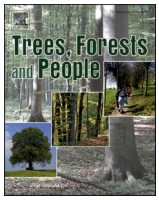
Trees, Forests and People 17 (2024) 100624

Contents lists available at ScienceDirect

Trees, Forests and People

journal homepage: www.sciencedirect.com/journal/trees-forests-and-people



Domestication of wild indigenous fruit trees in Rwanda: Perspectives from rural communities☆

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ARTICLE INFO

Keywords:
Domestication
Wild plant
Indigenous fruits
Livelihoods
Rwanda

ABSTRACT

Wild indigenous fruit trees (WIFTs) play a vital role in food and nutritional security in sub-Saharan Africa. However, these resources are currently less accessible to rural populations due to the expanding arable lands and over-exploitation of the trees in the wild, which lead to a decline in their population. This study (i) explored the availability and uses of WIFTs in the Nyamagabe and Bugesera districts of Rwanda (ii) identified challenges and potential interventions for domestication of WIFTs, (iii) assessed community perceptions on WIFTs domestication primarily as integrated system components in smallholder's farm (iv) and also determined the priority species for domestication. A total of 380 respondents from Bugesera and Nyamagabe districts were interviewed using a semi-structured questionnaire. Data were analyzed descriptively using the SPSS software analysis tools. Results revelaled a total of 19 WIFTs, 15 from the Bugesera district, and five from the Nyamagabe district with one species occurring in both districts. The recorded WIFTs were used mainly as food, medicine and fuel wood. Despite a decline in population locally, most respondents were interested in domesticating WIFTs and expressed willingness to integrate them on their farmlands once the planting materials are availed. From the study a suggestion to promote the domestication of the priority WIFTs through a collaborative initiative between the Ministry of Agriculture and Animal Resources, research institutions and other stakeholders is important. This will ensure not only the sustainability of the WIFTs species to communities but also contribute to their socio-economic development once the products are developed through proper value chains addition.

Introduction

The world is currently facing multiple challenges, including meeting the food needs of its growing population which was estimated at 8.5 billion in 2023 and is projected to reach 9.7 billion in 2050 (UN, 2022). In sub-Saharan Africa (SSA), more than 60 % of the population depends on agriculture for food and income (FAO, 2021). However, the agricultural systems are critically affected by land pressure, and climate variability and change which threaten food production, natural ecosystems, biodiversity and on-farm income at the local scale (Fraker et al., 2020). Sustainable means of achieving food security are therefore needed, and agroforestry is among the proposed methods (Kehlenbeck et al., 2013).

The Government of Rwanda has identified agroforestry as a major target in land restoration opportunity (GoR, 2014) and committed to the Bonn Challenge to restore 2 million hectares of degraded lands by 2030 (Stanturf and Mansourian, 2020). Despite this, many studies have reported very low adoption of agroforestry technology in the country (Mukoobwa et al., 2023; Ngango et al., 2023). Furthermore, there is little diversity in agroforestry options, with most agroforestry systems dominated by exotic tree species, such as *Eucalyptus spp, Grevillea robusta, Sesbania sesban, Leuceana leucocephala* and *Calliandra calothyrsus* (Iiyama et al., 2018). Since the 1970s, exotic agroforestry species have been introduced among smallholder farmers by the government and

☆ This article is part of a special issue entitled: "Forest and Food: Challenges and Opportunities" published at the journal Trees, Forests and People.

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https://doi.org/10.1016/j.tfp.2024.100624

Available online 14 July 2024

externally funded projects, while wild indigenous fruit trees (WIFTs) have been less valued and neglected (Ndayambaje et al., 2014). Most of the promoted agroforestry species also focused on the need for timber, fodder, fuelwood and soil erosion control (Kiyani et al., 2017; Ndayambaje and Mohren, 2011), further leading to the neglect of WIFTs. On the other side, invasive pests and drought (Umuhoza et al., 2023) have threatened agroforestry adoption, indicating the need for innovative approaches to identify agroforestry species that could respond to farmers' needs and their potential niches (Bucagu et al., 2013). Indigenous tree species offer opportunities for multiple products and services (Leakey et al 2021) since they are locally adapted (Umuhoza et al., 2023) and thus could be integrated into the agroforestry technology promotion in Rwanda. Wild indigenous fruit trees also have great importance in SSA because many households rely on them as the source of income and subsistence, and play a vital role in food and nutritional security, especially during the lean period (Akinnifesi et al., 2007).

The importance and possible contribution of indigenous fruit trees to food poverty reduction has been recognized (Schreckenberg et al., 2006), and several researchers (Ashraf et al., 2018; N'Danikou et al., 2015) have explored the nutritional and economic potentials of underutilized fruit trees in Africa and suggested their role in mitigating malnutrition and "hidden hunger". In the context of the food insecurity dimension "hidden hunger" refers to micronutrient deficiencies that affect over 2 billion people globally (Hodge, 2016; Omotayo and Aremu, 2020; Fortin et al., 2021). The effect of hidden hunger can be devastating, leading to poor health, or even death. The negative effects of this on the survival rate of a child are acute, especially within the early years of life, resulting in physical and cognitive problems (Britto et al., 2016; Mngadi et al., 2019; Omotayo and Aremu, 2020).

In Rwanda, these resources have over time become less accessible to rural populations due to the expanding arable lands and over-exploitation of the trees in the wild (Bigirimana et al., 2016). Despite their importance, little attention has so far been given to them, with no domestication program for WIFTs initiated in the country, posing a risk to their extinction. Nevertheless, the cultivation of WIFTs on farms has the potential to contribute to climate change mitigation, adaptation and diversification of of farming systems (Leakey et al., 2022), improve connectivity of remaining natural habitats for biodiversity conservation and decrease the pressure on the natural WIFTs in Rwanda. However, many of these indigenous fruits are still sourced from the wild and natural environments, which have generally limited their potential for higher yields and growth (Awodoyin et al., 2015). As research into the significance of the domestication of WIFTs augments in Rwanda, there is an urgent need to gather more information on the existing farmers' or users' awareness and perceptions about them that are currently lacking. It is also vital to identify the existing WIFT species, target farmers, farming practices and challenges, and farmers' needs, resources and perceptions of the uses and cultivation of WIFTs. Therefore, the objectives of this study were to (i) explore the availability and uses of WIFTs, (ii) identify challenges and potential interventions for their domestication, (iii) assess the Rwandan community's perceptions towards WIFTs domestication primarily as an integrated system component on smallholder's farm and (iv) determine and recommend selected priority species for domestication.

The information from this study will contribute to the database of invaluable WIFT species that could be domesticated and promoted to improve yields and enhance the complementarity and stability of food production in smallholder agroforestry systems in Rwanda (Frison et al., 2011; Leakey et al., 2022). The information further could be used by relevant institutions and policymakers to develop policies and strategies on sustainable management and utilization of WIFTs.

Materials and methods

Location of the study area

The study was carried out in two districts namely Bugesera and Nyamagabe (Fig. 1). Bugesera district is located in the Eastern Province of Rwanda at 2°09'S latitude and 30 °05'E longitude and covers a total surface area of 1337 km^2, with a population of 551,103 (NISR, 2023). A mixture of plateaus characterizes the district with an altitude varying between 1,100 m and 1,780 m above sea level (m.a.s.l). The district has a dry and hot climate (Henninger, 2013), with annual average rainfall of 943 mm and average annual temperature varying between 26 and 29°C. The district is dominated by savannah shrubs covering the hills and grassy savannahs covering the dry valleys (Bugesera District_Rwanda, 2019). Nyamagabe district is located in the South-West of the Southern Province of Rwanda at 2°24'S latitude and 29°28'E longitude and covers a total surface area of 1,090 km^2, with a population of 371,501 (NISR, 2023) and lies at an altitude varying from 1,800 to 3,000 m.a.s.l. Nyamagabe district is characterized by a south-Rwandan humid mountain climate (Henninger, 2013) rainfall that averages 13,000 mm annually, while the temperature varies between 11 and 18°C. Around 44.8 % of Nyamagabe District is also covered by Nyungwe National Park (Nyamagabe District Rwanda, 2018).

Sampling and data collection procedures

Purposive and random sampling methods were employed. The two districts (Bugesera and Nyamagabe) where the surveys were carried out were purposively selected based on the presence of rich flora and the reported presence of indigenous fruit trees. Three administration sectors from each district were purposively selected, from which two cells were randomly selected, and three villages in each cell were then chosen for household interviews. The sample size was determined based on Cochran's formula for calculating sample size when population size is finite (Cochran, 1977). For instance, with a population of 34,894 households in six selected sectors from two districts, a sample of 380 households was considered for the study as illustrated in Equation (1).

$$n = \frac{n0}{1 + \frac{(n0-1)}{N}} = \frac{384}{1 + \frac{383}{34894}} = 380 \quad (1)$$

Where n is the sample size of this study, n_0 is the theoretical Cochran's sample size (384) and N is the population size.

Data were collected between January and July 2022 using semi-structured questionnaires through face-to-face interviews and Focus Group Discussions held with selected respondents. The data collected included respondents' demographic status such as age, gender, marital status, level of education, family size, occupation and land ownership. Information on indigenous knowledge of WIFTs such as availability, propagation methods and respondent judgement towards the domestication of WIFTs were also recorded. Prior to the survey, the respondents were briefed on the nature of the study and its purpose. Thereafter, the oral consent from each respondent was filled followed by interviews in the local language (Kinyarwanda). Upon the completion of the household survey, a list of available WIFTs in each district was generated and used in Focus Group Discussions to identify the priority species for domestication. Each group was requested to rank the reported species in descending order based on their preference. The highest priority was assigned 15 points in Bugesera district and 5 in Nyamagabe district, while the least priority was assigned one (1) in each district. The total points for each species were summed up across all groups and then prioritized according to the total score.

Data analysis

Data analysis was done using the Statistical Package for Social

120

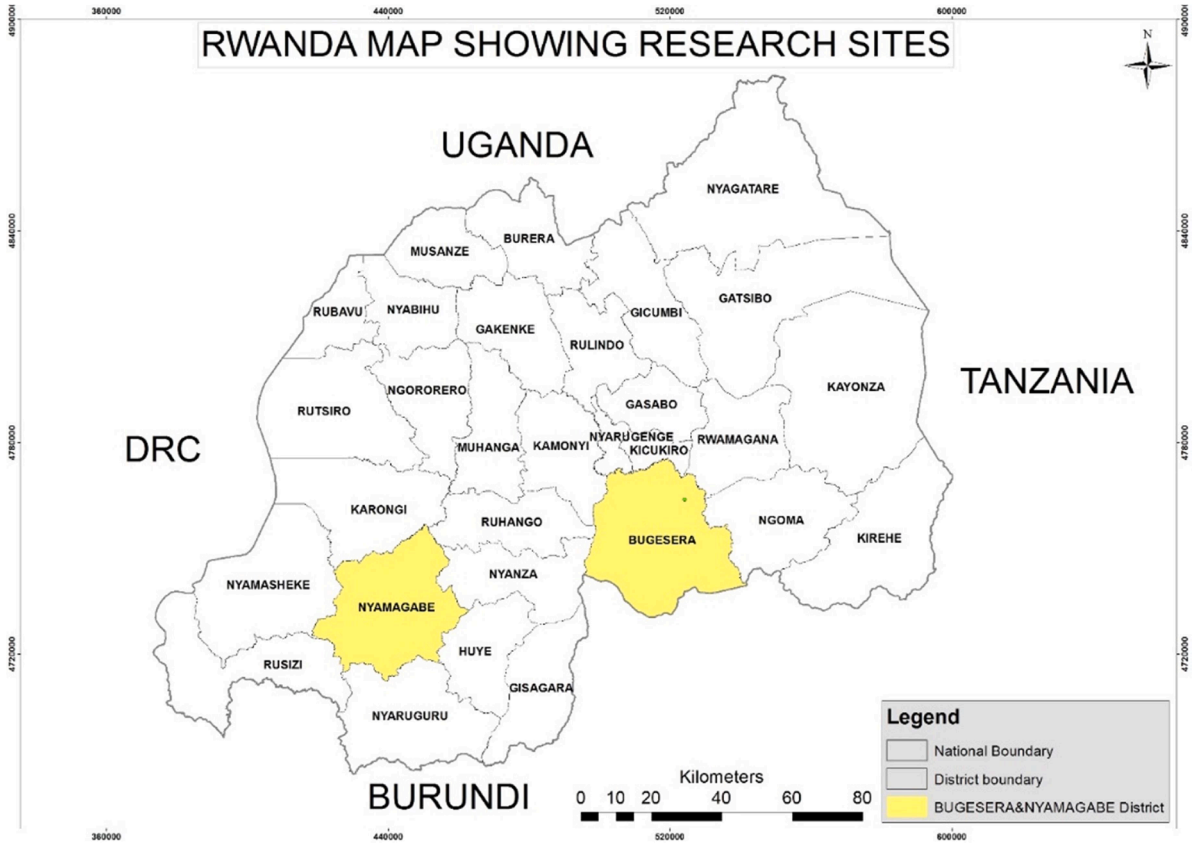

Fig. 1. Geographical location of the study areas.

Sciences software tools through descriptive and inferential analysis. The descriptive analysis involved the use of means comparison and frequency to determine skills on WIFTs uses and mode of utilization. Qualitative information through open-ended questions was thematically analyzed before subjection to descriptive analysis. The inferential analysis involved the comparison of means of responses on various issues discussed during interviews. The results were later summarized and presented through tabular forms and frequencies.

Results

Demographic characteristics of respondents

The majority of respondents were aged between 41 and 65 years in both districts, with many of them being males, corresponding to 58.2 % and 65.5 % in Bugesera and Nyamagabe, respectively. The majority of respondents were married in both Bugesera (88.80 %) and Nyamagabe (83.8 %). The study showed that over 62 % had completed primary school education in both districts, while 62.2 and 77.2 % of respondents in Nyamagabe and Bugesera districts, respectively had 5 to 10 members in each household. The majority of the respondents also comprised of 95.3 % in Bugesera and 98.6 % in Nyamagabe practiced farming on lands inherited by 70.7 % in Bugesera and 66.9. % in Nyamagabe districts, respectively (Table 1).

Documented WIFTs and their availability status

A total of 19 WIFTs belonging to 14 families were documented in the study areas. The documented WIFTs species belonged to the families Apocynacynaceae, followed by Anacardiaceae and Chrsobalaceae as dominant ones (Table 2). The majority of these species (15 WIFTs) were recorded in Bugesera district while five WIFTs were recorded in the Nyamagabe district, with *Annona senegalensis* the only WIFT found in both districts. However, the respondents revealed that all the reported WIFTs were scarcely distributed in the two districts (Table 2). *Carissa edulis* was occasionally available (41.3 %.) while *Syzygium guineense* was the most scarce (100 %) followed by *Garcinia buchananii* (78.3 %). The rarest or most difficulty WIFT species to find in the wild were *A. senegalensis* (100 %) and *Ximenia caffra* (91.4 %).

Uses of documented WIFTs in the study areas

Results indicated that most WIFTs are used as food, with a few being mentioned for use as medicine, firewood or fodder, stakes or as live fence. In Bugesera district *G. buchananii* was the most used as food (96.4 %) followed by *C. edulis* (95 %). In Nyamagabe district, *Myrianthus holstii* (89.3 %) and *A. senegalensis* (86.7 %) were the most used as food. *Carissa edulis* (62 %) was the most used for medicinal purposes, while *X. caffra* (66.7 %) was the most used as fuel wood. Others reported uses are stakes, fodders, timber, live fence, handicraft, soil erosion control and shelter. For instance, about 50 % of respondents used *S. guineense* as stakes while *Strychnos innocua* and *Grewia similis* were reportedly used by 40 % and 33.3 % of the respondents, respectively as fodder. The analysis also revealed that 27.7 % and 4.5% of the respondents used *Parinari curatellifolia* and *G. Buchananii*, respectively as charcoal (Table 3).

Challenges and potential interventions to the domestication of WIFTs

The most frequently mentioned challenge to the cultivation of WIFTs was the inadequate of planting materials as reported by 66.4 % and 72.3 % in Bugesera and Nyamagabe districts respectively. The other

Table 1
Demographic characteristics of respondent.

Variables	Bugesera		Nyamagabe	
	Frequency	%	Frequency	%
Age class (years)				
< 20	1	0.4	-	-
20-40	56	24.2	29	19.6
41-65	145	62.5	95	64.2
> 65	30	12.9	24	16.2
Gender				
Female	97	41.8	51	34.5
Male	135	58.2	97	65.5
Marital status				
Single	5	2.2	2	1.4
Married	206	88.8	124	83.7
Separated	4	1.7	3	2.0
Divorced	-	-	1	0.7
Widow	13	5.6	14	9.5
Widower	4	1.7	4	2.7
The level of education of the farmers				
No formal education	45	19.4	33	22.3
Primary school	146	62.9	92	62.2
Secondary school	36	15.5	23	15.5
University	5	2.2	-	-
Family size of the farmers				
Less than 5 members	53	22.8	52	35.1
5 to 10 members	179	77.2	93	62.8
Above 10 members	-	-	3	2.1
Occupation of the farmers				
Farming	221	95.2	146	98.6
Livestock keeping	2	0.9	2	1.4
Carpentry/masonry	3	1.3	-	-
Shop keeping	2	0.9	-	-
Formal employment	4	1.7	-	-
Land ownership				
No	12	5.2	6	4.1
Yes	220	94.8	142	95.9
Types of land ownership				
Inherited	164	70.7	99	66.9
Purchased	54	23.3	43	29.1
Rented	12	5.2	6	4.0
Communal land	2	0.8	-	-

mentioned challenges included insufficient information about the values of the wild indigenous fruits, land shortage, long waiting time to produce fruits, introduction and accessibility of exotic fruits, lack of land tenure, drought, and pests and diseases. However, the respondents proposed several interventions for the domestication of WIFTs including, availing planting materials, and training on the propagation and mobilization of WIFT values among others (Table 4).

Perceptions of respondents towards the domestication of WIFTs

Resulted revealed positive perceptions towards the domestication of WIFTs where the majority of respondents (99.1 %) in Bugesera district and (98.6 %) in Nyamagabe district, acknowledged its relevance. Mmost of the respondents further expressed their willingness to cultivate WIFTs if the planting material are availed to them (Table 5).

Priority species for domestication

The results showed variations in terms of priority species for domestication between the two study areas. While *G. buchananii; P. curatellifolia* and *Saba comorensis* were the most preferred species for domestication in the Bugesera district; *M. holstii, A. senegalensis and S. guineense* were the most priority WIFTs in the Nyamagabe district based on the socio-economic values (Table 6).

Discussion

Documented WIFTs and their availability status

In this study, a total of 19 WIFTs from 14 families were documented in both study areas. Among them, 15 WIFTs were recorded in Bugesera district, five in the Nyamagabe district and one species was reported in both districts. A great disparity in the number of recorded WIFTs between the two districts was observed, which could probably be attributed by differences in the vegetation covers of the areas and the agroecological characteristics. Bugesera district is covered by a densely shrubby savanna that favours WIFTs, which could be the reason for the greater number of WIFTs recorded. The number of WIFTs reported in this study was relatively low when compared to the previous study conducted in Nyungwe National Park and its vicinity which reported 35

Table 2
List of documented WIFTs and their availability status in the study areas.

District	WIFTs	Vernacular name	Family	Availability status				
				Frequency	Plentiy (%)	Occasional (%)	scarce (%)	rare (%)
Bugesera	*Acokanthera schimperi A.DC.* Schweinf.	Umusagwe	Apocynaceae	3	-	-	66.7	33.3
Bugesera	*Ancylobotrys amoena* Hua	Umukamire	Apocynaceae	52	-	23.1	28.8	48.1
Bugesera	*Annona senegalensis* Pers.	Umutimawimfizi	Annonaceae	7	-	-	-	100.0
Bugesera	*Carissa edulis Forssk.* Vah	Umunyonza	Apocynaceae	75	-	41.3	34.7	24.0
Bugesera	*Dovyalis macrocalyx Oliv.* Warb.	Umutegengeri	Flacourtiaceae	26	-	15.4	38.5	46.2
Bugesera	*Garcinia buchananii* Baker.	Umusarasi	Clusiaceae	106	-	11.3	78.3	10.4
Bugesera	*Grewia similis K.*Schum	Umukoma	Tiliaceae	17	-	-	64.7	35.3
Bugesera	*Lannea schimperi A. Rich.* Engl.	Umumuna	Anacardiaceae	17	-	35.3	47.1	17.6
Bugesera	*Pappea capensis* Eckl. and Zeyh.	Umumena	Sapindaceae	17	-	11.8	35.3	52.9
Bugesera	*Parinari curatellifolia Planch. Ex Benth.*	Umunazi	Chrysobalanaceae	120	-	18.3	64.2	17.5
Bugesera	*Rhus vulgaris* Meikle	Umusagara	Anacardiaceae	45	-	11.1	37.8	51.1
Bugesera	*Saba comorensis* Bojer ex A.DC.	Umubungo	Apocynaceae	124	-	20.2	43.5	36.3
Bugesera	*Strychnos innocua* Delile	Umuhonnyo	Loganiaceae	29	-	-	75.9	24.1
Bugesera	*Vangueria infausta* Burch.subsp.rotundata	Umuhame	Rubiaceae	7	-	-	71.4	28.6
Bugesera	*Ximenia caffra* Sond.	Umusasa	Olacaceae	35	-	-	8.6	91.4
Nyamagabe	*Annona senegalensis* Pers.	Umutimawimfizi	Annonaceae	15	-	-	33.3	66.7
Nyamagabe	*Myrianthus holstii* Engl.	Umwufe	Urticaceae	145	-	23.4	51.7	24.8
Nyamagabe	*Parinari excelsa* Sabine	Umunazi	Chrysobalanaceae	4	-	-	75.0	25.0
Nyamagabe	*Rubus kirungensis* Engl	Umukeri	Rosaceae	8	-	12.5	50.0	37.5
Nyamagabe	*Syzygium guineense* Willd. DC.	Umugote	Myrtaceae	2	-	-	100.0	-

***Note*:** Plenty = Abundant/locally numerous; Ocassional = irregular/ available depending on season; Scarce= Limited availability/not easily available; Rare= most difficult to find /unusual.

Table 3
Documented uses of WIFTs species in the study areas.

District	*WIFTs*	Frequency	Food (%)	Medicine (%)	Fuelwood (%)	Others (%)
Bugesera	*Acokanthera schimperi A.DC. Schweinf.*	2	50.0	50.0	–	–
Bugesera	*Ancylobotrys amoena Hua*	14	71.4	40.0	–	–
Bugesera	*Annona senegalensis Pers.*	7	85.7	33.3	–	–
Bugesera	*Carissa edulis Forssk. Vah*	40	95.0	62	–	–
Bugesera	*Dovyalis macrocalyx .Oliv..Warb.*	10	70.0	–	20.0	–
Bugesera	*Garcinia buchananii Baker.*	110	96.4	28.3	18.2	4.5
Bugesera	*Grewia similis K.Schum*	3	66.7	33.3	–	33.3
Bugesera	*Lannea schimperi A. Rich. Engl.*	5	80.0	40.0	–	–
Bugesera	*Pappea capensis Eckl. and Zeyh.*	10	60.0	25.0	30.0	–
Bugesera	*Parinari curatellifolia Planch. Ex Benth.*	65	92.3	30.8	–	27.7
Bugesera	*Rhus vulgaris Meikle*	9	55.6	37.5	55.6	–
Bugesera	*Saba comorensis Bojer ex A.DC.*	70	85.7	20.0	0.0	2.9
Bugesera	*Strychnos innocua Delile*	15	66.7	10.0	13.3	40.0
Bugesera	*Vangueria infausta Burch.subsp.rotundata*	7	57.1	28.6	0.0	–
Bugesera	*Ximenia caffra Sond.*	30	93.3	33.3	66.7	–
Nyamagabe	*Annona senegalensis Pers.*	15	86.7	13.3	–	–
Nyamagabe	*Myrianthus holstii Engl.*	140	89.3	–	12.1	3.6
Nyamagabe	*Parinari excelsa Sabine*	2	50.0	50.0	50.0	–
Nyamagabe	*Rubus kirungensis Engl*	7	71.4	–	–	–
Nyamagabe	*Syzygium guineense Willd. DC.*	2	50.0	50.0	–	50.0

Table 4
Challenges and proposed interventions to the domestication of WIFTs.

Variables	Bugesera		Nyamagabe	
	Frequency	%	Frequency	%
Factors which hinder the cultivation of WIFTs in the districts				
Lack of planting materials	154	66.4	107	72.3
Lack of land tenure	26	11.2	16	10.8
Introduction and accessibility of exotic fruits	34	14.7	28	18.9
Insufficient information about wild fruit values	73	31.5	105	70.9
Drought	10	4.3	-	-
Land shortage	87	37.5	48	32.4
Long waiting time to produce fruits	73	31.5	16	10.8
Pests and Diseases	8	3.4	7	4.7
What could be used to enhance WIFT cultivation in the districts?				
Availing planting materials	156	67.2	103	69.6
Availability of grants to conduct research on WIFTs	42	18.1	35	23.6
Market development	37	15.9	27	18.2
Mobilization of the farmers on values of WIFTs	83	35.8	50	33.8
Training on the propagation of WIFTs	109	47.0	39	26.4
Developing a conservation policy on the WIFTs	55	23.7	15	10.1
Granting incentives for the cultivation of WIFTs	63	27.2	70	47.3

Table 5
Perceptions of respondent on the domestication of WIFTs.

Variables	Bugesera		Nyamagabe	
	Frequency	%	Frequency	%
Is the domestication of WIFTS Relevant?				
Yes	230	99.1	146	98.6
No	2	0.9	2	1.4
Would you grow WIFTs if the planting materials were available?				
Yes	224	96.5	144	97.3
No	8	3.5	4	2.7
If yes, for which purpose do you want to grow WIFTs?				
Household consumption	224	100	144	100
Sales	90	40.2	102	70.8
Use as medicine	30	13.4	3	2.1
Shading for livestock	15	6.7	-	-
Erosion control	60	26.8	48	33.3
Have you ever tried to propagate WIFTs ?				
Yes	21	9.1	31	20.9
No	211	90.9	117	79.1
Which propagation method have you used?				
Seed	10	47.6	17	76.9
Root cuttings	4	19.0	-	-
Stem cuttings	2	9.6	-	-
Marcoting	1	4.8	-	-
Other	4	19.0	14	23.1
Do you think WIFTs can be intercropped with other crops				
Yes	210	90.5	143	96.6
No	22	9.5	5	3.4
If yes, how WIFTs would fit on farm?				
Along the border	124	57.7	55	37.2
Within the field	85	36.7	89	60.1
Others	14	5.6	4	2.7

species and 21 families (Nsengimana et al., 2020). The variations in number of species recorded could be attributed by the indigenous knowledge of the communities interviewed and study purposes. The same reason could explain the variations in number of WIFTs recorded in this study which less than those reported in other studies in different parts of Africa such as Zimbabwe (Macheka et al., 2022), Tanzania (Kilonzo, 2022) and Ethiopia (Melaku and Ebrahim, 2021).

The study also showed that the majority of WIFTs were claimed to be scarce avail in Nyamagabe and Bugesera districts, and the declining trend could perhaps be attributed to the over-exploitation and increased clearance of natural vegetation for settlement and farming as reported in past studies (Masozera and Alavalapati, 2004; Ndayambaje and Mohren, 2011; Leakey et al., 2021; Umuziranenge, 2021). Similar findings on decreasing availability of the WIFT plant species have been reported in South Africa (Paumgarten et al., 2018) and Uganda (Ndawula et al., 2005). Therefore, future agroforestry agenda should prioritize the domestication and conservation of these claimed rare species.

Uses of documented WIFTs in the study areas

The study findings showed that most of the documented WIFTs were reported to be used for food and medicine and to some extent as stakes, fodders, timber, living fences, handicrafts, shelter and control of soil erosion. These findings are comparable with what was reported in Ethiopia (Masresha et al., 2023) and South Africa (Sardeshpande and Shackleton, 2019) where the local communites claimed high exploitation of wild fruit trees with multiple uses. In many parts of SSA, indigenous fruits remain one of the major options for coping with hunger, nutritional deficiency and poverty. For, instance in Malawi, Mozambique and Zambia where 65-80 % of rural households lack food (Akinnifesi et al., 2002), indigenous fruits were found to play vital roles

Table 6
Priority ranking of WIFTs based on Socio-economic value.

No	List of WIFT/Group	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11	G12	G13	G14	G15	G16	G17	G18	Total	Rank
	Bugesera																				
1	*Acokanthera Schimperi*	11	9	9	8	7	8	9	6	7	10	8	9	9	8	7	7	6	9	147	8th
2	*Ancylobotrys amoenia*	9	1	8	9	9	7	8	9	9	5	7	8	7	9	8	8	9	7	137	9th
3	*Annona senegalensis*	14	7	7	7	8	12	7	7	8	8	12	7	13	7	9	9	7	8	157	7th
4	*Carissa edulis*	6	13	15	5	14	14	13	15	12	7	13	14	5	14	14	14	13	14	215	3rd
5	*Dovyalis macrocalyx*	2	2	1	3	2	3	3	1	6	4	1	4	12	1	2	3	2	2	54	14th
6	*Garcinia buchananii*	15	14	14	13	15	15	14	14	15	15	15	15	15	13	15	13	15	15	260	1st
7	*Grewia similis*	3	4	5	4	5	9	5	8	3	3	6	3	2	4	5	6	4	1	80	11th
8	*Lannea Schimperi*	4	6	2	1	1	2	4	4	4	1	2	1	3	2	3	2	1	3	46	15th
9	*Pappea capensis*	8	10	11	11	11	11	12	12	10	9	10	11	11	10	11	10	10	12	190	6th
10	*Parinari curatellifolia*	7	15	10	15	13	10	15	13	14	13	11	13	14	15	12	15	12	11	228	2nd
11	*Rhus vulgaris*	5	3	4	6	3	4	6	5	5	2	3	2	4	3	4	1	3	4	67	13th
12	*Saba comorensis*	12	11	12	10	10	13	11	10	11	12	9	10	8	11	10	11	14	13	198	4th
13	*Strychnos innocua*	10	8	6	12	6	6	1	2	2	6	5	6	6	5	13	4	8	6	112	10th
14	*Vangueria infausta*	1	5	3	5	4	5	2	3	1	5	4	5	1	6	1	5	5	5	66	12th
15	*Ximenia caffra*	13	12	13	14	12	1	10	11	13	11	14	12	10	12	6	12	11	10	197	5th
	Nyamagabe																				
1	*Annona senegalensis*	5	4	3	4	3	4	4	4	5	4	2	4	4	4	4	5	4	3	70	2nd
2	*Myrianthus holstii*	3	5	5	5	5	5	5	5	4	5	5	5	5	5	5	4	5	5	86	1st
3	*Parinari excelsa sabine*	1	2	1	3	2	3	2	3	2	2	1	3	3	1	1	1	1	2	34	4th
4	*Rubus kirungensis*	4	3	2	1	4	2	3	1	3	1	4	1	2	3	2	3	2	4	45	3rd
5	*Syzygium guineense*	2	1	4	2	1	1	1	2	1	3	3	2	1	2	3	2	1	1	33	5

Note: G = Group numbers for the focus group discussions.

in the livelihood security for many rural community members, especially during periods of famine and food scarcity.

Challenges and proposed interventions to the domestication of WIFTs

The major challenges to the cultivation of WIFTs included the lack of planting materials, insufficient information on wild indigenous fruit values, land shortage, long waiting time to produce fruit, introduction and accessibility of exotic fruits, lack of land tenure, drought and pests and diseases.

These challenges are similar to those reported in Uganda by Agea et al. (2010), indicating that the exotic fruits are increasingly displacing the indigenous fruit species that have fed Africa for millennia (Leakey et al., 2021). The other resons to support the observations from this study is based on the fact that, most research and investments have also targeted the exotic fruits rather than the indigenous fruit species in Africa, limiting the full potential for their exploitation in the continent (Awodoyin et al., 2015). Despite reported challenges, the majoritu of the respondents in the study areas proposed several required interventions towards the domestication of WIFTs including availing the planting materials, training farmers on their propagation and mobilizing and making farmers aware of their nutritional and other values.

Perceptions of respondent on the domestication of WIFTs

Results from this study indicated positive perceptions by with the majority of respondents towards domestication of the WIFTs, due to their willingness to participate if the planting materials are available.. Nevertheless, over 90 % of the respondents in both districts mentioned that theWIFTs could be intercropped with other crops, adding to the interest of the respondents in the domestication of WIFTs. From the study it can be urged that if indigenous fruit trees are domesticated, lives of large population of local communities could be saved by providing children and adults vulnerable to malnutrition with a nutritious source of food (Sileshi et al., 2023). Furthermore, domestication of these WIFTs trees could help to rehabilitate the degraded environment and prevent desertification (Najjar and Baruah, 2023).

Conclusion and recommendations

From the study it can be conclude that the two study sites had a total of 19 species available and used for various purposes mainly food and medicines. However, most of the documented WIFTs were scarcely distributed in the study areas, indicating a decline in these important resources due to challenges on how to grow them on farms, as a result of the lack of planting materials and insufficient information about the values of wild indigenous fruits. The study has documented several challenges for domestication of WIFTs including unavailability of planting materials and technical know how on how to practice. All in all agroforestry was mentioned as a potential intervention to promote the domestication of priority WIFTs in Rwanda. Communities have had positive perceptions on WIFTs domestication primarily as integrated system components in smallholder's farm and two species mainly . *buchananii* and *M. holstii* were found to be the priority species for domestication. From the study, since the majority of the respondents acknowledged the relevance of domesticating WIFTs and expressed their willingness to grow them; t there is a need to incorporate communities to address the issue of WIFT planting materials as a way forward to improve their availability and ensure sustainability in future. Research on propagation technologies and awareness of the food and nutritional values of documented WIFTs are also needed, since most of them were used as food, fodder or medicine, contributing to household food and nutrition security. Overall, *G. buchananii* and *M. holstii* were the most preferred WIFT species for domestication. Thus, there is a need to promote their domestication in collaboration with the Ministry of Agriculture and Animal Resources, research institutions and other

stakeholders in order to ensure sustainable production in future. Furthermore, the need to advocate for the two species inclusion in land restoration and reforestation programs in Rwanda is recommended.

Funding

Sida Grant Number 13394 financially supported this research through REFOREST programme.

CRediT authorship contribution statement

Gaudence Nishimwe: Writing – review & editing, Writing – original draft, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **A. Sigrun Dahlin:** Writing – review & editing, Investigation, Conceptualization. **Fidèle Niyitanga:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Conceptualization. **Suzana Augustino:** Writing – review & editing, Supervision, Methodology, Investigation, Conceptualization.

Declaration of competing interest

The authors did not report any prospective conflict of interest.

Data availability

Data will be made available on request.

Acknowledgements

The authors are grateful for the financial support provided by the Swedish International Development Cooperation Agency (Sida) through the Regional Research School in Forest Sciences (REFOREST) Programme based at Sokoine University of Agriculture (SUA). The entire REFOREST programme coordination is acknowledged for its administrative support. The authors would like to thank the administrative and communities of Bugesera and Nyamagabe districts, enumerators (Imaniriho Diace, Niyompuhwe Olivier, Uwiduhaye Fautine, Irambona Enock and Imaniraguha Pierre Celestin) for their great support and cooperation rendered during data collection.

References

Agea, J.G., Obua, J., Waiswa, D., Okia, C.A., Okullo, J.B.L., 2010. Farmers' attitudes towards on-farm cultivation of indigenous fruit trees in Adwari Sub-County, Lira District, Uganda. Ethnobotan. Leaflets 2010 (3), 13.

Akinnifesi, F. K., Ajayi, O. C., Sileshi, G., Kadzere, I., & Akinnifesi, A. I. (2007). *Domesticating and commercializing indigenous fruit and nut tree crops for food security and income generation in Sub-Saharan Africa*.

Akinnifesi, F.K., Kwesiga, F.R., Mhango, J., Mkonda, A., Chilanga, T., Swai, R., 2002. Domesticating priority miombo indigenous fruit trees as a promising livelihood option for small-holder farmers in Southern Africa. In: XXVI International Horticultural Congress: Citrus and Other Subtropical and Tropical Fruit Crops: Issues, Advances and, 632, pp. 15–30. https://www.actahort.org/books/632/632_1.htm.

Ashraf, M.Y., Ashraf, M., Ozturk, M., Ozturk, M., 2018. Underutilized vegetables: a tool to address nutritional issues, poverty reduction and food security. In: Hakeem, K.R., Ashraf, M., Ahmad, M.S.A. (Eds.), Global Perspectives on Underutilized Crops. Springer International Publishing, pp. 1–23. https://doi.org/10.1007/978-3-319-77776-4_1.

Awodoyin, R.O., Olubode, O.S., Ogbu, J.U., Balogun, R.B., Nwawuisi, J.U., Orji, K.O., 2015. Indigenous fruit trees of tropical Africa: status, opportunity for development and biodiversity management. Agric. Sci. 6 (01), 31.

Bigirimana, C., Omujal, F., Isubikalu, P., Bizuru, E., Obaa, B., Malinga, M., Agea, J.G., Lamoris, J.B., 2016. Utilisation of indigenous fruit tree species within the Lake Victoria Basin, Rwanda. Agric. Sci. Int. J. 1, 1–3.

Britto, P.R., Lye, S.J., Proulx, K., Yousafzai, A.K., Matthews, S.G., Vaivada, T., Fernald, L. C., 2016. Advancing early childhood development: from science to scale 2 nurturing care: promoting early childhood development. Safety (Eg, Rout. Protect. Harm) 3 (4). https://www.academia.edu/download/61241962/Lancet_ECD_Series_Paper_2_copy20191117-80210-y2ngsk.pdf.

Bucagu, C., Vanlauwe, B., Van Wijk, M.T., Giller, K.E., 2013. Assessing farmers' interest in agroforestry in two contrasting agro-ecological zones of Rwanda. Agrofor. Syst. 87 (1), 141–158. https://doi.org/10.1007/s10457-012-9531-7.

Bugesera District_Rwanda. (2019). *Bugesera District Development Strategy 2018/2019_2023/2024*. Bugesera District (Rwanda). https://bugesera.gov.rw.

Cochran, W.G., 1977. Sampling Techniques. John Wiley & Sons, Ltd.

FAO, 2021. Sub-Saharan Africa: Strengthening Resilience to Safeguard Agricultural Livelihoods. FAO. https://doi.org/10.4060/cb8098en.

Fortin, K., Harvey, S., Swearingen White, S., 2021. Hidden Hunger: understanding the complexity of food insecurity among college students. J. Am. Coll. Nutr. 40 (3), 242–252. https://doi.org/10.1080/07315724.2020.1754304.

Fraker, M.E., Keitzer, S.C., Sinclair, J.S., Aloysius, N.R., Dippold, D.A., Yen, H., Arnold, J. G., Daggupati, P., Johnson, M.V.V., Martin, J.F., Robertson, D.M., Sowa, S.P., White, M.J., Ludsin, S.A., 2020. Projecting the effects of agricultural conservation practices on stream fish communities in a changing climate. Sci. Total Environ. 747, 141112 https://doi.org/10.1016/j.scitotenv.2020.141112.

Frison, E.A., Cherfas, J., Hodgkin, T., 2011. Agricultural biodiversity is essential for a sustainable improvement in food and nutrition security. Sustainability 3 (1), 238–253.

GoR, 2014. *Forest Landscape Restoration Opportunity Assessment for Rwanda*. MINIRENA (Rwanda). IUCN, WRI. https://portals.iucn.org/library/sites/library/files/documents.

Henninger, S.M., 2013. Does the global warming modify the local Rwandan climate? Nat. Sci. 05 (01), 124–129. https://doi.org/10.4236/ns.2013.51A019.

Hodge, J., 2016. Hidden hunger: approaches to tackling micronutrient deficiencies. Nourish. Millions: Stories Change Nutr. 35–43.

Iiyama, M., Mukuralinda, A., Ndayambaje, J., Musana, B., Ndoli, A., Mowo, J., Garrity, D., Ling, S., Ruganzu, V., 2018. Tree-Based Ecosystem Approaches (TBEAs) as multi-functional land management strategies—evidence from Rwanda. Sustainability 10 (5), 1360. https://doi.org/10.3390/su10051360.

Kehlenbeck, K., Asaah, E., Jamnadass, R., 2013. Diversity of indigenous fruit trees and their contribution to nutrition and livelihoods in sub-Saharan Africa: examples from Kenya and Cameroon. In: Diversifying Food and Diets: Using Agricultural Biodiversity to Improve Nutrition and Health, pp. 257–269.

Kilonzo, M., 2022. Quantification of non-timber forest products utilized by local communities in Nyanjange forest reserve, Morogoro, Tanzania. Environ. Sustain. Indicat. 16, 100215.

Kiyani, P., Andoh, J., Lee, Y., Lee, D.K., 2017. Benefits and challenges of agroforestry adoption: a case of Musebeya sector, Nyamagabe District in southern province of Rwanda. Forest Sci. Technol. 13 (4), 174–180. https://doi.org/10.1080/21580103.2017.1392367.

Leakey, R.R., Mabhaudhi, T., Gurib-Fakim, A., 2021. African lives matter: wild food plants matter for livelihoods, justice, and the environment—a policy brief for agricultural reform and new crops. Sustainability 13 (13), 7252.

Leakey, R.R., Tientcheu Avana, M.-L., Awazi, N.P., Assogbadjo, A.E., Mabhaudhi, T., Hendre, P.S., Degrande, A., Hlahla, S., Manda, L., 2022. The future of food: domestication and commercialization of indigenous food crops in Africa over the third decade (2012–2021). Sustainability 14 (4), 2355.

Macheka, L., Manditsera, F.A., Ngadze, R.T., Mubaiwa, J., Nyarugwe, S., Bangira, C., Pachavo, G., Kembo, G., 2022. Agro-ecological distribution and consumption of wild harvested edible insects, fruits, and vegetables in rural Zimbabwe. Future Foods 6, 100187.

Masozera, M.K., Alavalapati, J.R.R., 2004. Forest dependency and its implications for protected areas management: a case study from the Nyungwe Forest Reserve, Rwanda. Scand. J. Forest Res. 19 (sup004), 85–92. https://doi.org/10.1080/14004080410034164.

Masresha, G., Melkamu, Y., Walle, G.C., 2023. Ethnobotanical study on wild edible plants in Metema District, Amhara Regional State, Ethiopia. Int. J. Forest. Res. *2023* https://www.hindawi.com/journals/ijfr/2023/9243343/.

Melaku, A., Ebrahim, M.A., 2021. Critical review on wild-edible fruit species in Ethiopia. Int. J. Forest. Res. 2021, 1–12.

Mngadi, S., Moodley, R., Jonnalagadda, S.B., 2019. Elemental composition and nutritional value of the edible fruits of Transvaal red milkwood (Mimusops zeyheri) and impact of soil quality. Environ. Monit. Assess. 191 (3), 135. https://doi.org/10.1007/s10661-019-7280-z.

Mukoobwa, D., Zaninka, B., Patrick Mugunga, C., 2023. The assessment of agroforestry practices in Mukura Sector, Huye District, Southern Rwanda. Int. J. Forest. Res. *2023* https://www.hindawi.com/journals/ijfr/2023/2288114/.

Najjar, D., Baruah, B., 2023. Even the goats feel the heat:" gender, livestock rearing, rangeland cultivation, and climate change adaptation in Tunisia. Clim. Dev. 1–14. https://doi.org/10.1080/17565529.2023.2253773.

N'Danikou, S., Achigan-Dako, E.G., Tchokponhoue, D.A., Agossou, C.O., Houdegbe, C.A., Vodouhe, R.S., Ahanchede, A., 2015. Modelling socioeconomic determinants for cultivation and in-situ conservation of Vitex doniana Sweet (Black plum), a wild harvested economic plant in Benin. J. Ethnobiol. Ethnomed. 11 (1), 28. https://doi.org/10.1186/s13002-015-0017-3.

Ndawula, J., Agea, J.G., Okello, T., 2005. Under-exploited woodland resources: the case study of indigenous fruit trees in Kiryandongo-Masindi district, Uganda. In: *African Crop Science Conference Proceedings, 7*(pt. 2 of 3), pp. 533–536. https://www.africabib.org/rec.php?RID=Q00041813.

Ndayambaje, J.D., Mohren, G.M.J., 2011. Fuelwood demand and supply in Rwanda and the role of agroforestry. Agrofor. Syst. 83 (3), 303–320. https://doi.org/10.1007/s10457-011-9391-6.

Ndayambaje, J.D., Mugiraneza, T., Mohren, G.M.J., 2014. Woody biomass on farms and in the landscapes of Rwanda. Agrofor. Syst. 88 (1), 101–124. https://doi.org/10.1007/s10457-013-9659-0.

Ngango, J., Musabanganji, E., Maniriho, A., Nkikabahizi, F., Mukamuhire, A., 2023. Examining the adoption of agroforestry in Southern Rwanda: a double hurdle approach. Forest Sci. Technol. 19 (4), 260–267. https://doi.org/10.1080/21580103.2023.2254317.

NISR. (2023). *The fifth Rwanda population and housing census; main indicators report, February 2023*. https://www.statistics.gov.rw.

Nsengimana, T., Nsengimana, V., Nsanganwimana, F., 2020. Local knowledge and use of wild edible plants in eastern part of Nyungwe National Park in Rwanda: Prospects for forest biodiversity conservation. J. Res. Forest., Wildlife Environ. 12 (4), 66–75.

Nyamagabe District (Rwanda). (2018). *Nyamagabe District development strategy 2018-2024*. Nyamagabe District (Rwanda). https://www.nyamagabe.gov.rw.

Omotayo, A.O., Aremu, A.O., 2020. Underutilized African indigenous fruit trees and food–nutrition security: opportunities, challenges, and prospects. Food Energy Secur. 9 (3), e220. https://doi.org/10.1002/fes3.220.

Paumgarten, F., Locatelli, B., Witkowski, E.T.F., 2018. Wild foods: safety net or poverty trap? A South African case study. Hum. Ecol. 46 (2), 183–195. https://doi.org/10.1007/s10745-018-9984-z.

Sardeshpande, M., Shackleton, C., 2019. Wild edible fruits: A systematic review of an under-researched multifunctional NTFP (non-timber forest product). Forests 10 (6), 467.

Schreckenberg, K., Awono, A., Degrande, A., Mbosso, C., Ndoye, O., Tchoundjeu, Z., 2006. Domesticating indigenous fruit trees as a contribution to poverty reduction. Forests, Trees Livelihoods 16 (1), 35–51. https://doi.org/10.1080/14728028.2006.9752544.

Sileshi, G.W., Dagar, J.C., Akinnifesi, F.K., Mng'omba, S.A., 2023. Potentials of indigenous fruit trees in enhancing nutrition, income and biodiversity conservation in African agroforestry. In: Dagar, J.C., Gupta, S.R., Sileshi, G.W. (Eds.), Agroforestry for Sustainable Intensification of Agriculture in Asia and Africa. Springer Nature, Singapore, pp. 321–361. https://doi.org/10.1007/978-981-19-4602-8_11.

Stanturf, J.A., Mansourian, S., 2020. Forest landscape restoration: state of play. R. Soc. Open. Sci. 7 (12), 201218 https://doi.org/10.1098/rsos.201218.

Umuhoza, E., Mugunga, C.P., William, A., Hagumubuzima, F., Bizimana, E., 2023. Farmer's perception and adoption of agroforestry technologies in Eastern Rwanda. J. Res. Forest., Wildlife Environ. 15 (2), 144–157.

Umuziranenge, G., 2021. People's Perceptions of Community Participation in Conservation of Natural Resources in Rwanda: The Case of Nyungwe National Park. Otto-Friedrich-Universität Bamberg, Fakultät Geistes-und Kulturwissenschaften] [PhD Thesis. https://fis.uni-bamberg.de/handle/uniba/49963.

UN. (2022). *World population prospects 2022: summary of results*.