Moba and Walungu *territoires* is presented in Table 1.

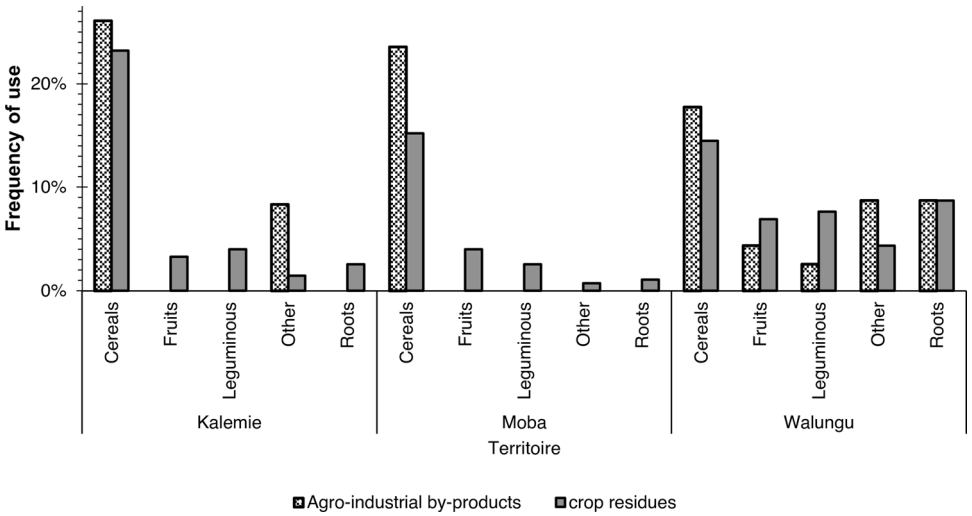

Fig. 3. Types of crop residues and agro-industrial by-products.

The study identified sixteen (16) crop residues including maize cobs, maize stover, maize husk, rice stove, bean haulms, soybean haulms, groundnut haulms, pea haulms, cassava peels, sweet potatoes peels, taro peels, banana peels, banana stem, avocado kernel, coffee pulp, and cabbage leaves. Nine agro-industrial by-products were identified, amongst them rice bran, rice brewery grain, maize bran, maize flour residues, cassava flour residues, palm kernel cake, banana local brewery residue, maize local brewery residue and boiled bean sauce. Walungu was the *territoire* where crop residues and agro-industrial by-products are most used and included: maize cob, maize stover, maize husk, bean haulms, cassava peel, potatoes peel, banana peel, banana stem, avocado kernel, cabbage leaves as well as maize bran, palm kernel cake, banana brewery residue and boiled bean sauce. In Kalemie territory maize cob, maize stover, potatoes peel, banana peel, avocado kernel, rice bran, maize bran, palm kernel cake and maize local brewery residue are the most crop residues and agro-industrial by-products used while maize stover, banana peel, avocado kernel, maize bran and maize local brewery residue were the most crop residues and agro-industrial by-products exploited by farmers in Moba *territoire*.

Utilization of crop residues and agro-industrial byproducts

The different methods of preparation, the frequency of collection, the distance and acceptability of agro-industrial byproducts in Walungu, South Kivu province are summarized in the Table 2.

Most farmers do not process their crop residues and agro-industrial byproducts before feeding them to livestock. However, in the case of maize cob, maize husk, potatoes peels, Taro peels, banana peel, farmers boil them. Coffee pulp, rice bran, palm kernel cake and maize bran are soaked in water. Maize and cassava flour residues are turned into fufu. Most of the crop residues and agro-industrial byproducts are readily available and utilized throughout the year, except maize cob, straw and swoop and rice swoop, which are only used during the dry season (June – September). Rice swoop, groundnut haulms, pea haulms, coffee pulp, cabbage leaves, rice bran, palm kernel cake, maize bran, rice brewery grain and boiled bean sauce are generally scarce in the 3 *territoires*. Maize stover, maize husk, cassava peel, taro peel, avocado kernel, residue from banana local brewery, maize flour residues and cassava flour residues are moderately available. Only maize cob, potatoes peel, banana peel and stem are easily available to the smallholder farmers. In the three territories, the majority of farmers feed their livestock on crop residues and agro-industrial byproducts twice daily. Except for agro-industrial byproducts, most crop residues are collected from nearby sources. Farmers feel that crop residues are generally fairly palatable but agro-industrial byproducts are usually highly palatable.

Challenges faced by farmers

Different problems encountered by farmers when collecting and feeding crop residues and agro-industrial byproducts have been identified. Common constraints faced in the use of crop residues in the three *territoires* are inadequate supply, bulky nature of residues, and inappropriate technologies for storage and preservation. In the case of agro-industrial by-products, common constraints are inadequate supply, inappropriate technologies for storage and preservation, high product cost, and high transport costs. Other problems limiting the use of crop residue and agro-industrial byproducts include poor road infrastructure, spoilage from micro-organism attack, fire hazards, plant diseases, and toxicity from secondary infections.

Table 2
Preparation, availability, frequency of collection, seasonality, distance and acceptability of agro-industrial byproducts.

	Processing procedure or methods[a]	Season of use[b]	Material accessibility[c]	Daily Harvesting/Collection frequency	Months of availability for use	Sourcing Distance (km)	Perceived palatability[d]
Crop residues							
Maize cob	Any, boil	Dry	Easy	4	January to December	4	More less
Maize stover	Any	Dry	Available	2	January to December	4	Palatable
Maize husk	Any, boil	Dry	Available	2	January to December	4	Palatable
Rice stover	Any	Dry	Scarce	3	April to October	2	Less
Bean haulms	Any	All	Available	4	January to December	4	More palatable
Soybean haulms	Any	All	Available	1	March to December	4	More palatable
Groundnut haulms	Any	All	Scarce	1	March to September	4	Palatable
Pea haulms	Any	All	Scarce	1	March to October	4	Palatable
Cassava peel	Any	All	Available	1	January to December	4	More less
Potatoes peel	Any, boil	All	Easy	4	January to December	4	More palatable
Taro peel	Boil	All	Available	1	January to December	3	Palatable
Banana peel	Any, boil	All	Easy	2	January to December	4	More palatable
Banana stem	Any	All	Easy	1	January to December	4	Less
Avocado kernel	Any	All	Available	1	January to December	3	Palatable
Coffee pulp	Soak in water	Dry	Scarce	1	May to September	2	More less
Cabbage leaves	Any, cut up	All	Scarce	1	January to June	3	More less
Agro-industrial byproducts							
Rice bran	Any, soak in water	All	Scarce	2	March to June	1	More palatable
Palm kernel cake	Any, soak in water	All	Scarce	2	January to December	1	More palatable
Maize bran	Any, soak in water	All	Scarce	2	March to June	1	More palatable
Rice brewery grain	Any	All	Scarce	2	January to December	1	More palatable
Banana local brewery residue	Any	All	Available	1	January to December	4	Palatable
Maize flour residues	Any, fufou	All	Available	2	January to December	4	More palatable
Cassava flour residues	Any, fufou	All	Available	2	January to December	4	More palatable
Boiled bean sauce	Any	All	Scarce	1	January to December	4	More palatable

[a] **Any:** no processing method applied; **fufu:** staple food in DR Congo made from cassava or maize flour mingled with warm water.
[b] **All:** both dry and rainy seasons.
[c] **Easy:** the material is locally founded whenever is needed and freely accessible; **Available:** the material can be accessed but require some expenditures or less produced in the region; **scarce:** the material is not commonly found in the region and whenever found, the price is not affordable by farmers.
[d] varies from less to more palatable and expresses the gradient of forage acceptability.

Logit models for crop residues and agro-industrial byproducts adoption

The results of the Table 3 show that seven factors influence the use of crop residues, including access to information, knowledge, poor road infrastructure, high transportation costs, poor storage and conservation facilities, toxicity and crop diseases. Improvements in these seven factors will increase the level of utilization of crop residues in smallholder animal feeding systems.

The use of agro-industrial byproducts was influenced by road conditions and costs of product, availability of storage and conservation facilities. When roads are adequate, the cost of products on the local market accessible to farmers, low

Table 3
Summary of logit models for adoption of crop residues and agro-industrial byproducts.

Source	Crop residue						Agro-industrial byproducts					
	β	S.E	z value	Pr(>|z|)		dF/dx	*β*	S.E	z value	Pr(>|z|)		dF/dx
Constant	−0.211	2.931	−0.072	0.943			3.652	2.289	1.595	0.111		
Territoire – Moba	−1.303	1.787	−0.729	0.466			−0.714	1.007	−0.709	0.479		
Territoire - Walungu	−2.360	1.754	−1.345	0.179			−0.203	0.884	−0.230	0.818		
Education level - None	3.782	2.312	1.636	0.102			0.556	1.219	0.456	0.648		
Education level - Primary	2.520	2.095	1.203	0.229			2.027	1.296	1.564	0.118		
Access to information	4.262	1.335	3.193	0.001	**	0.688	1.042	1.721	0.606	0.545		
Age	−0.076	0.049	−1.563	0.118			0.009	0.032	0.284	0.776		
Knowledge	4.448	1.287	3.456	0.001	***	0.478	0.709	0.759	0.934	0.350		
Road infrastructure	4.383	1.721	2.547	0.011	*	0.796	2.639	1.064	2.480	0.013	*	0.235
Cost of products	−0.915	1.374	−0.666	0.505			−3.815	0.962	−3.966	0.000	***	−0.617
Cost of transportation	−3.013	1.242	−2.427	0.015	*	−0.227	−1.631	1.005	−1.624	0.104		
Means of store and conservation	1.760	0.993	1.771	0.077	.	0.141	−2.160	0.975	−2.216	0.027	*	−0.158
Bulkiness of material	0.736	1.432	0.514	0.607			0.732	1.442	0.508	0.611		
Microbial spoilage	3.251	2.390	1.360	0.174			−3.236	1.029	−3.144	0.002	**	−0.588
Sufficient quantity	−0.413	0.959	−0.431	0.666			3.236	0.878	3.685	0.000	***	0.568
Availability	2.456	1.638	1.500	0.134			−0.688	0.888	−0.775	0.438		
Toxic substances	−2.051	1.003	−2.045	0.041	*	−0.123	−1.220	1.721	−0.709	0.478		
Fire incidence	−1.619	1.184	−1.367	0.172								
Plant disease	−3.159	1.280	−2.468	0.014	*	−0.132						

S.E = Standard Error; dF/dx= Calculated elasticity.
*, **, ***: significant at alpha = 0.1; 0.05 0.01 and 0.001, respectively.
Model for crop residue: −2 loglikelihood = 48.5; R^2(McFadden) = 0.700; R^2(Nagelkerke) = 0.819; AIC = 86.6.
Model for agro-industrial byproducts: −2 loglikelihood = 63.1; R^2(McFadden) = 0.601; R^2(Nagelkerke) = 0.738; AIC = 97.1.

microbial infestation and/or the availability of enough quantities on the market, agro-industrial byproducts are easily and rapidly adopted.

Discussion

The use/adoption of crop residues and agro-industrial byproducts is critical for the intensification of livestock feeding systems in SSA. Several factors are reported to have influence on use and adoption of the feed resources, amongst them socioeconomic and feed related characteristics [15–20].

This study revealed that most of the farmers involved in livestock are married men aged between 41 and 60 years, with a primary school education level. This concurs with the findings of Onyeonagu and Njoku [40]. Results of our study seem to suggest that men of the three *territoires* dominate in the livestock production compared to women because of cultural beliefs and practices considering livestock farming as restricted to men as families look up to men for solutions for tackling whole family needs [5]. However, households need to be sensitized to include women in livestock farming.

The level of education seems to constrain agriculture in all *territoires*. Smallholder participating in commercial agriculture require basic education to be able to obtain and utilize market information from different media or even to understand the nutritional requirements of the animals to feed them optimally. Maass et al. [11] reported that education level may influence on indigenous crop residues utilization at farm level. Most farmers involved in livestock production in the study area were above 41 years. According to the findings by Thornton [26], youths are often not interested in agriculture, preferring to look for jobs in urban areas for immediate salaries rather than venturing into farming, which is risky. However, in Walungu *territoire*, most of livestock keepers are between 26 and 40 years. This can be explained by the fact that, sedentarism is the system of livestock keeping in Walungu instead of Kalemie where pastoralism dominates. In addition, in Walungu *territoire,* many young people adopt livestock keeping because they are easily initiated by their parents unlike in Kalemie and Moba where the livestock keepers often live far from the families and thus find the activity less interesting for the young people because of lack of initiation.

In this study, chicken and goats were the most reared livestock and were owned by 93.1% and 88.8% of farmers, respectively. This is probably due to the lower acquisition cost, the small space required for their breeding and their easy management, such as feeding, healthcare and reproduction, compared to other livestock species like cattle that require much space. In eastern DR Congo, land scarcity is amongst the major challenges constraining livestock production, encouraging farmers to shift to small stock [11]. Also, goats and chicken are used in many cultural activities such as traditional ceremonies [27] and as a surety especially during times of need [28].

Agro-industrial byproducts are still left underutilized compared to crop-residues in the study area. Most of the time crop residues are left on farm for recycling while byproducts are purchased from agro-processing companies. In Eastern DR Congo, at the end of a wet season farmers can collect crop residues from any plot, even that belonging to their neighbors. There are no restrictions. However, it appears that both crop residues and agro-industrial byproducts are most utilized in Walungu than Kalemie and Moba *territoires*. This is due to several factors. Firstly, the *territoire* of Walungu is closer to the city of

Bukavu where there are several industries for processing agricultural products and hence the abundance of byproducts compared to Kalemie and Moba. Secondly, the business climate and trade between the cities of Bukavu and Goma and the bordering countries (Rwanda, Burundi and Uganda) facilitate the supply of imported by-products, unlike Moba and Kalemie which have just opened their borders to the outside world. Thirdly, livestock production systems are different in South Kivu and Tanganyika provinces. Animals in Walungu are on zero-grazing or semi-zero-grazing while in Kalemie and Moba, cattle are on extensive production system, and often going for transhumance. In addition, access to land for livestock production is scarcer in Walungu than in Kalemie and Moba *territoires*. Fourthly, the presence of organizations working in the agricultural sector in South-Kivu province for several decades has a positive impact on the exploitation of alternative feed sources for animal. Thus, South-Kivu farmers have more access to information and therefore make more profitable use of these feed resources compared to those in Kalemie and Moba.

Cereal crop residues and agro-industrial byproducts are the most widely used in the 3 *territoires*. World-wide, cereals are the most cultivated and, therefore the most processed crops around the world [29], as it is in the territories covered in this study. The range of crop residues ($n = 16$) identified in the three *territoires* is similar to the 14 and 15 types of residues reported respectively by Onyeonagu and Njoku [40] and Ayoola and Ayoade [30], in the northern part of Nigeria. Crop residues listed in our study were also identified by Mugerwa et al. [22] in Uganda, Castellanos-Navarrete et al. [31] in Kenya and Papageorgiou and Skendi [29] in India. This is justified by the fact that these plants are the most widely cultivated around the world [29] and common plants on which information on the use of their by-products in animal feed is available.

Even though crop residues and agro-industrial byproducts are currently used for various purposes, their importance as feedstuffs particularly for ruminants in small farming systems cannot be overemphasized. With less fibre content, agro-industrial byproducts, which are conventionally used in non-ruminant feeding, have fewer opportunities to be used in feeding ruminants due to growing trends in nutritional sciences. Better utilization of these less fibrous feedstuffs for non-ruminant feeding can be obtained by increasing the local production of protein feedstuff to correct the deficiencies in the former. Khajarern and Khajarern [32] reported that the deficiency of protein concentrates in Southeast Asia was 3.9 million tons or 62.4% of the requirement. Exploitation for novel protein feeds consequently appears to be of the priority for animal nutritionists in this region. On the other hand, fibrous crop residues seem to be currently utilized at lower efficiency levels even though they have been used as the main forage source for ruminants. During the period of feed shortage, straw is fed to livestock either alone or mixed with a small supplement of green forage and generally without any concentrates. It has long been established that straw has low protein (3–5%), calcium (0.25– 0.55%), phosphorus (0.02–0.16%) but is high in crude fibre (26–34%) and silica (12–16%) with slightly lower lignin than other crop residues [33].

Due to the proximity to the collection sources of most of the crop residues and agro-industrial byproducts, most farmers feed their livestock once or twice per day to meet the increasing feed requirements of the animals. This finding was already reported by Onyeonagu and Njoku [40] in Nigeria where most ruminants were fed with crop residues and agro-industrial byproducts twice a day. Throughout the year, availability of crop residues and agro-industrial by-products agreed with the findings by Ayoola and Ayoade [30] and Onyeonagu and Njoku [40]. These researchers found that most of the crop residues and agro-industrial byproducts are not processed before feeding them to animals. However, few farmers soak them in water, turn into fufu or boil them. Devendra [41] in Malaysia and Wanapat and Devendra [42] in Thailand have reported that, even though most of the farmers do not undertake any pre-treatment on crop residues and agro-industrial byproducts, some chop them to improve intake and digestibility. In South Asia, Doyle [34] suggested physical treatments, such as chopping and soaking and chemical treatment with cheap chemicals, such as calcium hydroxide or calcium oxide and urea [35] or urine [36] as ammonia sources.

Agro-industrial byproducts generally seem to be more palatable to livestock compared to crop residues. Mugerwa et al. [22] reported that, since natural grazing lands are usually deficient in protein and as such, livestock grazing them would benefit from supplementation with agro-industrial byproducts such as palm kernel cakes, dairy meal and home-made concentrates, to balance their nutritional deficiencies.

Major problems encountered by farmers in crop residue and agro-industrial byproducts adoption in livestock feeding systems are the lack of knowledge of farmers, insufficient quantity of material, the unavailability of residues, the inadequacy of the roads, the lack of means of store and conservation, the cost of the product, microbe infestation, the toxicity of the material and plant disease. These findings are in line with earlier studies that mentioned knowledge and capital [15], inadequate knowledge on utilization, unavailability and high cost [22], bad roads [40], high prices and limited availability [43] and toxicity [37] as main constraints. The results of the present study were suggestive that interventions to enhance the utilization of residues and agro-industrial byproducts need to focus first on ameliorating the constraints listed above.

Conclusion

The present study shows the possibility of integrating crop residues and agro-industrial byproducts in the livestock production system of Eastern DR Congo. Sixteen crop residues and eight agro-industrial byproducts were identified. Most of the crop residues and agro-industrial byproducts are available and utilized all the year-round and agro-industrial byproducts seem to be more palatable to livestock than crop residues. Access to information, lack of knowledge, the inadequacy of roads, cost of transportation of the material, means of store and conservation, the toxicity of the material and plant diseases are the main constraints affecting crop residues adoption while the inadequacy of roads, cost of products, means of store and conservation, microbial infestation and the insufficiency of the material are the major constraints affecting the agro-industrial

byproducts adoption in the three *territoires* of DR Congo. Improving the utilization of crop residues and agro-industrial by products in the livestock feeding system of these *territoires* should therefore first target improving the above-mentioned constraints. However, studies on anti-nutrients compounds in these identified crop residues and agro-industrial by products should be done for better livestock feeding management.

Declaration of Competing Interest

The authors declare no competing interests.

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