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SUSTAINABILITY OF NEGLECTED AND UNDERUTILISED SPECIES (NUS): TOWARDS AN ASSESSMENT MATRIX FOR CROP SPECIES

Hamid EL BILALI[1,*], Gianluigi CARDONE[1], Susanna ROKKA[2], Abdel Kader NAINO JIKA[3], Eleonora DE FALCIS[3], Ali Badara DIAWARA[4], Bassirou NOUHOU[5], Andrea GHIONE[6]

[1]International Centre for Advanced Mediterranean Agronomic Studies (CIHEAM-Bari), Valenzano (Bari), Italy
[2]Natural Resources Institute Finland (Luke), Jokioinen, Finland
[3]Alliance Bioversity International – CIAT (Centro Internacional de Agricultura Tropical), Rome, Italy
[4]Afrique Verte Burkina Faso (APROSSA), Ouagadougou, Burkina Faso
[5]Afrique Verte Niger (AcSSA), Niamey, Niger
[6]Italian Agency for Development Cooperation (AICS), Ouagadougou, Burkina Faso
*Corresponding author: elbilali@iamb.it

ABSTRACT
Neglected and underutilised species (NUS) are widely claimed to contribute to sustainability and sustainable development. Verifying such a claim implies the use of a scientifically sound assessment tool. In this context, the present article aims to suggest a matrix for the assessment of the environmental, economic and social sustainability of NUS. In particular, the paper provides a set of indicators and metrics to assess the different sustainability dimensions. It draws upon a search carried out on the Web of Science in May 2022 that returned 126 records. Eligible documents underwent two steps: in the first step, indicators, metrics and criteria regarding sustainability were identified; in the second step, expert knowledge was used to systematise the identified indicators and metrics according to the three sustainability dimensions and group them into themes. Agronomic aspects were included in the environmental dimension while nutrition, health and cultural aspects were included in the social dimension. One of the main results of the analysis is that there is a dearth of quality scholarly documents dealing with the assessment of NUS sustainability. Furthermore, economic and social indicators and metrics are hard to find. The operationalisation of the proposed indicators requires their contextualisation taking into consideration the conditions in each country/territory as well as the NUS concerned. A further important step to operationalise the proposed matrix implies the identification of a sustainability threshold and an assessment scale for each indicator. Apart from sustainability assessment, the proposed assessment matrix can allow selecting the NUS that have the highest potential and whose promotion can contribute to the sustainable development of the concerned countries and territories.

Keywords: *orphan crops, environmental sustainability, economic sustainability, social sustainability, sustainability assessment.*

INTRODUCTION

Neglected and underutilised species (NUS) – also known as orphan, minor, abandoned or lost crops (Padulosi, 2017) – represent tens of thousands of plant species (Chivenge et al., 2015). NUS are widely claimed to contribute to sustainability and sustainable development, thus sustainable food systems (SFS). Indeed, NUS offer the potential to diversify not only the human diets, but also farming systems, thus enabling more resilient and sustainable agri-food systems. They can help addressing various challenges such as food and nutrition insecurity, water scarcity, environmental degradation, poverty and climate change (Mabhaudhi et al., 2019). NUS contribute to climate-resilient food systems and offer opportunities to reduce greenhouse gas (GHG) emissions from agriculture (Mabhaudhi et al., 2019). Furthermore, NUS are critical for the conservation of agro-biodiversity and agro-ecosystems (Padulosi et al., 2013). NUS can also reduce environmental contamination from agriculture as they often tolerate diseases and grow on low-quality soils thus requiring lower levels of chemical inputs (Mabhaudhi et al., 2019). They play an important role in achieving food and nutrition security since millions of people, especially in developing countries, rely on NUS as their primary source of food (Mabhaudhi et al., 2019; Padulosi et al., 2013; Ulian et al., 2020). Certain NUS were also reported to have health protection properties (Tadele, 2018). NUS can also improve the livelihoods of rural people as they can enhance income from agriculture (Kour et al., 2018; Padulosi et al., 2013). Given all the above-mentioned benefits of NUS, Mabhaudhi et al. (2016) argue that their promotion could contribute to the achievement of the Sustainable Development Goals (SDGs).

Sustainability has been central in the current debate on food systems and their role in sustainable development, as shown by the United Nations’ Food Systems Summit held in September 2021 (United Nations, 2021). There are also many regional initiatives on SFS; for instance, the Farm to Fork strategy in the European Union (EU) aims at fostering transition towards sustainable, resilient and inclusive food systems (European Commission, 2020). Nevertheless, in a systematic review on sustainable agri-food systems (AFS), El Bilali et al. (2021) show an increasing interest in AFS but suggest that while environmental aspects are sufficiently addressed, social, economic, and political ones are generally overlooked. Over the last decades, different frameworks have been developed to assess sustainability in agriculture and food systems such as the SAFA (Sustainability Assessment of Food and Agriculture systems) approach (FAO, 2013, 2014). Such frameworks are based on the use of different indicators and metrics. However, Adinolfi et al. (2015) point out that the sustainability assessment focus (product, diet, food supply chain, food system) and geographical coverage (local, territorial, national, regional) should be clearly defined for the selection of appropriate indicators. This clearly shows that appropriate indicators should be developed ad-hoc for each sustainability assessment purpose depending on whose sustainability is assessed. Therefore, while sustainability assessment indicators exist for different levels of the food system and supply chain, to the best of our knowledge, no assessment matrix deals specifically with NUS. To address this gap, the present paper aims to suggest a matrix for the assessment of the environmental, social and economic sustainability of NUS.

MATERIAL AND METHODS

The present paper is based on a systematic literature review that follows the PRISMA guidelines (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) (Moher et al., 2009; Page et al., 2021). The paper draws upon a search of all documents indexed in the Web of Science (WoS) carried out on May 4th, 2022, using the following search string: *(sustainability OR sustainable) AND (indicator OR criteri* OR metric OR index OR evaluation OR assessment) AND ("neglected and underutilised species" OR NUS OR "neglected species" OR "underutilised species" OR "neglected and underutilized crop" OR "neglected crop" OR "underutilized crop" OR "abandoned crop" OR "abandoned species" OR "alternative crop" OR "alternative species" OR "local crop" OR "local species" OR "lost crop" OR "lost species" OR "minor crop" OR "minor species" OR "niche crop" OR "niche species" OR "orphan crop" OR "orphan species" OR "traditional crop" OR "traditional species" OR "underdeveloped crop" OR "underdeveloped species")*. The search on WoS returned 126 documents. Two eligibility criteria were considered: NUS and sustainability assessment. Only the documents that meet both eligibility criteria were included in the systematic review.

In total, 114 documents were excluded following the screening of titles and abstracts as well as the scrutiny of full-texts, as they weren't eligible. Out of these, 84 documents were excluded because they do not deal with NUS. For instance, some documents refer to some forest tree species, such as *pinus*, or the National University of Singapore (NUS), Nigerian University System (NUS), non-uniform sampling (NUS), norm-based user selection (NUS) or number of undeveloped seeds (NUS), rather than neglected and underutilised species (NUS). Some documents deal with major commercial crops such as wheat, potato, maize, hazelnut, corn/maize, grapevine, citrus, sugarcane, cotton and sugar beet. Also, documents referring to local and minor arthropod and insect species as well as animal species (e.g. buffalo) were discarded. Further 30 documents were excluded because they do not address sustainability assessment. Some articles address sustainability assessment but in relation to livelihoods or farms/farming systems rather than NUS. Consequently, only 12 documents resulted eligible and were included in the systematic review: Georgiadis (2022), Kakabouki et al. (2021), Eissler et al. (2021), Mugiyo et al. (2021), Mwangi et al. (2020), Ibrahim Bio Yerima et al. (2020), Pande et al. (2018), DeHaan et al. (2016), Balemie and Singh (2012), Manos et al. (2008), Schmidt et al. (2008) and Scott (2003).

The analysis of the eligible documents was structured in two different steps. In the first step, indicators, metrics and criteria regarding the sustainability, as well as the selection and/or prioritisation of NUS, were identified. In the second step, expert knowledge was used to systematise the identified indicators and metrics according to the three sustainability dimensions (environmental, social and economic). During this step, preference was given to indicators and metrics to the detriment of criteria. The grouping of indicators and metrics into themes was informed by the SAFA approach (FAO, 2013, 2014). For the purpose of the present work, agronomic aspects were included in the environmental dimension; nutrition, health and cultural aspects in the social dimension.

RESULTS AND DISCUSSION

Table 1 provides an overview of indicators and metrics proposed in the selected articles/documents for the assessment of the sustainability of NUS. It also includes criteria suggested by different scholars to perform the selection or prioritisation of NUS to be included in the domestication programs or in different endeavours aiming at enhancing NUS and their products as well as developing their value chains. The table specifies for each source the context of reference (country/region) as well as the NUS or botanical groups considered.

Georgiadis (2022) documents traditional ecological knowledge and reports ethnobotanical uses of 125 plant taxa by an indigenous Karen community in Northern Thailand. The author ranks the cultural significance of the reported species in the community based on different indices such as the cultural importance index (Tardío & Pardo-de-Santayana, 2008) and the cultural value index (Reyes-García et al., 2006). Kakabouki et al. (2021) evaluate the potential contribution of seven alternative crops (viz. quinoa, teff, tritordeum, camelina, nigella, chia, and sweet potato) to climate change mitigation in the EU and examine the factors that might determine their successful integration in the Mediterranean area. They conclude that the limiting factors for crop establishment include soil properties, environmental and climatic parameters, and crop performance and dynamics. A good alternative crop should have high adaptability to different soil types, reduced water demands, reduced fertilization needs, reduced CO_2 emissions, reduced agrochemical inputs, reduced tillage and multiple uses, and increased employment.

Eissler et al. (2021) use a sustainable intensification (SI) assessment framework – developed by the Feed the Future Innovation Lab for Collaborative Research on Sustainable Intensification (SIIL) (Musumba et al., 2017), that incorporates five measurable domains (productivity, economic, environmental, human condition, and social) – to assess the current uses of NUS as well as the perceived benefits and challenges to their use and management in northwestern Cambodia. They show a wide range of values and benefits associated with NUS that compose wild gardens. Mugiyo et al. (2021) develop land suitability maps for selected NUS – sorghum (*Sorghum bicolor*), cowpea (*Vigna unguiculata*), amaranth and taro (*Colocasia esculenta*) – in South Africa. They distinguish between natural or biophysical factors (e.g. rainfall, temperature and soil fertility) that directly affect the growth of crops, and social and economic factors that do not directly affect crop growth, but influence land use degree of appropriateness. They found that sorghum was highly suitable and rainfall was the most critical variable and the criterion with the highest impact on land suitability of the NUS.

Mwangi et al. (2020) use the FAO's seed security framework (FAO, 2016) to assess seed security among smallholder sweet potato producers in Kenya. The framework is based on four parameters namely availability, accessibility, varietal suitability and seed quality. They show that smallholder producers experienced mild seed insecurity and seed access is the most critical element influencing food security. Ibrahim Bio Yerima et al. (2020) assess the phenotypic variability of 180 accessions of fonio from West Africa (Guinea, Mali, Burkina Faso, Niger, Benin) using 20 agro-morphological descriptors, including both qualitative and quantitative traits. They found significant differences among fonio accessions for most of the quantitative traits. Furthermore, highly significant correlations were found between grain yield and harvest index, thousand seeds weight, flowering and maturity times.

Pande et al. (2018) examine the economic sustainability of alternative agri-horticultural systems – drumstick (*Moringa oleifera*)- and aonla (*Emblica officinalis*)-based agri-horticulture trees with *Phaseolus radiatus* and *Foeniculum vulgare* crops – on reclaimed ravine lands in Gujarat, western India. The analysis shows the financial viability of the alternative cropping systems on the marginal lands, but the sensitivity analysis pointed out market and yield risks in crop components that need to be taken into account before recommending the alternative agri-horticultural system to farmers. DeHaan et al. (2016) suggest a pipeline approach to increase the success in contemporary domestication of new grain crops. They list criteria for ranking domestication species and discuss strategies to prioritize initial research efforts once the candidates have been selected. The domestication pipeline consists of three phases: (1) screening of plant species to discover candidates; (2) developing each candidate according to one of three general development strategies designed to produce a partially domesticated species usable as a new crop (viz. addressing the primary limitations, building on strengths, breeding to improve quantitative traits); and (3) integrating strategies to develop a commodity crop. Balemie and Singh (2012) survey diversity in a range of local crops (especially wheat and tef - *Eragrostis tef*) in the Lume and Gimbichu districts of Ethiopia and analyse local people's knowledge regarding crop uses, socio-economic importance, conservation and management. They found that agronomic performance (yield and pest resistance), market demand, and nutritional and use diversity attributes of the crop varieties were the most important criteria for making decisions regarding crop planting and maintenance.

Manos et al. (2008) evaluate tobacco alternatives [aromatic and medicinal crops: oregano, mountain tea, basil, mint, thyme, lavender, camomile; energy crops: sunflower, sugar beet, oilseed rape, anise; organic crops: wheat, barley, maize, alfalfa, and vetch; fruit trees: cherries, plums, pears, pomegranates] in Greece and classified them according to different criteria, mainly economic ones such as profitability, in the context of the reform of Common Agricultural Policy (CAP) for the tobacco sector with phasing out of the subsidy payment for tobacco cultivation. This exercise led to the drafting of a list of the most suitable alternative crops for every region (Thessaly and Central Macedonia). They concluded that the most profitable alternatives are aromatic and medical crops. Schmidt et al. (2008) carried out farmer interviews and a literature review to prepare a 'masterlist' of promising NUS in China, Cambodia, north-eastern Thailand and northern Vietnam. Promising NUS underwent an initial pre-selection to narrow down the list then a multi-criteria and trans-disciplinary assessment involving different stakeholders (e.g. scientists, farmers, NGOs, policymakers). The process allowed identifying the most promising NUS for each country. The criteria for the evaluation of NUS were adapted from Padulosi et al. (1999). Scott (2003) highlights the importance of considering the commercial/market potential of minor/lost crops. Referring to the example of quinoa in the Andes region, he suggests a practical, low-cost procedure to evaluate the market prospects and procedures for these crops. According to Scott (2003), "*The principal steps involved in evaluating the commercial viability of processing and marketing new or improved agricultural products can be summarized as follows: Initial assessment. Evaluation of market competition and consumer demand. Input supply analysis. Analysis of costs and returns. Development of a marketing strategy*" (p. 207).

Table 1. Synthesis of documents considered in the systematic review.

Source	Country/region	NUS/crops considered	Indicators, metrics and criteria
Georgiadis (2022)	Thailand	125 plant taxa	Cultural importance index; Cultural value index
Kakabouki et al. (2021)	European Union	Quinoa, teff, tritordeum, camelina, nigella, chia, and sweet potato	Soil properties: texture, pH value, salinity, and sodicity (sodium adsorption ratio); Environmental and climatic parameters: temperature, altitude, latitude, photoperiod; Crop performance and dynamics: water demand (water use efficiency), fertilization needs (nitrogen use efficiency, nitrogen agronomic efficiency), light (growing degree days) and heat requirements

Source	Country/region	NUS/crops considered	Indicators, metrics and criteria
Eissler et al. (2021)	Cambodia	Various NUS including chaya (*Cnidoscolus aconitifolius*), galangal (*Alpinia galanga*), lemongrass (*Cymbopogon citratus*)	Productivity: ability to improve household consumption, ability to increase crop production, ability to diversify production; Economic: ability to increase income, ability to increase diversified income, ability to save on investments, ability to save time for labor; Environmental: ability to increase species diversity [biodiversity], reduce needs for chemical inputs, promote the use of natural composts; Human condition: ability to improve access to nutrition and nutritional diversity, ability to improve food security, ability to improve health [medicinal]; Social: gender, social cohesion, collective action
Mugiyo et al. (2021)	South Africa	Sorghum, cowpea, amaranth and taro	Climatic: temperature, rainfall, length of the growing season, reference evapotranspiration; Topographic: altitude, slope; Land use: land cover; Social/economic: distance to road
Mwangi et al. (2020)	Kenya	Sweet potato	Seed security: seed availability, seed access, varietal suitability and seed quality
Ibrahim Bio Yerima et al. (2020)	West Africa	Fonio	Qualitative: vigour at seedling, phenotypic grain colour; Quantitative: plant height, days to 50% flowering, days to 50% maturity, panicle length, dry biomass yield, grain yield, harvest index, thousand seeds weight
Pande et al. (2018)	India	Drumstick and aonla	Price; Net revenue
DeHaan et al. (2016)	Various countries/regions	Grain crops (maximilian sunflower,	Domestic morphology and phenology; ease of breeding and genetics; easily harvestable; high

Source	Country/region	NUS/crops considered	Indicators, metrics and criteria
		rice grass, chickpea, wild rice, sweet white lupin)	yield; grain similar to that of current crops; high-value product; high nutrition and quality attributes; available genetic resources; broadly adapted or adaptable; low input requirements; enhanced ecosystem services; culturally tenable; knowledge of the candidate's disease and pest risk; low potential to become invasive or contaminate the gene pool of a native species.
Balemie and Singh (2012)	Ethiopia	Wheat, tef, field pea, grass pea, fenugreek, lentil	Agronomic performance: yield and pest resistance; Use diversity; Nutritional and ethno-medicinal importance; Market demand; Socioeconomic importance
Manos et al. (2008)	Greece	Aromatic and medicinal plants	Income; Gross margin; Variable costs; Labour requirement
Schmidt et al. (2008)	China, Cambodia, Thailand and Vietnam	Various NUS e.g. Chinese white olive, taro, cashew, star goosbery	Economic and agronomic competitiveness: potential generated income, changing abiotic and biotic conditions (e.g. climate, pests), attractive traits; Local and national use, cultural acceptance; Traditional knowledge: knowledge on cultural practices, propagation techniques, knowledge on uses; Scientific Knowledge: research on genetic diversity, propagation techniques, knowledge on uses; Policy & legislation: extension and research activities by government and NGO's, favourable policies or government support; Opportunities for national/export niche market: availability of

Source	Country/region	NUS/crops considered	Indicators, metrics and criteria
			existing or potential future markets in the region, neighbouring countries or overseas
Scott (2003)	Andes	Quinoa	Consumer demand; Availability of inputs; Production costs; Returns

The analysis of the indicators, metrics and criteria proposed in the selected documents led to the drafting of the matrix for the assessment of the sustainability of NUS reported in Table 2. In the above-mentioned table, data from different sources have been merged and collated. Preference was given to indicators and metrics to the detriment of criteria that are hardly evaluated or for which no straightforward, simple evaluation method has been suggested. The analysis of the results reported in the table suggests that there are ways more environmental metrics and indicators than social and economic ways. Furthermore, some metrics need further elaboration in order to make them ready to use. In fact, not all metrics proposed satisfy all conditions to be considered SMART (Specific, Measurable, Achievable, Relevant and Time-bound) indicators. However, many general sustainability indicators are feasible in terms of the analysis of NUS as well.

Table 2. Proposed preliminary matrix for the assessment of the environmental, social and economic sustainability of NUS.

Sustainability dimension	Sustainability Theme	Proposed indicator/ metric	Source(s) informing proposal
Environmental	Environmental integrity	Fertiliser/nitrogen requirement	Kakabouki et al. (2021); Eissler et al. (2021); DeHaan et al. (2016)
		Pesticide requirement	Eissler et al. (2021); DeHaan et al. (2016)
		Water demand	Mugiyo et al. (2021); Kakabouki et al. (2021)
		Reference evapotranspiration	Mugiyo et al. (2021)
		Genetic diversity[2]	Eissler et al. (2021)
	Agronomic performance and productivity	Yield	Mugiyo et al. (2021); Eissler et al. (2021); Ibrahim Bio Yerima et al. (2020); DeHaan et al. (2016); Balemie and

[2] This metric might refer to the number of known varieties.

Sustainability dimension	Sustainability Theme	Proposed indicator/ metric	Source(s) informing proposal
			Singh (2012)
		Length of the growing season / Time to maturity	Mugiyo et al. (2021); Ibrahim Bio Yerima et al. (2020)
		Growing degree days	Kakabouki et al. (2021)
		Level of tolerance to salinity/sodicity	Kakabouki et al. (2021); DeHaan et al. (2016); Schmidt et al. (2008)
		Level of tolerance to high temperatures	Kakabouki et al. (2021); DeHaan et al. (2016)
		Level of tolerance/resistance to pests and diseases[3]	DeHaan et al. (2016); Balemie and Singh (2012); Schmidt et al. (2008)
		Seed security - Availability	Mwangi et al. (2020); DeHaan et al. (2016)
		Seed security - Varietal suitability	Mwangi et al. (2020)
		Seed security - Seed quality	Mwangi et al. (2020)
Social	Cultural significance and relevance	Number of documented uses[4]	Georgiadis (2022); DeHaan et al. (2016); Balemie and Singh (2012); Schmidt et al. (2008)
	Nutritional quality and diversity	Content of bioactive and health-promoting compounds	Eissler et al. (2021); DeHaan et al. (2016); Balemie and Singh (2012)
		Protein content	
	Employment	Labour requirement	Eissler et al. (2021); Manos et al. (2008)
	Equity and fair accessibility	Seed security - Access	Mwangi et al. (2020)
Economic	Competiveness	Price	Pande et al. (2018)
		Market demand	Balemie and Singh

[3] This metric might refer to the number of key pests and diseases.
[4] Human food, technology, medicinal, firewood, animal feed, symbolic uses, other.

Sustainability dimension	Sustainability Theme	Proposed indicator/ metric	Source(s) informing proposal
			(2012); Schmidt et al. (2008); Scott (2003)
		Production cost	Pande et al. (2018); Manos et al. (2008); Scott (2003)
	Profitability	Gross margin	Pande et al. (2018); Manos et al. (2008)
		Income	Eissler et al. (2021); Manos et al. (2008); Schmidt et al. (2008)

CONCLUSIONS

One of the main results of this analysis is that there is a dearth of quality scholarly documents that deal with the assessment of the sustainability of NUS. This is rather surprising and largely unexpected given the ongoing rhetoric on the enhancement and development of NUS and their value chains to address different challenges such as biodiversity loss, climate change, food insecurity and malnutrition, poverty and livelihoods vulnerability. This, in turn, clearly shows that the present work is timely and highly needed. Furthermore, economic and, especially, social indicators and metrics are hard to find. The operationalisation of the proposed indicators requires their contextualisation taking into consideration the conditions in each country/territory as well as the NUS concerned. Such a contextualization as well as the overall validation of the proposed assessment matrix should involve local stakeholders; which is foreseen in the framework of SUSTLIVES project that is being implemented in Burkina Faso and Niger[5]. A further important step to operationalise the proposed matrix, to make it functional for sustainability assessment, implies the identification of a sustainability threshold and an assessment scale for each indicator. The proposed assessment matrix can have different uses. In fact, apart from sustainability assessment, it can also guide initiatives for the selection and prioritisation of NUS to be included in the different programmes and initiatives aiming at the valorisation and enhancement of NUS and the development of their value chains. Given the limited resources, efforts should be concentrated on the most promising NUS; the proposed matrix allows selecting the NUS that have the highest potential and whose development can have the highest environmental, social and economic impacts thus contributing to the sustainable development of the concerned countries and territories.

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[5] https://www.sustlives.eu

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