Orphan crops in Burkina Faso and Niger: a systematic review

Hamid El Bilali*

Address: International Centre for Advanced Mediterranean Agronomic Studies (CIHEAM-Bari), 70010 Valenzano (Bari), Via Ceglie 9, Italy.

ORCID information: Hamid El Bilali (orcid: 0000-0002-0322-2034)

***Correspondence:** Hamid El Bilali. Email: elbilali@iamb.it

Received: 3 January 2020
Accepted: 31 March 2020

doi: 10.1079/PAVSNNR202015030

The electronic version of this article is the definitive one. It is located here: http://www.cabi.org/cabreviews

Abstract

Humanity faces unprecedented, interlinked challenges to achieve sustainable development (e.g., climate change, food and nutrition insecurity, livelihoods vulnerability and poverty, biodiversity loss, and ecosystem degradation). Orphan crops (i.e., neglected and underutilized species) are put forward by many scholars and practitioners to address these challenges, especially in developing countries of the Global South. However, the development of orphan crops requires investments in research and innovation. Therefore, this paper analyses the landscape of research dealing with orphan crops in Burkina Faso and Niger. The systematic review—drawing upon a search carried out on Scopus in November 2019—provides an overview on both the bibliographical metrics (journals, subject areas, authors, institutions, countries, and funding) and the topics addressed (species, food chain stages, climate change, food security and nutrition, and livelihoods). Available scholarly literature focuses on the production stage and on biological sciences; social sciences and economics are underserved. The review shows that although orphan crops are resilient, nutritious, and adapted to marginal agro-ecosystems, research dealing with them is still marginal and at an early stage of development in both countries. Therefore, the paper highlights the urgent need to strengthen research on orphan crops within the Agricultural Knowledge and Innovation Systems (AKIS) of both countries. For that, both domestic funding and international support are needed to implement a long-term agenda for research and development on these crops.

Keywords: neglected and underutilized species, Burkina Faso, Niger, agriculture research, food and nutrition security, livelihoods, climate change

Review Methodology: The article draws upon a systematic review of records indexed in Scopus. The systematic review follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. For inclusion, a document had to meet simultaneously three criteria relating to thematic focus (viz. orphan crops); geographical coverage (viz. the document deals with Burkina Faso and/or Niger); and document type (viz. the document is a journal article, book chapter, or conference paper; gray literature such as reports and discussion papers, letters to editors, and notes were excluded).

Introduction

Broadly speaking, crops can be divided into staple crops and underutilized crops (also called "orphan," "neglected," "minor," "promising" crops) [1]. A wide range of terminology is used to refer to neglected and underutilized crops, including orphan, minor, abandoned, lost, local, underdeveloped, traditional, alternative, or niche [2]. According to Padulosi *et al*. [3], "Neglected and underutilized species (NUS) are those to which little attention is paid or which are entirely ignored by agricultural researchers, plant breeders and policymakers" (p. 5). Worldwide, between 300,000 and 500,000 plant species exist, of which 30,000 are identified as edible plant species [4]. According to Kermali *et al*. [5], about 80,000 plant species are used by humans for food and fiber as well as medical and industrial purposes. A multitude of plant species are used for human consumption, but only a limited number of these species are used as commercial cash crops [6]. While the number of edible plant species varies in the literature, 10,000 appears to be a realistic

number [7, 8]. More than 7,000 crop species have been either cultivated and domesticated for food, or collected from the wild throughout human history [4, 9]. However, only about 150 species are cultivated commercially and, of these, only 103 provide up to 90% of the dietary calories [10, 11]. What is even more alarming is that only four main crops (rice, wheat, maize, and potato) supply more than 60% of the human's energy intake [10, 12]. Therefore, tens of thousands of edible plant species remain relatively "underutilized" [13].

Numerous NUS offer the potential to diversify not only the human diet but also farming systems and, thus, to enable more resilient and sustainable agro-food systems [6, 14]. Referring to orphan crops, Mabhaudhi *et al.* [15] stated that "Owing to reports of their potential under water scarcity, there is an argument to promote them to sustainably address challenges such as increasing drought and water scarcity, food and nutrition insecurity, environmental degradation, and employment creation under climate change" (p. 695). Mabhaudhi *et al.* [16] went even further and argued that the promotion of orphan crops could contribute to the achievement of the Sustainable Development Goals (SDGs), specifically SDGs 1 (No poverty), 2 (Zero Hunger), 3 (Good health and well-being), 8 (Decent work and economic growth), and 15 (Life on land).

Orphan crops are put forward to improve the *resilience of farming systems* in the face of *climate change*. Indeed, orphan crops can contribute to sustainable food systems under climate change [3, 15, 17]. Including such crops in the monocultural cropping systems supports more diverse farming systems in marginal agricultural environments, which, in turn, offers opportunities for the reduction of greenhouse gas (GHG) emissions from agriculture [15]. Moreover, orphan crops are critical for the conservation of *agro-biodiversity* and agro-ecosystems, which is vital for long-term sustainability of farming and food systems [3, 6]. Changes in the food habits and consumption patterns have led to an overdependence on a limited number of energy-rich and nutrient-poor staple crops [18, 19] and, in turn, diets with high environmental footprints [20, 21]. Therefore, replacing meat and resource-intensive foods with more plant-based products from orphan crops could also lead to healthier diets, and reduce the environmental impact of the global food system as well as its contribution to climate change [13, 19]. Orphan crops can also reduce environmental contaminants from agriculture as they can tolerate diseases and grow on low quality soils, thus requiring lower levels of chemical inputs (e.g., pesticides, fertilizers) [15].

Orphan crops can also play an important role in achieving *food and nutrition security*. Indeed, they offer new opportunities to address food insecurity and malnutrition [1, 3, 15, 17] that are aggravated by population growth, climate change, and land degradation [15]. Millions of people, especially in developing countries of the Global South, rely on orphan crops as their primary sources of food. Moreover, many researches showed that orphan crops (e.g., finger millet, pearl millet, cowpea, sword bean, sweet potato, amaranth, Chinese cabbage) are more nutritious (i.e., they contain higher proportions of vitamins and micronutrients) than major common crops and their staple counterparts [15, 17, 22–24]. Certain orphan crops were also reported to have health protection properties (e.g., finger and pearl millets have anticancer properties) against the major chronic diseases [17]. Orphan crops are also an important component for nutritious diets for low-income households as their inclusion into diets can promote dietary diversity and improve the availability of some proteins, essential amino acids, and fibers [14, 24].

Orphan crops can also improve the *livelihoods* of rural people. Indeed, they can enhance income for the rural poor, especially women and youth, that generate income from agriculture [3, 25–27]. They also reduce production costs as they require less inputs for fertilization and pest management [25, 28]. Their higher resistance to pests and tolerance to environmental extremes and weather shocks [13, 17] mean that they make rural livelihoods more resilient. Therefore, they can benefit low-income consumers and producers who have limited capacity to adapt to climatic risks [29]. Doing so, they also contribute to promoting livelihood security and empowering vulnerable communities and groups [15] especially women.

Mabhaudhi *et al.* [15] argued that, with adequate research and development, orphan crops could play an important role in climate-change adaptation in the Global South and that research is also needed to advocate for policies on orphan crops. In fact, there are many challenges that hinder the mainstreaming of orphan crops relating, among others, to seed production and seed systems; agronomy, genetics, and ecophysiology; and utilization and marketing [15]. To promote orphan crops, barriers against their mainstreaming have to be identified and analyzed; these barriers are mainly attributed to the lack of sound data on their nutritional and protective properties; poor economic competitiveness of orphan crops compared to staple crops; inefficiencies in production, storage, and processing; disorganized or non-existing value chains [6]. Padulosi *et al.* [3] stated that "Neglect by agronomic researchers and policy makers, genetic erosion, loss of local knowledge, marketing and climate change are major challenges to the sustainable use of NUS" (p. 6). Williams and Haq [30] enumerated among constraints to NUS development: lack of interest by farmers, researchers, and extension workers; limited availability of germplasm; and lack of technical information and national policy. For that, research is highly needed to unlock the potential of orphan crops [31], especially in developing countries [13] such as Sub-Saharan Africa. Therefore, this review paper analyzes the landscape of research on orphan crops in Burkina Faso and Niger, two poor countries of Sub-Saharan Africa that face various development challenges (e.g., climate change, food and nutrition insecurity, livelihoods vulnerability, biodiversity loss). It provides an overview on both the bibliographical metrics and the topics addressed (e.g., species, stages of the food chain, climate change, food security and nutrition, livelihoods).

Methods

Target countries: Burkina Faso and Niger

Burkina Faso and Niger are two landlocked countries in Sahelian West Africa. Both countries are in the low human development category (Niger ranks 189 and Burkina Faso 182 out of 189 countries in the Human Development Index—HDI) [32] and affected by multiple forms of malnutrition [33–35]. Burkina Faso and Niger also should fill the gap in terms of sustainable development; Burkina Faso ranks 138 and Niger 151 out of 157 countries in progress toward meeting the Sustainable Development Goals (SDGs) [36]. Agriculture is the leading sector for the economy of Niger and Burkina Faso (BF). According to the latest World Bank's data, agriculture contributes to 28.6% of GDP in BF and 39.6% in Niger, while employment in agriculture is at 75.9% in Niger and 28.6% in BF. Furthermore, in 2018, 83.5% of the population in Niger and 70.6% in BF lived in rural areas [37]. However, agriculture in both countries, and the Sahel region in general, is extensive, poorly mechanized, and almost entirely reliant on the variable summer rainfall (June–September), making it vulnerable to climate change. Staple dryland crops include cereals (e.g., millet, sorghum) and legumes (e.g., cowpea), while cotton and groundnut constitute major cash crops [38].

In *Niger*, natural resources and land production potential are deteriorating in a context of changing climate and recurrent droughts [38]. Niger's economy is based largely on subsistence agriculture (e.g., maize, millet, sorghum, fonio, and), livestock (e.g., cattle, sheep, goats, and camels), and large uranium deposits. Pearl millet, sorghum, and cassava are the main rain-fed subsistence crops. About 15% of land is arable and distributed mainly in the southern part of the country; this is also where about four-fifths of the population is concentrated and mostly engaged in small-scale farming [39]. Climate change represents a challenge for Nigerien agriculture [38, 40, 41] and is also an important driver of poverty and livelihoods vulnerability. The degraded environmental conditions have fostered the growing pattern of north-south and rural-urban migration taking place in Niger and BF [38]. With a poverty rate of 44.1%, Niger is one of the poorest nations in the world. Although poverty is declining in the country, it remains widespread, especially in rural areas [39, 42]. The incidence of poverty varies across regions; it ranges from 67.2% in Maradi and 59.4% in Dosso to 6.3% in Niamey [39]. Rural people suffer from chronic malnutrition aggravated by recurrent food crises (e.g., 1973, 1984, 2005, 2010, and 2012) that lead to decapitalization and important migration [43, 44]. According to FAO *et al.* [33], while the prevalence of undernourishment in the total population decreased from 24.9% in 2004–2006 to 21.3% in 2015–2017; the number of undernourished people in the country increased in the same period from 3.3 to 4.0 million. Meanwhile, micronutrient deficiencies of iron, vitamin A, and iodine continue to affect the health and well-being of Nigeriens (especially children and women, e.g., 73% of children under 5 years and 58% of pregnant women suffer from anemia) [34, 45].

In *BF*, 43.7% of the population lives below the international poverty line of US$1.90 per day [37]. Poverty rate is higher in rural areas [46]. Data from the *State of Food Security and Nutrition in the World 2018* [33] show that there was some progress regarding the prevalence of undernourishment (from 15.1% in 2004–2006 to 14.1% in 2015–2017) but the number of undernourished people increased in the same period from 2.1 to 3.0 million. Moreover, deficiencies of micronutrients such as iron, iodine, and vitamin A are widespread in the country [35, 47]. Food security situation and livelihoods are particularly deteriorating in northern areas of the country due to heightened violence [48]. Climate is characterized by high rainfall variability [38, 40], making life difficult for the majority of farmers. Compounding this problem, climate change is leading to higher temperatures, an increase in the frequency and magnitude of extreme weather events and a decline in rainfall [38]. Water, agriculture, and forest resources are highly vulnerable to climate variability and extreme events. The economy of BF is heavily reliant on agriculture, with close to 80% of the active population employed in the agricultural sector [49]. More than a half of the cultivated land is dedicated to cereal production (e.g., sorghum, pearl millet, maize, and rice) [46]. Subsistence production predominates against cultivation occurring during the rainy season. The major cash crops are cotton, groundnuts, cowpeas, and sesame. However, crop production is more diversified in the Sudanian zone in the southwest, with a variety of roots and tubers (e.g., yam, sweet potato, and cocoyam), fruits (e.g., mango, banana, citrus), cashew, and sugarcane. Agricultural exports are little diversified and essentially limited to cotton and livestock products [46].

Systematic review

The paper draws upon a systematic review of documents indexed in Scopus. The methodology used for documents selection is similar to that suggested by Moher *et al.* [50] and adopted by El Bilali [51, 52]. The literature search was carried out on 17 November 2019 and yielded 33 records. The selection of articles to be included in the systematic review was performed as described in Table 1.

Therefore, only 13 articles (Table 2) were included in the systematic review and underwent bibliometric and other analyses.

First, the bibliographical metrics (sources/journals, subject areas, authors, affiliation institutions, affiliation countries, and funding) were analyzed. Then, the selected records were interrogated in relation to: crop species and botanical groups (vegetables, legumes, roots and tubers, cereals, fruits and nuts, etc.); stages of the food chain [production (agronomy), processing, distribution/trade/retail, consumption]; and whether they address different topics such as food security and nutrition, climate change and resilience of farming systems, and livelihoods (cf. income).

Table 1. Articles selection process.

Steps	Number of selected records	Step description
Step 1: Identification of records	33	Records identified through searches on Scopus: – 7 records identified using the search string: ("Burkina Faso" OR Burkina OR Niger) AND ("neglected and underutilized species" OR "neglected species" OR "underutilized species" OR "neglected and underutilized crops" OR "neglected crops" OR "underutilized crops") – 19 records identified using the search string: ("Burkina Faso" OR Burkina OR Niger) AND ("abandoned crops" OR "abandoned species" OR "alternative crops" OR "alternative species" OR "local crops" OR "local species" OR "lost crops" OR "lost species" OR "minor crops" OR "minor species") – 7 records identified using the search string: ("Burkina Faso" OR Burkina OR Niger) AND ("niche crops" OR "niche species" OR "orphan crops" OR "orphan species" OR "traditional crops" OR "traditional species" OR "underdeveloped crops" OR "underdeveloped species")
Step 2: Merging of search results	33	No duplicates
Step 3: Screening of records based on titles and abstracts	33	16 records excluded: 11 records excluded because they do not address orphan crops [53–63] 5 records excluded because they do not deal with BF or Niger [64–68]
Step 4: Scrutiny of full-texts	17	4 records excluded because they do not deal with orphan crops [69–72]
Step 5: Inclusion of articles in the systematic review	13	—

Table 2. Selected articles dealing with orphan crops in BF and Niger.

Year	Articles number	References
2018	3	Ibrahim *et al*. [73]; Romba *et al*. [74]; Sandwidi *et al*. [75]
2017	1	Guira *et al*. [76]
2015	2	Kouawa *et al*. [77]; Ben Salah [78]
2013	2	Gebauer *et al*. [79]; Sultan *et al*. [80]
2011	1	Mainardi [40]
2009	1	Bernholt *et al*. [81]
2005	1	Sultan *et al*. [41]
1999	1	Mertz and Reenberg [82]
1982	1	Agnew [83]

As any systematic review, this research was not without *limitations*. The results are affected by the search process. First, the choice of Scopus means that only quality scholarly literature was considered (e.g., reports are not included in the systematic review). It also implies that pieces of research published in journals that are not indexed in Scopus were not considered. The results are also affected by the choice of the search terms. This systematic review is no exception in this regard although different synonyms were used in order to broaden the initial screening basis. Furthermore, the categorization of "orphan crops" is subjective and far from being unanimous as it is also, to a certain extent, context-specific. Nevertheless, the merit of this research is that it is the first of its kind and sets a baseline for future studies and research projects on orphan crops in BF and Niger.

Results and discussion

Bibliographical metrics of research on orphan crops in BF and Niger

Metrics (journals, subject areas, authors, institutions, and countries) for research dealing with orphan crops in BF and Niger are presented in Table 3.

The average output of papers in the considered period (1982–2019) is less than one paper per year; it ranges from zero in many years to a maximum of three papers published in 2018.

As for sources and journals, the analysis of results indicates that the maximum number of papers (two) was published in *Genetic Resources and Crop Evolution* journal. However, the results of the research on orphan crops in BF and Niger were published in other 11 journals and sources, which shows that, so far, there is no earmarked journal. Most of the selected papers are in the domains of "agricultural and biological sciences" (9 papers) and "environmental sciences" (4 papers). However, articles can be categorized in many subject areas (including "earth and planetary sciences," "biochemistry, genetics, and molecular biology," and "social sciences"), which may explain that the research is rather multidisciplinary. Notwithstanding, it can be argued that the focus is on biological sciences, while social sciences and economics are underserved.

The bibliometric analysis shows that there is no consistency in the research field as the maximum number of articles per author is two. That means that even authors that deal with orphan crops in BF and/or Niger do that in a sporadic, rather than systematic, way. This might be due to the absence

Table 3. Bibliographical metrics of literature on orphan crops in BF and Niger.

Journals (a)	Subject areas (b)	Authors (c)	Affiliations (d)	Countries (e)
Genetic Resources and Crop Evolution (2)	Agricultural and Biological Sciences (9)	Baron, C. (2) [41, 80]	Institut de l'Environnement et de Recherches Agricoles Ouagadougou (3)	BF (4)
Agricultural and Forest Meteorology (1)	Environmental Sciences (4)	Bernholt, H. (2) [79, 81]	Sorbonne Université (2)	France (4)
Agricultural Economics (1)	Earth and Planetary Sciences (3)	Dingkuhn, M. (2) [41, 80]	Universität Kassel (2)	Niger (3)
Agroforestry Systems (1)	Biochemistry, Genetics and Molecular Biology (2)	Gebauer, J. (2) [79, 81]		Germany (2)
Ecological Engineering (1)	Social Sciences (2)	Sultan, B. (2) [41, 80]		Benin (1)
Ecology and Evolution (1)	Economics, Econometrics and Finance (1)			Denmark (1)
Environmental Research Letters (1)	Energy (1)			Italy (1)
Food Science and Nutrition (1)	Engineering (1)			Kenya (1)
Fruits (1)	Medicine (1)			Poland (1)
Geografisk Tidsskrift (1)				Tunisia (1)
Transactions Institute of British Geographers (1)				UK (1)

Legend: figures in brackets refer to the number of records by journal (a), subject area (b), author (c), affiliation (d), or country (e).

of any structured, articulated national research project/program on orphan crops in both countries.

The analysis of author countries and affiliations suggests that slightly more research on this topic is carried out in BF than in Niger. However, it is worth highlighting that most research is performed by scholars based in other countries, especially European ones such as France and Germany. While collaborations with researchers from other countries are highly needed and should be encouraged, this is also an indicator of the weakness of the national research systems in general and the Agricultural Knowledge and Innovation Systems (AKIS) in particular in both countries. Interestingly, also some researchers based in African countries (e.g., Benin, Kenya, Tunisia) have been carrying out research on orphan crops in BF and Niger. As for affiliation institutions, "Institut de l'Environnement et de Recherches Agricoles" (INERA) (3 papers), "Sorbonne Université" (2 papers), and "Universität Kassel" (2 papers) are major contributors. Active domestic research centers and institutions in BF include, besides INERA and other departments of the "National Centre for Scientific and Technological Research" (CNRST), the University Ouaga I Professor Joseph KI-ZERBO. Meanwhile, the National Agricultural Research Institute of Niger (INRAN) and the regional center AGRHYMET [specialized agency of the Permanent Inter-State Committee against Drought in the Sahel (CILSS)] are active centers in the field in Niger.

Research on orphan crops in BF and Niger is financed, among others, by many foreign research agencies and funds [*Agence Nationale de la Recherche* (ANR—France), *Deutsche Forschungsgemeinschaft* (Germany)], universities (e.g., City University of London) as well as international development agencies (e.g., United States Agency for International Development, USAID).

Analyzed crops

The selected scholarly literature deals with different types of crops including vegetables (e.g., okra, monkey bread, Malabar nightshade, rutabaga, garden rocket, African eggplant), legumes (e.g., Bambara groundnut, cowpea), roots and tubers (e.g., cassava), cereals (e.g., millet, African wild rice), and fruits and nuts (e.g., Shea butter tree, donkey berry, velvet tamarind, monkey guava, sycamore fig, white mulberry, cutleaf groundcherry). The definition of "orphan crops" is somehow subjective so even crops that are common in some areas can be considered as "orphan"/"alternative" in other places; for instance, date palm is considered as a an alternative crop in BF [78]. For many species, different traditional varieties are used by farmers; for instance, *manchien*, *santidougou*, *tchinda yaar*, and *léo* varieties of cassava in BF [76].

Topics addressed in the research field

Production is the most-addressed *stage of the food chain* [40, 74, 76, 78–82], but there is a few papers that deal with processing [76], marketing, distribution and trade [73], and consumption [75, 76]. Some authors adopt a more holistic approach and deal with different stages of the food chain. For instance, Ibrahim *et al.* [73] analyzed production (seed sources, farmers' management practices), utilization, conservation, and marketing of Bambara groundnut in Western Niger. Likewise, Guira *et al.* [76] investigated

Table 4. Crops analyzed in the literature.

Reference	Crops	Group
Ibrahim *et al*. [73]	Bambara groundnut (*Vigna subterranea* (L.) Verdc.)	Legumes
Romba *et al*. [74]	Cassava (*Manihot esculenta* Crantz)	Roots and tubers
	Cowpea (*Vigna unguiculata* (L.) Walp.)	Legumes
Sandwidi *et al*. [75]	Shea butter tree (*Vitellaria paradoxa* C.F. Gaertn.)	Fruits and nuts
Guira *et al*. [76]	Cassava	Roots and tubers
Kouawa *et al*. [77]	African wild rice (*Oryza longistaminata* A. Chev. & Roehr.)	Cereals
Ben Salah [78]	Date palm (*Phoenix dactylifera* L.)	Fruits and nuts
Gebauer *et al*. [79]	Donkey berry (*Grewia flavescens* Juss.)	Fruits and nuts
Sultan *et al*. [80]	Sorghum and millet	Cereals
Mainardi [40]	Sorghum and millet	Cereals
	Cowpea/black-eyed pea	Legumes
Bernholt *et al*. [81]	For example, wild custard apple (*Annona senegalensis* Pers.), African fan palm (*Borassus aethiopum* Mart.), velvet tamarind (*Dialium guineense* Willd.), monkey guava (*Diospyros mespiliformis* Hochst. ex A.DC.), sycamore fig (*Ficus sycomorus* L.), gingerbread palm (*Hyphaene thebaica* (L.) Mart.), white mulberry (*Morus alba* L.), cutleaf groundcherry (*Physalis angulata* L.), pomegranate (*Punica granatum* L.)	Fruits and nuts
	For example, okra (*Abelmoschus esculentus* (L.) Moench), monkey bread (*Adansonia digitata* L.), Malabar nightshade (*Basella alba* L.), moringa (*Moringa oleifera* Lam.), rutabaga (*Brassica napus* L.), garden rocket (*Eruca vesicaria* (L.) Cav.), African eggplant, (*Solanum macrocarpon* L.)	Vegetables
Sultan *et al*. [41]	Millet	Cereals
Mertz and Reenberg [82]	Calabash gourd (*Lagenaria siceraria* (Molina) Standl.), jute (*Corchorus* spp.)	Vegetables
	Amaranth (*Amaranthus* spp.)	Cereals
	Bambara groundnut	Legumes
	Shea, African locust bean (*Parkia biglobosa* (Jacq.) G.Don)	Fruits and nuts

origins, production, and utilization of cassava in BF. As for production, aspects considered include pest management [74], soil fertility management [82], and irrigation and water resources management [40, 41, 80, 83].

Orphan crops play an important role in marginal agro-ecosystems (e.g., dry or saline lands). This is due, among others, to their ability to do well in harsh conditions and to improve soil fertility, especially in intercropping systems. Ibrahim *et al*. [73] argued that Bambara groundnut is an important legume crop grown in marginal soils of Sub-Saharan Africa. The legume crop contributes to soil fertility through biological fixation of nitrogen making it beneficial in intercropping and crop rotations [84]. About 55,228 ha of Bambara groundnut are grown in Niger [85]. Orphan crops also improve the diversity of urban farming systems [81], with positive implications in terms of the provision of ecosystem services and, consequently, quality of life in urban areas. They can also play an essential role in the adaptation of the Sahelian agriculture to *climate change*. For instance, Sultan *et al*. [80] assessed the impacts of climate change on the yields of sorghum and millet in the Sudanian and Sahelian savannas of West Africa (including BF and Niger) and stated that "the major effect of climate change on the yields of millet and sorghum in West Africa was yield losses induced by higher temperature… Millet and sorghum yields are likely to decrease by some 0–41% in the 21st century over West Africa because of the expected warming, irrespective of whether rainfall increases or decreases" (p. 6). However, they added that "simulations show that the photoperiod-sensitive traditional cultivars of millet and sorghum used by local farmers for centuries seem more resilient to future climate conditions than modern cultivars bred for their high yield potential" (p. 1) and pointed to the need for further research to identify varieties that are more resilient to high temperatures during the growing season.

Some papers highlighted the contribution of orphan crops to *food and nutrition security* in BF and Niger. Ibrahim *et al*. [73] underlined that Bambara groundnut is important for food security in Niger. Indeed, it is the third most important food legume crop in semi-arid Africa, both in terms of production and consumption, after groundnut and cowpea [86]. Bambara groundnut is also rich in carbohydrates and lysine [87] and constitutes a balanced diet to the rural populations [73]. Guira *et al*. [76] highlighted the contribution of cassava to household food security in BF. Indeed, cassava is the third most important calories source in the tropics, just after rice and maize [88]. It is used by many Burkinabe households to deal with food shortage, especially during the lean season (March–October) [76]. Likewise, Gebauer *et al*. [79] reported that the fruits of donkey berry are mainly eaten in Niger during the dry pre-cropping period of March–June when food is less available. While the focus is on "rural" agriculture, Bernholt *et al*. [81] argued that traditional and alternative crops used in urban and peri-urban agriculture (UPA) contribute to food and nutrition security of urban dwellers in Niamey (Niger). Guira *et al*. [76] highlighted that diverse food products based on cassava are found in Burkinabe communities such as "raw roots, boiled roots, roasted roots, tô, attiéké, tapioca, ragout,

beignets, boiled leaves, soup (with leaves), cassava juice, etc." (p. 415) as well as processed products such as *attiéké*, *gari*, *tapioca*, and flour and argued that "Cassava contributes greatly to household food security during food shortage period" (p. 415). Besides food uses, many orphan crops are also utilized for medicinal purposes. For instance, Gebauer *et al*. [79] reported that the fruits of the donkey berry are used in Niger as food and for traditional medicinal treatments (cf. stomach problems). On the other hand, food safety issues should be taken into consideration; for instance, Guira *et al*. [76], referring to cassava in BF, reported that "cases of intoxication evoked by some farmers are evidence that some of those varieties may have a high level of cyanohydric acid content" (p. 415).

As for the role of orphan crops in rural *livelihoods*, Ibrahim *et al*. [73] stressed the importance of Bambara groundnut in income generation for small-scale farmers in Niger. Sandwidi *et al*. [75] argued that "*Vitellaria paradoxa* (shea) is an economically important edible oil-producing tree for local populations in African savannahs" (p. 141). Guira *et al*. [76] emphasized the links between food security and livelihoods and stated that cassava "sustains families for weeks as food and is also exchanged with other foods or sold to buy food or meet household needs" (p. 415).

Authors highlighted different *constraints* that hinder the mainstreaming of NUS. Ibrahim *et al*. [73] stated that Bambara groundnut "remains as a neglected and underutilized crop and the productivity is very low in the field due to the lack of improved varieties and lack [of] adequate farming practices" (p. 1907) and added that "to boost the productivity of Bambara groundnut future research should be focused on dissemination of improved varieties and adequate management practices, as well as facilitation to women access to inputs, lands and credits" (p. 1913). What is common for all orphan crops is a huge research gap; for instance, Gebauer *et al*. [79] argued that donkey berry "*G. flavescens* is a prime candidate for domestication as a useful horticultural plant. However, so far little is known of cultivation practices, vegetative propagation, orchard establishment, pests and disease management, nutritional characteristics and potential yield" (p. 1918).

The abovementioned results highlight that it is of paramount importance to develop an articulated national research strategy on orphan crops in both countries, with possibility for cross-country and regional collaboration. Such a strategy should address all scientific disciplines from natural sciences (e.g., agronomic research on adaptation of orphan crops to changing climate, poor soils, and dry environments) as well as social sciences and economics. It should also deal with the relations between NUS and food security and nutrition, and livelihoods of rural communities. Attention should be also paid to political and governance issues. In this respect, it is vital to raise the awareness of all actors, both in the academia and policy arenas, on the benefits of mainstreaming orphan crops in farming systems and local diets. This requires ad hoc policies that integrate NUS in sectoral strategies regarding, inter alia, agriculture, environment, health, and gender. Indeed, Padulosi *et al*. [3] suggested that ensuring that NUS are conserved and used sustainably implies taking action in eight areas: changing perceptions of NUS as a food of the poor; developing capacity in research, policymaking, marketing, and farming; undertaking more research on NUS, particularly with regard to the links between NUS and nutrition and livelihoods; setting up on-farm NUS conservation programs; involving the full range of stakeholders (e.g., farmer and women's organizations) in participatory partnerships to promote and conserve NUS; upgrading NUS market chains and developing market value-added products; putting in place legal frameworks, policies, and financial incentives to promote NUS; encouraging collaboration on NUS and coordinating multi-stakeholder platforms across sectors. These recommendations are also valid in the context of BF and Niger.

Conclusions

This systematic review contributes to research on orphan crops and provides insights into how such research can help addressing the challenges faced by BF and Niger. Orphan crops offer opportunities to address many environmental and socio-economic challenges in the Sahel region in general and BF and Niger in particular. However, despite the noted benefits of orphan crops in addressing multiple challenges—such as climate change, livelihoods vulnerability and poverty, food and nutrition insecurity, and biodiversity loss and ecosystem degradation—current gaps in knowledge and research hinder the capacity to promote and exploit these crops in both countries. Therefore, the paper highlights the urgent need to strengthen research on orphan crops within the Agricultural Knowledge and Innovation Systems (AKIS) of both countries by developing a long-term agenda for research, innovation, and development through concerted efforts involving all the stakeholders within AKIS and food system from researchers to policymakers, farmers, and consumers. An important step in this respect is to identify, in a participatory and inclusive way, priority resilient, nutritious NUS on which to focus research and development efforts, given the limited financial and human resources in both Sahel countries. For that, both domestic funding and international support are needed. In this context, projects such as SUSTLIVES (Sustaining and improving local crop patrimony in Burkina Faso and Niger for better lives and ecosystems)—financed by the initiative of the European Union on climate-relevant Development Smart Innovation through Research in Agriculture and food systems in developing countries (DeSIRA[1])—can play a crucial role. Indeed, to fully exploit the potential of orphan crops, coordinated approaches have to be integrated on the local, regional, and international levels and involve various

[1]https://europa.eu/capacity4dev/hunger-foodsecurity-nutrition/documents/annex-3

stakeholders from the public, private, and civil society sectors. There is also a need for a policy framework that recognizes the use of orphan crops in the strategy for climate change adaptation and sustainable food systems, especially in remote rural communities. This will foster local researchers to engage meaningfully with other domestic stakeholders, as well as international research networks, to research and develop orphan crops as significant contributors to the implementation of the 2030 Agenda for Sustainable Development and Paris Climate Agreement in BF and Niger. Indeed, if adequately nurtured through research and innovation, orphan crops can play a key role in building a resilient and economically vibrant agricultural sector that is able to sustain food and nutrition security and sustainable rural livelihoods under climate change.

Acknowledgements

I would like to thank Dr. Stefano Padulosi (Alliance Bioversity-CIAT), Dr. Veli-Matti Rokka (Natural Resources Institute Finland—LUKE) and Dr. Generosa Calabrese (CIHEAM Bari) for constructive comments and valuable editorial suggestions on an earlier version of this paper.

References

1. Li X, Siddique KHM. Future smart food - rediscovering hidden treasures of neglected and underutilized species for zero hunger in Asia. Bangkok: FAO; 2018.
2. Padulosi S. Bring NUS back on the table! GREAT insights magazine [Internet]. 2017. p. 21–22. Available from: URL: http://ecdpm.org/great-insights/sustainable-food-systems/bring-nus-back-table
3. Padulosi S, Thompson J, Rudebjer P. Fighting poverty, hunger and malnutrition with neglected and underutilized species (NUS): needs, challenges and the way forward [Internet]. Rome: Bioversity International; 2013. Available from: URL: https://www.bioversityinternational.org/fileadmin/_migrated/uploads/tx_news/Fighting_poverty__hunger_and_malnutrition_with_neglected_and_underutilized_species__NUS__1671_03.pdf
4. Garn SM, Leonard WR. What did our ancestors eat? Nutrition Reviews [Internet] 2009;47(11):337–45. doi: 10.1111/j.1753-4887.1989.tb02765.x
5. Kermali S, Anishetty N, Cooper H. Promoting development and commercialization of underutilized crops and species in the FAO global plan of action. Southampton (UK): International Centre for Underutilised Crops (ICUC); 1997.
6. Baldermann S, Blagojević L, Frede K, Klopsch R, Neugart S, Neumann A, et al. Are Neglected Plants the Food for the Future? Critical Reviews in Plant Sciences [Internet] 2016;35(2):106–19. doi: 10.1080/07352689.2016.1201399
7. Kunkel G. Plants for human consumption. Koenigstein, Germany: Koeltz Scientific Books; 1984.
8. Wiersema J, Leon B. World economic plants: a standard reference. Boca Raton (FL): CRC Press; 1999.
9. FAO. The state of the world's plant genetic resources for food and agriculture. Rome: FAO; 1998.
10. FAO. Dimensions of need: An atlas of food and agriculture [Internet]. Rome: FAO; 1995. Available from: URL: www.fao.org/docrep/u8480e/U8480E00.htm#Dimensions of need
11. Prescott-Allen R, Prescott-Allen C. How many plants feed the world? Conservation Biology [Internet] 1990;4(4):365–74. doi: 10.1111/j.1523-1739.1990.tb00310.x
12. FAO. Report on the state of the world's plant genetic resources for food and agriculture. Rome: FAO; 2010.
13. Chivenge P, Mabhaudhi T, Modi A, Mafongoya P. The potential role of neglected and underutilised crop species as future crops under water scarce conditions in Sub-Saharan Africa. International Journal of Environmental Research and Public Health [Internet] 2015;12(6):5685–711. Available from: URL: http://www.mdpi.com/1660-4601/12/6/5685
14. Fanzo J. Diversifying food and diets: using agricultural biodiversity to improve nutrition and health [Internet]. Abingdon (UK): Routledge; 2013. Available from: URL: https://www.taylorfrancis.com/books/9780203127261
15. Mabhaudhi T, Chimonyo VGP, Hlahla S, Massawe F, Mayes S, Nhamo L, et al. Prospects of orphan crops in climate change. Planta [Internet] 2019;250(3):695–708. doi: 10.1007/s00425-019-03129-y
16. Mabhaudhi T, O'Reilly P, Walker S, Mwale S. Opportunities for underutilised crops in southern Africa's post–2015 development agenda. Sustainability [Internet] 2016;8(4):302. Available from: URL: http://www.mdpi.com/2071-1050/8/4/302
17. Tadele Z. African orphan crops under abiotic stresses: challenges and opportunities. Scientifica (Cairo) [Internet] 2018;2018:1–19. Available from: URL: https://www.hindawi.com/journals/scientifica/2018/1451894/
18. Nyadanu D, Aboagye LM, Akromah R, Dansi A. Agro-biodiversity and challenges of on-farm conservation: the case of plant genetic resources of neglected and underutilized crop species in Ghana. Genetic Resources and Crop Evolution [Internet] 2016;63(8):1397–409. doi: 10.1007/s10722-015-0327-2
19. Springmann M, Godfray HCJ, Rayner M, Scarborough P. Analysis and valuation of the health and climate change cobenefits of dietary change. Proceedings of the National Academy of Sciences [Internet] 2016;113(15):4146–51. doi: 10.1073/pnas.1523119113
20. Aboussaleh Y, Capone R, El Bilali H. Mediterranean food consumption patterns: low environmental impacts and significant health-nutrition benefits. The Proceedings of the Nutrition Society 2017;76(4):543–8.
21. Galli A, Iha K, Halle M, El Bilali H, Grunewald N, Eaton D, et al. Mediterranean countries' food consumption and sourcing patterns: an ecological footprint viewpoint. Science of the Total Environment [Internet] 2017;578:383–91. doi: 10.1016/j.scitotenv.2016.10.191
22. Kour R, Sharma BC, Kumar A, Kour P. Nutrient uptake by chickpea + mustard intercropping system as influenced by weed management. Indian Journal of Weed Science 2013;45:183–88.
23. Magbagbeola JAO, Adetoso JA, Owolabi OA. Neglected and underutilized species (NUS): a panacea for community focused development to poverty alleviation/poverty reduction

in Nigeria. International Journal of Economics and Finance 2010;2:208–11.

24. Nyadanu D, Lowor ST. Promoting competitiveness of neglected and underutilized crop species: comparative analysis of nutritional composition of indigenous and exotic leafy and fruit vegetables in Ghana. Genetic Resources and Crop Evolution [Internet] 2015;62(1):131–40. doi: 10.1007/s10722-014-0162-x
25. Kour S, Bakshi P, Sharma A, Wali VK, Jasrotia A, Kumari S. Strategies on conservation, improvement and utilization of underutilized fruit crops. International Journal of Current Microbiology and Applied Sciences [Internet] 2018;7(03):638–50. Available from: URL: https://www.ijcmas.com/abstractview.php?ID=6903&vol=7-3-2018&SNo=75
26. Meaza H, Demssie B. Managing fragile homestead trees to improve livelihoods of land-poor farmers in the Northern Highlands of Ethiopia. Singapore Journal of Tropical Geography [Internet] 2015;36(1):57–66. doi: 10.1111/sjtg.12098
27. Chadha ML, Olouch M. Healthy diet gardening kit - for better health and income. Acta Horticulturae [Internet] 2007;752(752):581–4. Available from: URL: https://www.actahort.org/books/752/752_109.htm
28. Dansi A, Vodouhè R, Azokpota P, Yedomonhan H, Assogba P, Adjatin A, et al. Diversity of the neglected and underutilized crop species of importance in Benin. Scientific World Journal [Internet] 2012;2012:1–19. Available from: URL: http://www.hindawi.com/journals/tswj/2012/932947/
29. Vermeulen SJ, Campbell BM, Ingram JSI. Climate change and food systems. Annual Review of Environment and Resources [Internet] 2012;37(1):195–222. doi: 10.1146/annurev-environ-020411-130608
30. Williams JT, Haq N. Global research on underutilized crops - an assessment of current activities and proposals for enhanced cooperation. Southampton (UK): International Centre for Underutilised Crops; 2002.
31. Mabhaudhi T, Chimonyo VGP, Chibarabada TP, Modi AT. Developing a Roadmap for Improving Neglected and Underutilized Crops: A Case Study of South Africa. Frontiers in Plant Science [Internet] 2017;8: 1–13. doi: 10.3389/fpls.2017.02143/full
32. UNDP. Human development report 2019. New York: UNDP; 2019.
33. FAO, IFAD, UNICEF, WFP, WHO. The state of food security and nutrition in the world 2018. Building climate resilience for food security and nutrition. Rome: FAO; 2018.
34. USAID. Niger: nutrition profile [Internet] 2018. Available from: URL: https://www.usaid.gov/sites/default/files/documents/1864/Niger-Nutrition-Profile-Mar2018-508.pdf
35. USAID. Burkina Faso: nutrition profile [Internet] 2018. Available from: URL: https://www.usaid.gov/sites/default/files/documents/1864/Burkina-Faso-Nutrition-Profile-Mar2018-508.pdf
36. Sachs J, Schmidt-Traub G, Kroll C, Durand-Delacre D, Teksoz K. SDG index and dashboards report 2017. New York: Bertelsmann Stiftung & Sustainable Development Solutions Network (SDSN); 2017.
37. World Bank. World Bank open data [Internet] 2019 [cited 2019 November 24]. Available from: URL: https://data.worldbank.org
38. USAID. Climate change risk in West Africa Sahel: regional fact sheet [Internet] 2017. Available from: URL: https://www.climatelinks.org/sites/default/files/asset/document/2017 April_USAID ATLAS_Climate Change Risk Profile - Sahel.pdf
39. Institut National de la Statistique. Le Niger en Chiffres 2018 [Internet]. Niamey: Institut National de la Statistique; 2018. Available from: URL: http://www.stat-niger.org/statistique/file/Affiches_Depliants/Niger_Chiffres_2018.pdf
40. Mainardi S. Cropland use, yields, and droughts: spatial data modeling for Burkina Faso and Niger. Agricultural Economics 2011;42(1):17–33.
41. Sultan B, Baron C, Dingkuhn M, Sarr B, Janicot S. Agricultural impacts of large-scale variability of the West African monsoon. Agricultural and Forest Meteorology 2005;128(1–2):93–110.
42. World Bank. Niger: country overview [Internet] 2017 [cited 2017 December 15]. Available from: URL: http://www.worldbank.org/en/country/niger/overview
43. Loewenberg S. Niger's hunger crisis: a legacy of lessons unlearned. Lancet [Internet] 2010;376(9741):579–81. Available from: URL: https://linkinghub.elsevier.com/retrieve/pii/S0140673610612809
44. WHO. WHO Update on the health situation in Niger [Internet] 2013 [cited 2013 March 26]. Available from: URL: https://www.who.int/mediacentre/news/briefings/2005/mb1/en
45. Institut National de la Statistique, ICF International. Enquête Démographique et de Santé et à Indicateurs Multiples du Niger 2012. Calverton (Maryland, USA): ICF International; 2013.
46. Institut National de la Statistique et de la Démographie. Annuaire statistique 2018 [Internet]. Ouagadougou: Institut National de la Statistique et de la Démographie; 2019. Available from: URL: http://www.insd.bf/n/contenu/pub_periodiques/annuaires_stat/Annuaires_stat_nationaux_BF/Annuaire_Statistique_National_2018.pdf
47. Institut National de la Statistique et de la Démographie, ORC Macro. Enquête Démographique et de Santé du Burkina Faso 2003. Calverton (MD, USA): ORC Macro; 2004.
48. FAO. Burkina Faso: food security situation deteriorating in northern areas due to heightened violence [Internet]. Rome: FAO; 2019. Available from: URL: http://www.fao.org/3/ca5486en/ca5486en.pdf
49. World Bank. Burkina Faso: overview [Internet] 2019. Available from: URL: https://www.worldbank.org/en/country/burkinafaso/overview
50. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. PLOS Medicine [Internet] 2009;6(7):e1000097. doi: 10.1371/journal.pmed.1000097
51. El Bilali H. Transition heuristic frameworks in research on agro-food sustainability transitions. Environment, Development and Sustainability [Internet] 2020;22(3):1693–1728. doi: 10.1007/s10668-018-0290-0
52. El Bilali H. Research on agro-food sustainability transitions: where are food security and nutrition? Food security [Internet] 2019;11(3):559–77. doi: 10.1007/s12571-019-00922-1
53. Asfaw S, Pallante G, Palma A. Diversification strategies and adaptation deficit: evidence from rural communities in Niger. World Development [Internet] 2018;101:219–34. Available

from: URL: https://linkinghub.elsevier.com/retrieve/pii/S0305750X16301863

54. Villa-Ruano N, Pacheco-Hernández Y, Cruz-Durán R, Lozoya-Gloria E. Volatiles and seasonal variation of the essential oil composition from the leaves of *Clinopodium macrostemum* var. *laevigatum* and its biological activities. Industrial Crops and Products 2015;77:741–7.

55. Arditi C. The date trade in Borkou, Chad | Le commerce des dattes du Borkou (Tchad). Cahiers des Sciences Humaines 1995;31(4):849–82.

56. Tragust S, Feldhaar H, Espadaler X, Pedersen JS. Rapid increase of the parasitic fungus *Laboulbenia formicarum* in supercolonies of the invasive garden ant *Lasius neglectus*. Biological Invasions 2015;17(10):2795–801.

57. Owen-Smith N, Le Roux E, Macandza V. Are relatively rare antelope narrowly selective feeders? A sable antelope and zebra comparison. Journal of Zoology 2013;291(3):163–70.

58. Traoré L, Sop TK, Dayamba SD, Traoré S, Hahn K, Thiombiano A. Do protected areas really work to conserve species? A case study of three vulnerable woody species in the Sudanian zone of Burkina Faso. Environment, Development and Sustainability 2013;15(3):663–86.

59. Saito T, Otani T, Seike N, Okazaki M. A comparison of dieldrin residues in various vegetable crops cultivated in a contaminated field. Soil Science & Plant Nutrition 2012;58(3):373–83.

60. Hauber ME, Bierbach D, Linsenmair KE. The traditional Whedo aquaculture system in northern Benin. Journal of Applied Aquaculture 2011;23(1):67–84.

61. Spaan WP, Sikking AFS, Hoogmoed WB. Vegetation barrier and tillage effects on runoff and sediment in an alley crop system on a Luvisol in Burkina Faso. Soil and Tillage Research 2005;83(2):194–203.

62. Sterk G, Haigis J. Farmers' knowledge of wind erosion processes and control methods in Niger. Land Degradation and Development 1998;9(2):107–14.

63. Lazard J, Rognon X. Genetic diversity of Tilapia and aquaculture development in Côte d'Ivoire and Niger. Israeli Journal of Aquaculture – Bamidgeh 1997;49(2):90–8.

64. Adu-Dapaah H, Berchie JN, Amoah S, Addo JK, Akuamoah-Boateng M. Progress in bambara groundnut research in Ghana: breeding, agronomy and utilization. Acta Horticulturae [Internet] 2016;1127:1–8. Available from: URL: https://www.actahort.org/books/1127/1127_1.htm

65. Tiwari S, Kumar S. Neglected oil crop biotechnology. In: Biotechnology of neglected and underutilized crops [Internet]. Dordrecht, the Netherlands: Springer; 2013. p. 117–71. doi: 10.1007/978-94-007-5500-0_7

66. Tiwari S, Kumar S, Gontia I. Biotechnological approaches for sesame (*Sesamum indicum* L.) and niger (*Guizotia abyssinica* L.f. Cass.). Asia-Pacific Journal of Molecular Biology and Biotechnology 2011;19(1):2–9.

67. Dholakia RH. Exports of agri-products from Gujarat: problems and prospects. Vikalpa 2003;28(4):41–52.

68. Mihail JD. Diseases of alternative crops in Missouri. Canadian Journal of Plant Pathology 1993;15(2):119–22.

69. Neya T, Daboue E, Neya O, Ouedraogo I. Germination characteristics of *Parinari curatellifolia* planch. Ex benth, *Vitex doniana* Sweet and *Zanthoxylum zanthoxyloides* (Lam) watermann seeds. Annual Review & Research in Biology 2017;12(3):1–12.

70. Bognounou F, Ouédraogo O, Zerbo I, Sanou L, Rabo M, Thiombiano A, et al. Species-specific prediction models to estimate browse production of seven shrub and tree species based on semi-destructive methods in savannah. Agroforestry Systems 2013;87(5):1053–63.

71. Hayashi K, Abdoulaye T, Wakatsuki T. Evaluation of the utilization of heated sewage sludge for peri-urban horticulture production in the Sahel of West Africa. Agricultural Systems 2010;103(1):36–40.

72. Walbadet E, Perrochet P, Mermoud A. Hydraulic regimes for natural climatic conditions of soils in Burkina Faso | Regime hydrique en conditions climatiques naturelles d'un sol lateritique du Burkina Faso. In: The state-of-the-art of hydrology and hydrogeology in the arid and semi-arid areas of Africa Proc Sahel Forum, Ouagadougou, 1989. Urbana (USA): International Water Resources Association (IWRA); 1990. p. 361–9.

73. Ibrahim AR, Dansi A, Salifou M, Ousmane A, Alzouma A, Alou W. Farmers' practices, utilization, conservation and marketing of Bambara groundnut (*Vigna subterranea* (L.) Verdc.) in Dosso Region, Western Niger. Genetic Resources and Crop Evolution 2018;65(7):1907–14.

74. Romba R, Gnankine O, Drabo SF, Tiendrebeogo F, Henri H, Mouton L, et al. Abundance of *Bemisia tabaci* Gennadius (Hemiptera: Aleyrodidae) and its parasitoids on vegetables and cassava plants in Burkina Faso (West Africa). Ecology and Evolution 2018;8(12):6091–103.

75. Sandwidi A, Diallo BO, Lamien N, Vinceti B, Sanon K, Coulibaly P, et al. Participatory identification and characterisation of shea butter tree (*Vitellaria paradoxa* C.F. Gaertn.) ethnovarieties in Burkina Faso. Fruits 2018;73(3):141–52.

76. Guira F, Some K, Kabore D, Sawadogo-Lingani H, Traore Y, Savadogo A. Origins, production, and utilization of cassava in Burkina Faso, a contribution of a neglected crop to household food security. Food Science & Nutrition 2017;5(3):415–23.

77. Kouawa T, Wanko A, Beck C, Mose R, Maïga AH. Feasibility study of faecal sludge treatment by constructed wetlands in Sahelian context: experiments with *Oryza longistaminata* and *Sporobolus pyramidalis* species in Ouagadougou. Ecological Engineering 2015;84:390–7.

78. Ben Salah M. Date palm status and perspective in sub-Sahelian African countries: Burkina Faso, Chad, Ethiopia, Mali, Senegal, and Somalia. In: Date palm genetic resources and utilization [Internet]. Dordrecht, the Netherlands: Springer; 2015. p. 369–86. doi: 10.1007/978-94-017-9694-1_10

79. Gebauer J, Bernholt H, Hammer K. *Grewia flavescens*: a potential horticultural crop? Genetic Resources and Crop Evolution 2013;60(6):1915–9.

80. Sultan B, Roudier P, Quirion P, Alhassane A, Muller B, Dingkuhn M, et al. Assessing climate change impacts on sorghum and millet yields in the Sudanian and Sahelian savannas of West Africa. Environmental Research Letters. 2013;8(1):1–9.

81. Bernholt H, Kehlenbeck K, Gebauer J, Buerkert A. Plant species richness and diversity in urban and peri-urban gardens of Niamey, Niger. Agroforestry Systems 2009;77(3):159–79.

82. Mertz O, Reenberg A. Building on diversity: pathways to agricultural intensification in Burkina Faso. Geografisk Tidsskrift 1999;2:125–37.

83. Agnew CT. Water availability and the development of rainfed agriculture in south-west Niger, West Africa. Transactions of the Institute of British Geographers 1982;7(4):419–57.

84. Mkandawire C. Review of Bambara groundnut (*Vigna subterranean* (L.) Verdc.) production in sub-Sahara Africa. Agricultural Journal 2007;2:464–70.

85. Institut National de la Statistique . Le Niger en chiffres 2014. Niamey: Institut National de la Statistique; 2014.

86. Aremu MO, Olaofe O, Akintayo ET. Chemical composition and physicochemical characteristics of two varieties of Bambara groundnut (*Vigna subterrenea*) flours. Journal of Applied Sciences [Internet]. 2006;6(9):1900–3. Available from: URL: http://www.scialert.net/abstract/?doi=jas.2006.1900.1903

87. Ngwako S, Balole T, Malambane G. The effect of irrigation and planting date on the growth and yield of Bambara groundnut landraces. International Journal of Agriculture and Crop Sciences 2013;6(3):116–20.

88. Food Safety Network. Cassava nutritional network. Guelph: University of Guelph; 2014.