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Orphan Crops and Sustainability Transitions in Agri-Food Systems: Towards A Multidimensional and Multilevel Transition Framework

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***Abstract*— Neglected and underutilized species (NUS i.e. orphan crops) are widely claimed to contribute to sustainable development. However, the relationship between NUS and sustainable agri-food systems is still unclear. Therefore, this paper analyses the role of NUS in the transition towards sustainable and resilient agri-food systems and identifies actions needed and levers of change. It draws upon a systematic review of 35 articles identified through a search performed in July 2022 on the Web of Science. The analysis of the literature was conducted following the Multi-Level Perspective on socio-technical transitions (MLP) and its three elements viz. niches, sociotechnical regime and sociotechnical landscape. The review suggests that the transition dynamics and success depend not only on the features of the niche NUS (cf. strengths and weaknesses), regime (cf. barriers to change and competitiveness of major crops with NUS) and landscape (cf. macro-trends and policies) but also on the interactions among them. The levers of change lie in the areas of policy, market and finance, technology, culture, and science and innovation. Further research is needed to elucidate the mechanisms leading to the mainstreaming of NUS into agri-food systems as well as the dynamics of interaction between niche NUS and commercial, staple crops.**

***Index Terms*—niche, NUS, orphan crops, sustainability transitions, sustainable agriculture, sustainable food systems.**

I. INTRODUCTION

According to Markard et al. [1], sustainability transitions refer to "*long-term, multi-dimensional and fundamental transformation processes through which established socio-technical systems shift to more sustainable modes of production and consumption"* (p. 956). The research field on agro-food sustainability transitions is rather young; El Bilali [2] argues that the first paper was published in 2003 [3]. Research on sustainability transitions mainly deals with the development of niches. A wide range of niches has been studied in agri-food systems. These include alternative food systems/networks and farming systems. Indeed, considered niches include agroecology, organic agriculture, permaculture, urban agriculture, conservation agriculture, integrated farming, care farming, and alternative food networks [4].

Tens of thousands of crop species remain relatively underutilized [5]; these are referred to as neglected and underutilized species (NUS) or underutilized, neglected, niche and orphan crops [6]. Padulosi et al. [7] argue that "*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). More than 7,000 crop species have been used for food during the course of human history [8], [9]. However, only about 150 species are cultivated commercially [10], [11].

NUS are widely claimed to contribute to sustainable development. The promotion and enhancement of NUS have been reported to contribute to agrobiodiversity conservation [7], food and nutrition security [7], [12], climate change adaptation and mitigation [13], environmental integrity and health [13], human health [14], and rural livelihoods sustainability and resilience [7], [15]. Mabhaudhi et al. [13] argue that NUS could play an important development role in the Global South; for that, research, enabling policies and strategies as well as investments are needed. Indeed, many challenges hinder the mainstreaming of NUS [13]. To promote NUS, barriers against their mainstreaming have to be identified and thoroughly analyzed [16]. Padulosi et al. [7] posit 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). Similarly, Williams and Haq [17] enumerate the lack of interest by food chain actors (e.g. farmers, researchers and extension agents), limited germplasm availability, and lack of technical information and tailored national policies among the constraints to NUS development. Hence, research, innovation and development are highly needed to unlock the potential of NUS [18], especially in developing countries [5].

The promotion of NUS should contribute to sustainable and resilient agri-food systems. However, the interplay between NUS and sustainability in agri-food systems is still unclear and there is a gap in the existing scholarly literature. Therefore, the present review analyses the role of NUS in the transition towards sustainable and resilient agri-food systems. It also identifies actions needed and levers of change to bring about such a transition.

II.MATERIAL AND METHODS

The present article is based on a systematic literature review that follows the PRISMA guidelines (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) [19], [20]. It draws upon a search of all documents indexed in the Web of Science (WoS) performed on July 1st, 2022, using the following search string: *(transition OR transformation OR mainstream OR integration OR scaling OR change) AND (agriculture OR food) AND ("neglected and underutilised species" OR NUS OR "neglected species" OR "neglected and underutilized crop" OR "neglected 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 438 documents. Two eligibility criteria were considered; eligible documents had to deal with NUS *and* sustainability transitions in agri-food systems. Only the documents that met both criteria were included in the systematic review. The selection of articles to be included in the systematic review is described in Table 1.

Table 1. Articles selection process.

Steps	*Number of selected records*	*Step description*
Screening of records based on titles	438	113 records excluded because they do not address crop NUS
Screening of records based on abstracts	325	226 records excluded: • 159 documents because they do not deal with crop NUS • 67 documents because they do not address sustainability transitions in agri-food systems
Scrutiny of full-texts to check eligibility	99	64 records excluded: • 9 documents do not deal with NUS • 55 documents do not address sustainability transitions in agri-food systems
Inclusion of articles in the systematic review	35	--

In total, 403 documents were excluded following the screening of titles and abstracts as well as, when needed, the scrutiny of full-texts, as they weren't eligible. Out of these, 113 documents were excluded following the screening of records based on titles. For instance, documents dealing with animals/livestock, birds, insects/arthropods, fish and amphibians were excluded. In addition, 226 documents were discarded following the analysis of abstracts. For instance, since the paper focuses on crop NUS, documents dealing with forest and forestry were excluded. Furthermore, articles dealing with the genetics and genomics of NUS, without any reference to transition, were discarded. Likewise, documents dealing with major commercial crops were considered ineligible. Further 64 documents were excluded following the analysis of articles as they do not meet at least one of the eligibility criteria. Therefore, 35 articles (Table 2) were considered in the systematic review and underwent analyses.

Table 2. Selected articles.

Year	Articles number	References
2022	4	Aditika et al. [21]; Andreotti et al. [22]; Khoury et al. [23]; Masao et al. [24]
2021	5	Amelework et al. [25]; Matthews and Ghanem [26]; McMullin et al. [27]; Meinhold and Darr [28]; Neupane and Poudel [29]
2020	4	Darr et al. [30]; Kodahl [31]; Mbosso et al. [32]; Sharma and Chen [33]
2019	3	Bachewe et al. [34]; Hunter et al. [35]; Lambein et al. [36]
2018	2	Jha et al. [37]; Padulosi et al. [38]
2017	3	Cheng et al. [39]; Mabhaudhi et al. [18]; Notaro et al. [40]
2015	2	Alemayehu et al. [41]; Nyadanu and Lowor [42]
2014	2	Galluzzi and Noriega [43]; Hernández [44]
2013	4	Hermann et al. [45]; Marshall et al. [46]; Padulosi et al. [47]; Rudebjer et al. [48]
2011	1	Taylor et al. [49]
2009	3	Hegde [50]; Rojas et al. [51]; Sthapit and Rao [52]
2007	2	Allemann and Swart [53]; Odeny [54]

The analysis of the selected documents was informed by the Multi-Level Perspective on socio-technical transitions (MLP) [55], [56]. The MLP framework suggests that transitions are the result of the interaction of niches, sociotechnical regime and sociotechnical landscape [57]. The socio-technical *regime* refers to the shared cognitive routines, practices and rules that stabilize existing incumbent and dominant systems. *Niches* offer safe and protected spaces apart from the regime rules where innovations can be developed [58]. The socio-technical *landscape* is the exogenous environment that regime and niche actors cannot influence directly. The MLP is particularly interested in the systemic dimensions of transitions that are reflected by the different degrees of structuration of each analytical level [59]. Systemic change is a result of multi-level interactions. When the landscape puts pressure on the regime, windows of opportunity may open for niche innovations to break through, enabling a transition of the incumbent regime [60], [61]. In MLP, niche-innovations build up internal momentum, changes in the sociotechnical landscape create destabilizing pressure on the sociotechnical regime, whose destabilization creates windows of opportunity for radical niche innovations [62], [63]. MLP stresses the importance of the alignment of processes at niche, regime and landscape levels for a transition to happen and be successful [63].

While the first studies focused on energy and mobility sectors, MLP is nowadays widely used in the analysis of sustainability transitions in agriculture and food systems [4]. In the context of this research, the three elements of MLP are framed as follows:

- Niches: These are neglected and underutilized species (NUS).

- Socio-technical regime: This relates to the incumbent, dominant system of major commercial, staple crops. It includes factors that hinder the integration of NUS along the food chain.

- Socio-technical landscape: It refers to policies and macro-trends that affect both the niche and the socio-technical regime.

The grouping of the proposed actions to mainstream and enhance the integration of NUS into agri-food systems under *levers of change* was informed by the proposal made in the context of the Food Systems Summit organized by the United Nations in New York in September 2021 [64] as well as the conceptualization of the socio-technical system and regime [65]. According to the United Nations [66] "*A lever of change can be understood as an area of work that has the potential to deliver wide-ranging positive change beyond its immediate focus*". Therefore, a 'lever of change' is an area of work and action to bring about the desired change. With regards to the Food Systems Summit, four levers of change have been identified: human rights, innovation, finance, and gender equality and women's empowerment [66]. Niche NUS must compete with crops that benefit from well-developed systems around them. According to Geels [65], the alignment of existing technologies, regulations, infrastructures, user patterns and cultural discourses results in socio-technical systems. Since transition is conceived as a change from one regime to another, mainstreaming of niche NUS implies that they acquire the level of structuration of the regime in order to compete with major crops and, eventually, substitute them. For that, it is necessary to act on the different constituting elements of the sociotechnical regime (cf. markets and user preferences, industry, policy, technology, culture, science) to bring about such a transition that transforms a niche NUS into a main, commercial crop. By combining insights from both sources [65], [66], and taking into consideration the peculiarities of agri-food systems (cf. removing 'industry', adding 'practices' to "technology'), the following levers of change have been identified: policy, finance and market, technology and practices, culture, science and innovation.

As with any systematic review, this study has some *limitations*. The results are affected by the search process. First, the choice of the Web of Science database means that only quality scholarly literature, i.e. peer-reviewed articles published in journals with impact factor or tracked for impact factor, 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 the Web of Science were not considered. The results are also affected by the choice of search terms. This systematic review is no exception in this regard, although different synonyms of NUS were used in order to widen the initial screening basis. Furthermore, the categorization of NUS is subjective and far from being unanimous as it is also, to a certain extent, context-specific. Likewise, there is no common, unanimous understanding of 'transition' and 'transformation' in agri-food systems and this might imply some degree of bias as the selection of eligible articles is affected by the background of the involved researchers.

III.RESULTS AND DISCUSSION

The analysis of the selected literature suggests that the geographical coverage of the studies ranges from global to local through regional and national levels (Table 3). Many studies deal with developing regions and countries in Africa (e.g. Ethiopia, Ghana, Kenya, Malawi, Mali, South Africa, Tanzania), Asia (e.g. India, Nepal, Sri Lanka) and Latin America (e.g. Bolivia, Peru). While many studies address NUS in general, others deal with specific botanical families/groups (e.g. cereals/grains, legumes, vegetables, fruits, roots/tubers, leafy vegetables, medicinal and aromatic plants, nuts) or, even species (e.g. amaranth, Bambara groundnut, baobab, canihua, cassava, fonio, grass pea, minor millet, pigeon pea, quinoa, sacha inchi, taro, teff, yam).

Table 3. Overview of documents analyzed: countries/regions and NUS.

Document	Country/region	NUS
Masao et al. [24]	Tanzania	Various NUS
Aditika et al. [21]	Global	Taro (*Colocasia esculenta*)
Andreotti et al. [22]	Global (Andes, Ethiopia, India)	Quinoa, teff and minor millet
Khoury et al. [23]	Global	Various NUS
Amelework et al. [25]	South Africa	Cassava
Matthews and Ghanem [26]	Global	Taro
McMullin et al. [27]	Africa	Various NUS
Neupane and Poudel [29]	Nepal	Various NUS
Meinhold and Darr [28]	Kenya	Baobab (*Adansonia digitata* L.)
Darr et al. [30]	Malawi	Baobab
Mbosso et al. [32]	Mali	Fonio and Bambara groundnut
Kodahl [31]	Latin America (Amazon)	Sacha inchi (*Plukenetia volubilis* L.)
Sharma and Chen [33]	India	Medicinal and aromatic plants
Bachewe et al. [34]	Ethiopia	Teff
Hunter et al. [35]	Global (Brazil, Kenya, Sri Lanka and Turkey)	Various NUS
Lambein et al. [36]	Global	Grass pea (*Lathyrus sativus* L.)
Jha et al. [37]	India	Various NUS
Padulosi et al. [38]	Global (Latin America and Southeast Asia)	Various fruit, vegetable and nut NUS
Mabhaudhi et al. [18]	South Africa	Various NUS (cereals, legumes, roots/tubers and leafy vegetables)

Document	Country/region	NUS
Cheng et al. [39]	Ethiopia	Teff
Notaro et al. [40]	India	Small millet
Alemayehu et al. [41]	East Africa	Amaranth (*Amaranthus* spp.)
Nyadanu and Lowor [42]	Ghana	Leafy vegetables and fruits
Galluzzi and Noriega [43]	Americas	Various NUS
Hernández [44]	American tropics	Various NUS (quinoa, amaranth, cassava and yams)
Marshall et al. [46]	Global	Oats
Hermann et al. [45]	Global	Various NUS
Padulosi et al. [47]	Global	Various NUS
Rudebjer et al. [48]	Sub-Saharan Africa	Various NUS
Taylor et al. [49]	Pacific	Various NUS
Hegde [50]	India	Various NUS
Rojas et al. [51]	Bolivia and Peru	Andean grains [quinoa (*Chenopodium quinoa* Willd.), canihua (*C. pallidicaule* Aellen) and amaranth (*Amaranthus caudatus* L.)]
Sthapit and Rao [52]	Nepal	Various NUS
Odeny [54]	Africa	Pigeon pea (*Cajanus cajan* (L.) Millsp.)
Allemann and Swart [53]	South Africa	Various NUS

The review of the literature shows that there is no single document that analyses the development of niche NUS using the multi-level perspective (MLP). However, the selected documents provide insights into the dynamics of transition (Table 4). The dynamics as well as the success of transition depend not only on the features of the niche NUS, sociotechnical regime and sociotechnical landscape but also on the interactions and relationships among the three elements.

Different features of the *niche* NUS determine not only their potential but also whether they can stand the rules of the dominant system (cf. socio-technical system) and compete with the major commercial crops. These relate to the intrinsic strengths and weaknesses of NUS. The strengths of NUS include adaptability to grow in harsh and difficult environmental and climatic conditions as well as marginal, poor and nutrient-depleted soils/lands. Furthermore, many NUS seem adapted to cultivation systems with low inputs (cf. fertilizers, agrochemicals) as they are tolerant to biotic (cf. pests and diseases) and abiotic/environmental (e.g. drought) stresses. Other strengths of NUS are their outstanding nutritional properties and benefits. Indeed, many NUS have high nutrient density and high contents of proteins as well as health-enhancing and health-protecting compounds. Bottlenecks to the use of NUS include planting material availability, market availability, and knowledge about the crop and its uses [27]. The weaknesses of NUS relate, among others, to low yield and productivity, especially when compared to modern, commercial varieties. Another constraint regards difficult access to and availability of quality seeds and propagation materials. Difficult access to information is another problem faced by producers and value chain actors. Moreover, there is a lack of adequate technologies, which determines difficulties in processing. Only a few products from NUS are available on the market and their quality does not always meet the expectations of consumers.

The characteristics of the sociotechnical *regime* that affect the enhancement and mainstreaming of niche NUS regard the constraints that it creates, which hinder the development of NUS, as well as the competitiveness of the major commercial crops, which are already adapted to the regime context. The current agricultural knowledge and innovation system (AKIS), including research and development, is unfavorable for NUS. For instance, Mabhaudhi et al. [18] point out the limited and often incoherent research available to support NUS (cf. lack of clear research goals, limited funding directed at NUS and journal apathy toward publishing work on NUS). These factors, in turn, determine a lack of interest from emerging and established researchers. Hunter et al. [35] suggest that the key barriers to the integration of NUS into agri-food systems relate to limited and fragmented data on NUS, low recognition of NUS values, limited capacity on NUS and disabling agriculture and food policies. Matthews and

Ghanem [26] argue that different perception gaps hinder the development of NUS and their mainstreaming. They put that "*Perception gaps exist because of many factors: dogma, linguistic diversity, social biases, under-research, limited physical visibility of living wild populations, poor archaeological visibility, missing production numbers and inaccurate distribution maps"* (p. 99). The example of teff in Ethiopia [34] shows that while NUS have generally low yields compared to other major crops, the production and productivity are rapidly increasing - due, among others, to the contributions of modern input use and agricultural extension - while value chains and markets are improving over time, which can make them not only more appealing for producers and other value chains actors but also more competitive towards commercial crops [34]. This, in turn, may favor their enhancement and mainstreaming in the local food systems and diets.

The elements of the sociotechnical *landscape* relevant to the transition of NUS relate to macro-level societal, economic, cultural and environmental trends and processes that put pressures on the current agri-food system, and consequently major commercial crops, thus creating, eventually, windows of opportunities for the niche NUS. It is clear that challenges and problems faced by the current agri-food system (e.g. climate change, biodiversity loss, natural resources depletion/degradation, food insecurity and malnutrition) shows that it is not fit-for-purpose and makes the case for its transformation by fostering a transition towards more resilient and sustainable food systems. To this should be added a wider awareness of the limits of the Green Revolution. This critique of the dominant agri-food system touches upon its constituting elements such as major commercial and staple crops. This, in turn, creates opportunities for the promotion of NUS. Indeed, NUS are put forward not only as a means to contribute to food and nutrition security, especially in developing countries, but also to adapt to climate change and improve the livelihoods of rural communities. Referring to Andean grains, Rojas et al. [51] show the far-reaching impacts and implications of the abandonment of NUS and argue that "*the reduced use of Andean grains has been accompanied by the loss of their genetic diversity with important, albeit less obvious, repercussions for the livelihoods of Andean communities in terms of reduced sustainability and resilience of local agricultural systems, wasted opportunities for improving food and nutrition security, impoverishment of local cultures resulting in reduced self esteem and identity of people*" (p. 87). On the other hand, NUS are considered one of the tools to address the identified challenges. Indeed, there is a wider recognition of the role and potential of NUS in climate resilience and adaptation, biodiversity conservation, food and nutrition security and rural livelihoods. Moreover, there is an ongoing positive change in socio-cultural preferences and perceptions about NUS that favor their use and consumption. Indeed, there is a growing demand for NUS as a part of healthier, diversified and more balanced diets. Interestingly, income growth and urbanization seem to have a positive impact on NUS consumption. To this positive trend also contribute the development of NUS processing, which widens the array of products available on the market, as well as the opportunities offered by the internet and ICT for the promotion of NUS and their products. *Policies* are an important component of the socio-technical landscape that should play a central role in the mainstreaming and enhancement of the NUS. In general, many countries adopted more incisive policy interventions in support of sustainable development agendas including actions to conserve and promote biodiversity, protect natural resources and adapt to climate change in agriculture and food systems. Also the international policy and legal frameworks on biodiversity and plant genetic resources contribute to this momentum. However, in their analysis focusing on the Americas, Galluzzi and Noriega [43] point out that "*current international policy and legal instruments have so far provided limited stimulus and funding for the conservation and sustainable use of the genetic resources of these crops*" (p. 980).

Table 4. NUS in the transition towards sustainable agri-food systems: analysis through the lens of the Multi-Level Perspective (MLP).

MLP element	Items	Sources
NUS niches characteristics	Climate resilience and ability to grow under diverse climatic regimes	Amelework et al. [25]; Cheng et al. [39]; Hegde [50]; Matthews and Ghanem [26]; Mbosso et al. [32]; Lambein et al. [36]; Kodahl [31]; Masao et al. [24]; Odeny [54]
	Cultivability on marginal lands and various soil types	Cheng et al. [39] ; Lambein et al. [36]; Kodahl [31]
	Disorganized or non-existent market chains	Rojas et al. [51]
	Drought and heat tolerance	Lambein et al. [36]; Mabhaudhi et al. [18]; Odeny [54]

MLP element	Items	Sources
	Enormous nutritional and pharmaceutical potential as functional food products	Aditika et al. [21]
	Good adaptability to environmental stresses	Alemayehu et al. [41]; Cheng et al. [39]; Odeny [54]; Rojas et al. [51]
	High nutritional value, nutrient-richness and optimal nutritional profile	Alemayehu et al. [41]; Cheng et al. [39]; Darr et al. [30]; Hunter et al. [35]; Kodahl [31]; Mabhaudhi et al. [18]; Matthews and Ghanem [26]; Mbosso et al. [32]; Meinhold and Darr [28]; Nyadanu and Lowor [42]; Odeny [54]; Rojas et al. [51]
	Rich associated food culture and traditions	Rojas et al. [51]
	Sources superfoods and health-promoting nutraceuticals	Lambein et al. [36]; Neupane and Poudel [29]
	Vast geographical range	Matthews and Ghanem [26]
	Versatility in use	Darr et al. [30]; Rojas et al. [51]
	Fragile or non-existent seed supply systems and lack of improved varieties	Rojas et al. [51]
	Low quality of commercialized products	Mbosso et al. [32]
	Low input crops	Marshall et al. [46]
	Low yield	Bachewe et al. [34]
Regime factors hindering the development and mainstreaming of NUS	Research and development systems marginalizing NUS	Amelework et al. [25]; Bachewe et al. [34]; Cheng et al. [39]; Galluzzi and Noriega [43]; Hermann et al. [45]; Jha et al. [37]; Kodahl [31]; Mabhaudhi et al. [18]; Masao et al. [24]; Matthews and Ghanem [26]; Rojas et al. [51]
	Barriers to cultivation, and marketing, processing and consumption in the dominant agri-food system	Amelework et al. [25]; Andreotti et al. [22]; Galluzzi and Noriega [43]; Matthews and Ghanem [26]; Mbosso et al. [32]; Nyadanu and Lowor [42]; Sharma and Chen [33]
	Changes in lifestyles, erosion of traditional dietary habits and standardization of local food culture	Hermann et al. [45]; Padulosi et al. [47]
	Competition from major, commercial crops	Hermann et al. [45]; Marshall et al. [46]; Rojas et al. [51]
	Negative perceptions and stigmas about NUS	Taylor et al. [49]; Matthews and Ghanem [26]; Rojas et al. [51]; Padulosi et al. [47]; Lambein et al. [36]
	Trade regimes increasing reliance on imported food products	Taylor et al. [49]
	Replacement of local and traditional NUS by exotic crops and modern varieties	Khoury et al. [23]

MLP element	Items	Sources
	Difficult access to inputs and equipment	Mbosso et al. [32]
	Lack of efforts geared towards NUS sustainable utilization and conservation	Masao et al. [24]
	Official education, training and extension systems unfavorable to NUS	Hunter et al. [35]; Mabhaudhi et al. [18]; Mbosso et al. [32]
	Lack of information, documentation and knowledge on NUS	Galluzzi and Noriega [43]; Hunter et al. [35]; Kodahl [31]; Taylor et al. [49]
	Lack of plant breeding efforts and commercial varieties of NUS	Galluzzi and Noriega [43]; Masao et al. [24]; Matthews and Ghanem [26]; Rojas et al. [51]
Landscape factors putting pressure on the regime	Loss of biodiversity/agro-biodiversity	Cheng et al. [39]; Khoury et al. [23]; Padulosi et al. [47]; Sthapit and Rao [52]
	Climate change and variability	Alemayehu et al. [41]; Amelework et al. [25]; Cheng et al. [39]; Galluzzi and Noriega [43]; Kodahl [31]; Lambein et al. [36]; Masao et al. [24]; Matthews and Ghanem [26]; Mbosso et al. [32]; Padulosi et al. [47]; Rudebjer et al. [48]; Taylor et al. [49]
	Food insecurity and malnutrition	Alemayehu et al. [41]; Allemann and Swart [53]; Cheng et al. [39]; Galluzzi and Noriega [43]; Kodahl [31]; Rudebjer et al. [48]; Sthapit and Rao [52]; Taylor et al. [49]
	Critique to reliance on few staple crops (rice, maize, wheat) for human nutrition	Hunter et al. [35]
	Resources degradation, depletion and scarcity	Kodahl [31]; Matthews and Ghanem [26]
	Population growth and increasing food demand	Matthews and Ghanem [26]
	Critique to the legacy of the Green Revolution such as declining biodiversity and stagnant rural income	Jha et al. [37]
Landscape factors creating opportunities for niche NUS	Adoption of more incisive interventions in support of sustainable development agendas	Mbosso et al. [32]
	Awareness of the limits of the Green Revolution	Rojas et al. [51]
	Changing consumer demands in favor of healthier, diverse and more balanced diets	Alemayehu et al. [41]; Andreotti et al. [22]; Hernández [44] Cheng et al. [39]; Darr et al. [30]; Hunter et al. [35] Marshall et al. [46]; Matthews and Ghanem [26]
	Changing socio-cultural preferences and perceptions about NUS	Aditika et al. [21]; Marshall et al. [46]; Masao et al. [24]; Meinhold and Darr [28]

MLP element	Items	Sources
	Recognition of NUS potential to contribute to rural livelihoods, especially for smallholders	Andreotti et al. [22]; Darr et al. [30]; Kodahl [31]
	NUS considered as a tool to foster climate resilience	Masao et al. [24]
	Growing demand for NUS	Matthews and Ghanem [26]; Andreotti et al. [22]
	Growing interest in agricultural diversification	Bachewe et al. [34]; Notaro et al. [40]; Padulosi et al. [38]; Rudebjer et al. [48]
	International policy and legal frameworks on biodiversity and plant genetic resources	Galluzzi and Noriega [43]
	Internet opportunities for the promotion of NUS	Hermann et al. [45]
	More attention to biodiversity and natural resources conservation	Hernández [44]; Masao et al. [24]; Notaro et al. [40]; Padulosi et al. [38]
	Positive impact of income growth and urbanization on NUS consumption	Bachewe et al. [34]
	Projected growth in global food demand	Alemayehu et al. [41]; Matthews and Ghanem [26]; Sharma and Chen [33]; Notaro et al. [40]
	Significant industrial opportunities for NUS	Amelework et al. [25]

The *recommendations* provided by scholars for the development of NUS relate to one or more levers of change (viz. policy, finance and market, technology and practices, culture, science and innovation) (Table 5). The lack of research, innovation and development on NUS is identified as one of the main barriers to their development and enhancement. Indeed, Hermann et al. [45] suggest that "*the much-needed enhancement of NUS knowledge management should be at the centre of collective efforts of the NUS community*" (p. 65) both to underpin future research advances as well as inform advocacy of policies. Therefore, it comes as no surprise that one of the most recurring recommendations is the development of a research program on NUS, substantiating NUS attributes relevant, inter alia, to consumers, nutrition and climate change. For example, Hunter et al. [35] posit that "*Two key strategic actions that any country can take to promote the greater utilization of NUS to address healthy diets and improved nutrition are: (i) establish effective research partnerships that undertake nutritional composition work to strengthen a key part of the knowledge base. (ii) set up multi-sectoral platforms or target already existing platforms that are in a position to use this new knowledge to better mainstream NUS into relevant national nutrition and food security policies, strategies and actions*." (p. 719). The analyzed documents also provide some features of such research programs that should be inclusive and based on participatory approaches to allow the largest involvement of the concerned actors and stakeholders (e.g. decision makers/planners, government agencies, national ministries, producers, academics/researchers, entrepreneurs, consumers, civil society). Research on NUS has also some peculiarities that call for transforming agronomic research itself. For instance, Rudebjer et al. [48], referring to Sub-Saharan Africa, underline that "*Traditional agriculture research tends to be specialised and compartmentalised, whereas NUS research requires a multi-sector approach involving disciplines and stakeholders along the value chain from farm to fork*" (p. 577).

However, the literature also shows that the development of research while representing a prerequisite for the promotion and enhancement of the NUS is not enough. In fact, there is a need for further complementary actions such as the development of the value chains of NUS. Referring to the context of South Africa, Mabhaudhi et al. [18] suggest a roadmap that includes different actions to promote NUS. They consider the development of human capital/capacity, market and policy fundamental in any undertaking for the enhancement of NUS and put "*It is recommended that the available limited resources should be targeted on improving these priority NUS as they offer the best prospects for success. Focus should be on developing value chains for the priority NUS. This should be underpinned by science to provide evidence-based outcomes. This would assist to attract more funding for NUS research, development and innovation in South Africa*". Hermann et al. [45] argue that the NUS promotional rhetoric, preaching to convert the discrimination of the 'food of the poor' and the loss of traditional dietary habits are unlikely to address the neglect of the vast majority of NUS, unless supply and demand constraints affecting NUS production and consumption are overcome. Therefore, any strategy for the development of NUS should combine different elements. For instance, the regional strategy on "Crops for the future" in the Pacific contains elements relating to the generation and collection of knowledge/research, communication and dissemination, policy advocacy, market development, partnerships, capacity building and institutional strengthening [49]. Likewise, Padulosi et al. [47] introduce a framework for the enhancement of NUS that encompasses the conservation of NUS and associated indigenous knowledge, participatory selection of cultivars and production of quality seed, development of enhanced cultivation practices and value addition technologies, assessment of nutritional content and role, marketing, strengthening value chains and popularization of NUS, and capacity building and self-sustainability. Such strategies should also cover all stages of the value chain. For instance, referring to the example of cassava in South Africa, Amelework et al. [25] enumerate among the actions needed for its promotion, the following ones: training farmers and producers, creating awareness to promote the crop, developing suitable business model, creating market and diversifying products, and investing in processing and product development enterprises. Enabling policies have an important role to play in the mainstreaming and enhancement of the NUS. However, Notaro et al. [40] highlight that "*Despite the important role of Neglected and Underutilized Species (NUS) in diversifying agriculture, supporting traditional farming systems and improving food and nutritional security particularly in marginal lands, very little attention is being paid to their mainstreaming in national policies and institutions*" (p. 393).

Table 5. Recommendations to mainstream NUS in agri-food systems.

Levers of change	Recommended actions	Sources
Culture	Training farmers, producers and value chain actors	Amelework et al. [25]
Culture Finance and market Policy Science and innovation	Promoting coordination among stakeholders in the value chain and adopting multi-stakeholder, multi-disciplinary and participatory approaches in pursuing the use-enhancement of NUS	Hunter et al. [35]; McMullin et al. [27]; Padulosi et al. [47]; Sharma and Chen [33]
Culture Finance and market Policy Science and innovation Technology and practices	Lessening the supply and demand constraints that affect the production and consumption of NUS	Hermann et al. [45]
Culture Policy	Linking NUS to school meals/feeding programs, public food procurement, dietary guidelines and sustainable gastronomy	Hunter et al. [35]; Padulosi et al. [47]
	Recognizing and supporting the central role of women in deploying NUS diversity in everyday life	Padulosi et al. [38]; Padulosi et al. [47]
	Empowering farmers and community institutions to improve farmers' access to a wide range of NUS	Sthapit and Rao [52]
Culture Science and innovation	Increasing the knowledge, appreciation and awareness about NUS	Amelework et al. [25]; Hegde [50]; Hermann et al. [45]; Hunter et al. [35]; Meinhold and Darr [28]

Levers of change	Recommended actions	Sources
	Strengthening capacities of young scientists and agriculturalists for enhancing their knowledge and know-how on NUS	Padulosi et al. [38]; Rudebjer et al. [48]
	Empowering farmers and community institutions by actively engaging them in research for development activities while creating space for social learning and innovation	Sthapit and Rao [52]; Padulosi et al. [38]
	Making greater use of internet knowledge repositories to deposit and share research results and knowledge on NUS	Hermann et al. [45]
Finance and market	Developing suitable business models and value chains for priority NUS	Amelework et al. [25]; Hegde [50]; Mabhaudhi et al. [18]
	Creating local/domestic markets and improving the marketing of NUS and their products	Amelework et al. [25]; Cheng et al. [39]; Darr et al. [30]; Meinhold and Darr [28]
	Investing in processing and product development enterprises	Amelework et al. [25]
Finance and market Policy	Commercialization of NUS should be considered as a dietary intervention strategy for addressing malnutrition and hidden hunger in poor communities	Aditika et al. [21]
	Strengthening NUS seed systems and paying greater attention to in-situ conservation of NUS at the farm (cf. community-based participatory monitoring, custodian farmers' networks, crop diversity fairs)	Cheng et al. [39]; Padulosi et al. [47]
Finance and market Policy Science and innovation	Creating technological platforms that combine with innovation to support the development and improvement of NUS value chains	Hernández [44]
Finance and market Science and innovation	Promoting investments in human and institutional capacity for research, marketing and knowledge sharing on NUS	Hermann et al. [45]; Rudebjer et al. [48]
Finance and market Technology and practices	Promoting NUS through improved packaging and marketing	Masao et al. [24]
Policy	Creating a more supportive policy environment for NUS in agriculture, food and trade fields	Hermann et al. [45]; McMullin et al. [27]; Notaro et al. [40]
Policy Science and innovation	Improving the connection of science and policy on NUS	Hunter et al. [35]
	Reviewing current plant breeding programs in developing countries in terms of relevance and efficiency to optimize benefits for poor farmers through the use of underutilized diversity	Sthapit and Rao [52]
Science and innovation	Screening diverse genotypes for bioactive compounds to aid breeding efforts directed at biofortification	Aditika et al. [21]
	Importing, characterizing and breeding high potential germplasm for local conditions to ensure its sustainable primary production	Amelework et al. [25]

Levers of change	Recommended actions	Sources
	Establishing effective research and development programs and partnerships on NUS including all potential participants such as governments, academics, entrepreneurs and producers to promote NUS	Hunter et al. [35]; Kodahl [31]; McMullin et al. [27]; Neupane and Poudel [29]
	Promoting targeted breeding programs on NUS for the development of varieties relevant for yield, nutritional qualities, and tolerance to biotic and abiotic stresses	Mabhaudhi et al. [18]; Lambein et al. [36]; Kodahl [31]
	Using aggressive breeding programs through advanced biotechnological tools such as tissue culture, micropropagation, genomics and bioinformatics	Jha et al. [37]
	Introducing new varieties with tailored agronomic approaches to ensure sustainability	Marshall et al. [46]
	Adopting a new R&D paradigm for NUS directed toward cultural-sensitive objectives and not solely toward economic benefits	Padulosi et al. [47]
	Promoting 'grassroots breeding' to strengthen the capacity of farmers and institutions to assess existing diversity, select locally adapted materials, produce sufficient quality seeds, and integrate them into farmers' seed systems	Sthapit and Rao [52]

IV.CONCLUSIONS

The present systematic review uses the Multi-Level Perspective (MLP) to shed light on the role of NUS in the transition towards sustainable and resilient agri-food systems, and identifies recommended actions and levers of change to bring about such a transition.

The review suggests that the dynamics, as well as the success of the transition, depend not only on the features of the niche NUS, sociotechnical regime and sociotechnical landscape but also on the interactions and relationships among the three elements. Different features of the niche NUS determine not only their potential but also whether they can stand the rules of the dominant system (cf. socio-technical system) and compete with the major commercial crops. These relate to the intrinsic strengths and weaknesses of NUS. The characteristics of the sociotechnical regime that affect the enhancement and mainstreaming of niche NUS regard the constraints that it creates, which hinder the development of NUS, as well as the competitiveness of the major commercial crops, which are already adapted to the regime context. The elements of the sociotechnical landscape relevant to the transition of NUS relate to macro-level societal, economic, cultural and environmental trends and processes that put pressures on the current agri-food system, and consequently major commercial crops, thus creating, eventually, windows of opportunities for the niche NUS. Policies are an important component of the socio-technical landscape that should play a central role in the mainstreaming and enhancement of the NUS.

In general, there is a wide consensus among scholars on the need to transform food systems and the central role that can be played by NUS in such a transition towards more sustainable and resilient food systems. However, solutions differ. While some scholars promote environmentally-benign and agroecology-inspired approaches, others support more 'controversial' ones such as biotechnologies. This is particularly seen when referring to breeding, which is a central element in the journey of NUS from neglect and underutilization to the mainstream of the food system and diet. Indeed, some scholars call for more grassroots and participatory breeding programs, whereas others are supportive of 'aggressive' ones that rely on biotechnological advances.

The lack of research, innovation and development on NUS is identified as one of the main barriers to their development and enhancement. Therefore, it comes as no surprise that one of the most recurring recommendations is the development of a research program on NUS, substantiating NUS attributes relevant, inter alia, to consumers, nutrition and climate change. However, the literature also shows that the development of research while representing a prerequisite for the promotion and enhancement of NUS is not enough. Indeed, there is a need for further complementary actions such as the development of the value chains of NUS. To be successful, any strategy for the development of NUS should combine different elements such as research and knowledge generation, communication and dissemination, market development, policy advocacy, partnerships, capacity building and institutional strengthening. Indeed, the levers of change lie in the areas of policy, finance and market, technology and practices, culture, science and innovation.

Further research is needed to elucidate the mechanisms leading to the mainstreaming of orphan crops and their integration into food systems and diets as well as the dynamics of interaction between niche NUS and commercial, staple crops in the regime domain. In a few words, there is a need for an articulated research program on the role and potential contribution of NUS to sustainability transitions in agri-food systems, especially in developing countries.

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