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Review

More than Yield: Ecosystem Services of Traditional versus Modern Crop Varieties Revisited

Anoush Ficiciyan [1,*], Jacqueline Loos [1,2], Stefanie Sievers-Glotzbach [3] and Teja Tscharntke [1]

[1] Agroecology, Department of Crop Sciences, University of Goettingen, Grisebachstr. 6, 37077 Göttingen, Germany; jacqueline.loos@agr.uni-goettingen.de (J.L.); ttschar@gwdg.de (T.T.)
[2] Institute of Ecology, Faculty of Sustainability Science, Leuphana University, Universitätsallee 1, 21335 Lüneburg, Germany
[3] Department of Business Administration, Economics and Law, Carl-Von-Ossietzky-University, 26111 Oldenburg, Germany; stefanie.sievers-glotzbach@uni-oldenburg.de
* Correspondence: anoush.ficiciyan@uni-goettingen.de; Tel.: +40-0551-3922111

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Abstract: Agricultural intensification with modern plant breeding focuses on few high-yielding crops and varieties. The loss of traditional crop species and variety diversity contributes to the current decline of provisioning, regulating, and cultural ecosystem services, as reported in the Millennium Ecosystem Assessment. Access to local and adapted varieties is pivotal for resilient agroecosystems, in particular under current global change. We reviewed the scientific literature to understand the role of different crop varieties for ecosystem services, comparing the performance and perception of traditional landraces versus modern varieties and ask the following questions: 1. Do landraces and modern varieties differ in terms of provisioning and regulating ecosystem services? 2. When and why do farmers prefer cultural ecosystem services of landraces over high-yielding varieties? Based on 41 publications, our results document that modern varieties are preferred over landraces because of their typically higher provisioning services such as crop yield. However, landraces often guarantee higher provisioning services under non-optimal farming conditions. Landraces can show high resilience under harsh environmental conditions and are a trusted source achieving stable crop yield (e.g., under droughts stress). Regulating services such as resistance against pests and diseases appear to often become lost during breeding for high-yielding, modern varieties. Furthermore, small-scale farmers typically prefer local landraces due to regional cultural features such as family traditions and cooking characteristics for special dishes. In conclusion, both landraces and modern varieties have merit depending on the farmers' priorities and the social-ecological context. In any case, maintaining and restoring the huge diversity of landrace varieties is necessary for sustaining current and future needs.

Keywords: agrobiodiversity; ecosystem services; food sovereignty; seed commons; variety diversity; protection laws; landraces

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1. Introduction

Despite the success of agricultural intensification and the green revolution toward mitigating global hunger [1,2], the FAO (2017) reports 767 million people remaining in an insecure nutritional situation [3]. With approximately one third of the planet's population earning less than $2 a day [4,5], hunger is inevitably caused by poverty as a result of unequal resource distribution [6,7]. At the same time, global agrobiodiversity continuously decreases due to the loss of diversity in species and varieties of food crops [8,9]. Since the start of modern plant breeding (cross-breeding, F1-hybrid breeding, in vitro breeding, gene technology, smart breeding, and genomics), breeding efforts focus on the development of a few economically important plant species like maize, rapeseed, soy, and rice [9,10]. The intensive spread and wide use of improved, modern varieties has led to a genetic bottleneck, resulting in the loss of crop, variety and allele diversity [11,12]. For example, 75% of the genetic diversity of farmers' crops has been lost since the 1900s in favor of genetically uniform, high-yielding varieties, and only 150–200 out of the 300,000 known edible plant species are used by humans [13]. This concentration on few crops and varieties is promoted by the privatization of seed material and usage restrictions by patents and variety protection laws [14,15]. However, high-yielding crop varieties may cause crop failure under sub-optimal cultivation conditions on marginal locations, thereby increase hunger and downgrade sovereign food production in countries of the global South [16–18]. Further, this development contributes to the proceeding decline of ecosystem services as reported in the MEA (2005) [19]. Hence, provisioning, regulating, and cultural ecosystem services in agricultural systems/farming evolved from a diversity of food crops and varieties that are highly endangered. Within this context, a wide range of species and varieties represents an important component of agrobiodiversity [20], and access to locally adapted varieties is pivotal for resilient agroecosystems [21,22]. Farming systems using agroecological practices focus on resilient agricultural practices that also consider the socio-economic background of farmers and their families [23]. Such an approach often includes high functional biodiversity, farming techniques rooted in traditional knowledge systems, and locally adapted landraces, aiming at a sovereign food production and providing the ecosystem services that are essential for human well-being [24,25].

In this review we compare the performance and the farmers' perception of improved, modern varieties versus traditional and locally adapted landraces, and synthesize their agronomic, ecological and social role for agroecosystems, i.e., provisioning, regulating and cultural services. Improved modern varieties are bred for high yield levels in high-input environments and are often genetically homogeneous [26]. In contrast, landraces are "dynamic population(s) of a cultivated plant that has historical origin, distinct identity and lacks formal crop improvement, as well as often being genetically diverse, locally adapted and associated with traditional farming systems" [27]. Thus, landraces aim to provide genetic resources and plant traits that are well adapted to local environmental and cultural conditions. Landraces have been maintained and selected over time by farmers to meet their personal economic, ecological and cultural needs and cultivated in small-scale farming systems with low input of external factors and high surrounding diversity [28]. Genetic heterogeneity vs. homogeneity influences the performance of a variety and the degree of diversity within the cultivation systems [29]. By comparing modern varieties with traditional landraces, we aim to identify the role of plant genetic diversity for resilient food production systems, providing for food security, and the role of freedom of variety choice, providing for food sovereignty. To our knowledge, this topic has not yet been studied in a systematic review.

To collate scientific evidence on the services of modern varieties versus landraces for agroecosystems and the entire food system, we raise the following questions:

(1) Do landraces and modern varieties differ in terms of provisioning and regulating ecosystem services?
(2) When and why do farmers prefer cultural ecosystem services of landraces over high-yielding, modern varieties?

2. Materials and Methods

We reviewed academic publications from 1945 to 2017 using the Web of Science database, which includes peer-reviewed international journals in agricultural and social disciplines. Our search string included the following terms: "landrace, participatory plant breeding, farmer participatory breeding, collaborative plant breeding, participatory variet* selection, participatory crop improvement, community based seed*, client-oriented breeding, seed variety, commons based seed*, open source seed*", AND "soil quality, pollination, fertilization, yield, product*, harvest, divers*, variet*, variation*, pesticides, agrobiodiversity, agrodiversity, nitrogen, nutrient*, trait*, resistance, ecosystem, ecosystem service*”. We excluded the terms: “pig” or “piglet” because the term “landrace” is also used in animal breeding and searched in title, keywords, and abstract, only including scientific publications from the following fields: Agronomy, plant science, horticulture, genetics heredity, agriculture multidisciplinary, multidisciplinary science, evolutionary biology, ecology, soil science, environmental science, reproductive biology, environmental studies, forestry, biology, green sustainable science technology, entomology, sociology, biodiversity conservation, zoology, parasitology, social science interdisciplinary, and ethics. After title and abstract scanning of 344 papers and completely reading of 113 papers, we evaluated 41 full texts as eligible, because these texts compare the agronomic, ecological, and/or cultural characteristics of landraces against modern varieties (for detailed information see Supplementary Materials: Table S1 List of included 41 publications comparing landraces against other variety types). The group of modern crop varieties captures all commercial varieties that have been greatly improved towards high yields though advanced plant breeding techniques. These techniques include traditional on field selection methods, use of inbred-lines creating F1-hybrids, laboratory techniques at the tissue or cell level, and techniques at DNA level. The group of modern varieties includes cultivars, improved cultivars, modern cultivars, local cultivars, improved varieties, modern varieties, commercial varieties, research breed lines, and F1-hybrids.

Provisioning ecosystem services refer in our case to the performance and productivity of a variety. In addition to crop yield (n = 26), we also refer to the crop nutrient use efficiency (n = 6) and the cultivation effort and the storability of harvested crops (n = 4). The regulating ecosystem services refer in our case to the interaction of a crop variety with its biotic and abiotic environment. We focus on the resilience to environmental changes (n = 24) and also to biological pest and disease control (n = 10), biodiversity richness (n = 1), and crop pollination (n = 1). We finally refer to tradition, cooking characteristics, nutritional values, taste, and color (n = 5) as measurable performances for cultural ecosystem services. Landraces can exhibit a positive, negative or unclear (i.e., varying or absent) performance in comparison with modern varieties (see Table 1). We are aware that there are more subcategories for every group of ecosystem services. In our review we present a selection composed out of ecosystem services mentioned in the included publications.

Table 1. Detailed performance classification, showing the effect of selecting landrace varieties over modern varieties. More precise context of the findings is given in the results section.

Ecosystem Services	Measured Performance	Total No. of Publications	Positive Effect	Negative Effect	Unclear Effect	Most Important Findings
Provisioning services	Crop yield	26	9	8	9	- Landraces yield equally or higher under harsh local conditions [30–32] - Modern varieties exhibit higher yield, but costs for fertilizers and pesticides may be also high, even counterbalancing the benefit from higher yields [32] - Modern varieties typically outyield landraces under optimal conditions [33]
	Crop nutrient use efficiency	6	3	1	2	- Landraces tend to deliver more stable yields under limited environments [34,35] - But modern breeding can improve the water use efficiency [36]
	Cultivation effort and crop storability	4	2	1	1	- Higher storability of landraces, and lower levels of storage losses to insects using landraces [37,38]
Regulating services	Resilience to environmental changes	24	22	1	1	- Landraces are often better adapted to drought stress [39–41] - Landrace varieties may be more pest resistant [17] - Landraces are better adapted to local climate conditions [17,42]
	Biological pest & disease control	10	6	2	2	- Landraces maintain high levels of resistance against pest and disease [43–45]
	Crop pollination	1	1	0	0	Small sized vineyards based on the use of local landraces maintain complex ecological infrastructures, i.e., treed riparian strips, as well as forest remnants, natural edges, out of forest trees, which positively influence pollinator's presence [46]
	Biodiversity richness	1	1	0	0	To maintain landscape complexity, and therefore biodiversity richness, accounts also the viticulture that is tightly linked to the local grapevine genetic resources. The structure of the vineyards, at the base of a traditional use of the local landraces, reflects the principle of landscape ecology. That maintains landscape complexity, and therefore species and biodiversity richness [46]
Cultural services	Tradition, cooking characteristics, nutritional values, taste, and color	5	5	0	0	- Cooking characteristics are highly important for variety decisions [38,47] - Landraces are passed over generations together with recipes [48]

3. Results and Discussion

In our review, we found a total of 41 publications with results from 28 experiments testing different varieties against each other, 10 surveys among small-scale farmers investigating reasons of variety selection and 3 conceptual papers from 19 different countries. The larger share of publications focuses on countries in developing regions such as Africa, South and Central America, Asia as well as Eastern Europe (n = 13; 68.4%). The remaining countries are mainly located in Europe (n = 5; 26.3%), and just one study in the western USA.

Crop yield and resilience to environmental changes were the two most measured performances when comparing landraces with modern varieties, followed by biological pest and disease control (Table 1). Most publications deal with several types of variety performance. In the following the results will be presented along the three categories of ecosystem services (provisioning, regulating, and cultural).

3.1. Provisioning Services

3.1.1. Crop Yield

Twenty-six studies used crop yield as a response variable comparing landraces against modern varieties: one conceptual paper, seven surveys among farmers, and 18 experimental approaches testing varieties. Among these 26 publications, a positive effect of landraces on crop yield was found nine times, a negative effect eight times, and an unclear effect nine times. Stability of crop yield is a major economic value, in particular under harsh and changing environments and plays a key role for food security [40,49].

(1) Findings from field experiments

Results from the 18 publications on field experiments show that landraces tend to produce fewer yields than modern varieties if environmental conditions are optimal. Lafitte et al. [35] show for example that improved maize varieties had on average 56% higher yields (independent of N-levels). Kante et al. [33] also showed that mean yields for F1-hybrids varieties were 3 to 17% (ranging from 60 to 28 kg/ha) higher across different environmental conditions compared to local landraces.

In contrast, Maggs-Kolling et al. [37] found that the yield of watermelon landraces in Namibia was higher than that of modern varieties. Landrace varieties of water melon produced smaller, less sweet fruits with larger seed, and a thicker rind compared to modern varieties, attributes which are considered positive by local people. Under non-optimal farming conditions, results from field experiments show that landraces tend to yield the same or even higher than modern varieties. These trends are confirmed by Noguera et al. [50] for rice. They found that local landraces are highly adapted to harsh environmental conditions and respond well in biomass to earthworm application. However, they cannot compete with modern varieties in terms of rice grain biomass under optimal conditions. In Burkina Faso, farmers have a strong interest in sorghum landraces due to their ability to produce secure and stable yields in the face of unpredictable climate conditions [31]. Field experiments from semi-arid and arid regions of South Asia and Africa comparing pearl millet landraces against modern varieties also showed that landraces yielded significantly more grain under drought stress than modern varieties [30]. Annicchiarico, P. [39] documents the high provisioning value of lucerne landraces in Italy in comparison to modern varieties in terms of forage yield. Farmers chose landraces for sandy soils in their region due to a lower winter mortality of landraces. Olson et al. [17] tested factors that influence farmers' choices between landraces and modern varieties of maize for small-scale coffee farms in El Salvador. Yields in plots planted with modern varieties were significantly higher than yields in plots planted with landraces. However, landrace varieties were more commonly planted on steep slopes compared to modern varieties, suggesting negative effects of the slope rather than seed type appeared to drive the yield difference. Slope was negatively correlated with yield for both seed types, while other analyses showed that yield between modern varieties and landraces did not differ [17].

(2) Findings from farmer surveys

Farmers' perceptions of yield differences between landraces and modern varieties were also studied. Li et al. [32] and Knezevic-Jaric et al. [51] compared via farmer interviews the yield of landraces with the yield of F1-hybrid varieties and concluded that F1-hybrids provide higher yield. Li et al. [32] found that 71% of the respondents within their survey among small-scale farmers in China mentioned the yielding qualities of F1-hybrid varieties compared to landrace varieties, but only 4% of them increased their final income by adopting F1-hybrids due to additional costs for inputs such as pesticides and fertilizers. The farmers also reported that the maize F1-hybrids were not adapted to upland and infertile land and that weather variation as well as pest and diseases easily influenced the yield. Sixty-two percent of the interviewed farmers considered landraces better adapted to the local conditions leading to a more stable productivity. A similar outcome was reported from Serbia [51] where commercial maize F1-hybrids are increasingly used since they offer higher yields in shorter time frames. However, interviewed farmers mentioned that even if the yield of maize landraces is lower they still show higher production stability under changing environmental conditions. Farmers in Northeast Turkey were found to prefer Kirik, a local landrace wheat variety, over modern wheat varieties, even if the suggested yield of modern varieties was higher [52]. This is because, unlike modern varieties, landraces (especially Kirik) can sometimes be sown twice per year, in spring and autumn, giving the farmers a flexibility to match seasonal changes and a higher level of protection against extreme agronomic conditions [52].

3.1.2. Crop Nutrient Use Efficiency

The crop nutrient use efficiency describes the capacity of a variety to use available soil nutrients in an efficient way [34]. We found six studies (five experiments and one conceptual paper) that use crop nutrient use efficiency as a response variable comparing landraces against modern varieties. In terms of maize landraces, Lafitte et al. [35] found that landraces have a higher capability to use available nitrogen (N) under limited N-levels compared to modern varieties and therefore, perform better in N-limited environments, although modern varieties outyielded landraces under optimal farming conditions. Sangabriel-Conde et al. (2014) [34] conducted a greenhouse experiment evaluating the response of maize landraces and a F1-hybrid maize variety to arbuscular mycorrhizal fungi under different phosphorus (P) levels. Results show that local landraces interacted better with mycorrhiza resulting in an enhanced P-uptake. P acquiring capacity of the F1-Hybrid is severely lower than those of some landrace varieties, despite a high mycorrhizal dependency. According to Sangabriel-Conde et al. (2014) [34] some landraces appear to have adaptive mechanisms to obtain P more efficiently, a trait important in milpa cultivation systems [34]. In contrast, Fang et al. [36] (2014) provide evidence that modern breeding towards greater and more stable yield can also promote water use efficiency. Hence, modern varieties may overtake landraces even under environmental stress [36].

3.1.3. Cultivation Effort and Crop Storability

Many factors influence farmers' working time and how it is affected by a certain crop variety. The timespan of the growing period, the time spent for crop storage minimizing losses from pest infestation or decay, and finally the time spent on field during the growing period was dealt with in four studies. They analyze the farmers' time required during cultivation and the storability of the harvested crops for different varieties, with three studies reporting results from field experiments and one survey among farmers. In one publication, local landraces were connected with a higher required time because of additional work for seedbeds for landraces [53]. The other studies (n = 3) state a positive or unclear effect of landraces on the time of required work during cultivation and the storability of the harvested crops. As an example, watermelon landraces could be stored up for more than 12 month in the shade, while the storability of modern varieties was limited to just a few weeks [37]. Anastasi et al. [54] mention the earliness of sesame landraces as a useful trait in semiarid environments, because it shortens the cropping cycle, reduces water use and makes the field available sooner for the next crop. Moreno et al. (2006) [38] analyzed how different landraces and modern varieties affect crop storability for small-scale farmers in México and found that they have more problems with pest infestation in case of modern varieties than landraces. One third of farmers does not report high levels of storage losses to insects when using their local landraces, and do not see the need to implement pest control measures.

3.1.4. Context Dependency of Provisioning Ecosystem Services

The yield outcome of landraces and modern varieties appears to be contingent on local environmental conditions. Modern varieties have often higher yields, which may be much reduced under harsh local conditions. In contrast, landraces are a trusted, resilient and successfully cultivated seed/crop source of reliable yields for many small-scale farmers around the globe. This applies especially to the nutrient-use efficiency of the crop and the storability of harvested crops. Therefore, landraces should be considered for their production potential in marginal areas and as genetic material for the future, even if modern varieties yield better under optimal farming conditions [30,55,56]. Both landraces and modern varieties have merit, and the right variety choice depends on the site-specific conditions, since it is impossible to find all desired performances realized in a single variety [57]. Crop variety selection needs to take advantage of a portfolio of (agronomic) performances corresponding to different land qualities [32].

3.2. Regulating Services

3.2.1. Resilience to Environmental Changes

High yields from landraces are in most cases directly connected with their ability to sustain under local environmental changes or sub-optimal farming conditions. Out of the 24 publications on resilience to environmental changes, we found seven surveys among farmers, three conceptual papers, and 14 publications experimentally testing varieties against each other, in the categories positive effects ($n = 22$), negative effects ($n = 1$), and unclear ($n = 1$) respectively.

(1) Findings from field experiments

Eleven out of 14 publications reporting results from field experiments found positive effects of landraces compared to modern varieties under sub-optimal farming conditions. In one publication, the authors conclude that resilience capacity is unclear, and one study detected a negative effect. A merit of landraces in comparison with modern varieties is their ability to use limited water resources more efficiently and therefore be better adapted to drought stress [39,58,59]. For example, pearl millet landraces yielded significantly more grain when the plants were under drought stress compared to modern varieties, while crosses of landraces with modern varieties resulted in the highest mean "Drought Response Index" based on flowering and grain yield [30]. With this index, Yadav [30] quantifies that landraces are more productive than modern varieties under poor or changing water conditions and should especially be considered as gene material in breeding for water stress resilience. In the case of maize landraces they yielded poorer under optimal conditions, but often performed similar to, or even better under stress conditions [40]. In general, under severe water stress, a more stable prolificacy of landrace varieties may compensate for lower yields. Therefore, landraces should be considered for breeding and production in areas with non-optimal farming conditions [40]. Furthermore, Leiser et al. [60] detected that photoperiod sensitive landraces showed better P-tolerance and less delay of heating under P-limited conditions for grain yield compared with modern varieties. Dry beans and watermelons led to comparable results in that landraces outperformed modern varieties under stress [37,41]. The only study that detected a negative result of landraces comparing old, modern and newly released varieties was the case of winter wheat varieties, showing that improved and newly released varieties consume more soil water during anthesis (compared to landraces) under drought stress conditions, leading to higher yields [61].

(2) Findings from farmer surveys

Responses from surveys among farmers to the resilience of a variety to environmental changes proved a generally high valuation of landraces compared to F1-hybrids or modern varieties. Strikingly, in China, steadily fewer households use maize landraces [32]. In the two Chinese provinces Guangxi and Yunnan, the area cultivated with landraces decreased significantly from 65% to 7% and from 84% to 18%, respectively, between 1998 and 2008. This reduction was accompanied by a rapid expansion of F1-hybrids of maize, especially in Guangxi, where the area under hybrids reached up to 93%. Seventy-one percent of the farmers were positive about the F1-hybrid yields, but still, 54% of them also indicated that they are concerned about the yield stability of F1-hybrids due to uncertainties about the performance by weather extremes, high pest and disease infestation levels. Sixty-two percent of the farmers considered maize landraces as better adapted to their local conditions, offering more stable productivity. In Serbia, respondents claimed that old maize varieties mature earlier, an attribute that is considered positively, and are more resistant to unfavorable environmental conditions such as drought [51]. In El Salvador, farmers stated that landrace seeds are more pest resistant. In focus groups the respondents explained landrace seeds as generally "stronger", having "stronger roots" and F1-hybrid seeds as "more prone to rotting" and "less resistant to rain" [17]. Despite an increased introduction and supply of modern maize varieties in the Yucatan Peninsula (México), farmers maintained a substantial amount of traditional maize varieties over 12 years and still plant more than three quarters of milpa, which is a crop mixture of corn, legumes, and squashes (see Figure 1) [62] with traditional varieties [42]. Also, in the Catalan Pyrenees, farmers prefer potato landraces to modern varieties due to their higher adaptability to the local climate and pests [53]. In Ethiopia, several local potato varieties were preferred over new ones even for yield, since they are well adapted to the particular agroecological zones. Additionally, they may serve as valuable resources for further variety improvement [57].

Figure 1. Small-scale Milpa cultivation in Guatemala, April 2014.

3.2.2. Biological Pest and Disease Control

Biological pest and disease control emerges as an important performance in the literature changing with variety selection ($n = 10$). We found 5 farmer surveys, 2 conceptual papers, and 3 publications experimentally testing landraces against modern varieties. These papers found positive ($n = 6$), negative ($n = 2$), and unclear ($n = 2$) effects respectively. Sánchez-Martin et al. [43] showed that oat landraces maintain high levels of resistance against rust, and their degree of infestation was generally 25% lower than that of modern varieties. Similar effects were also cited for sorghum landraces, where F1-hybrid varieties entail good yield potential, are weaker in combining the performance for yield with resistance against pests and diseases such as shoot fly or charcoal rot [44]. In the case of maize landraces, results from field experiments demonstrate that landraces have a higher degree of plant defense mechanisms like herbivore-induced plant volatiles, an advantage in defending themselves against pest damage [45]. This performance only occurred in certain landraces and was undetectable in the tested F1-hybrid varieties. The landraces attracted not only egg parasitoids but also larval parasitoids [45]. Tamiru et al. [45] conclude that these defense traits of plants against herbivores may have been lost over time due to crop breeding toward high yields at the cost of other traits.

When farmers were asked about the ecological benefits of landraces over modern varieties, most argued that landraces are better adapted to the local environment and are more resistant to pests and diseases [17]. For instance, farmers had no problem with the potato beetle (*Leptinotarsa decemlineata*) before the implementation of modern potato varieties. This pest resistance, in combination with other benefits, was the reason why almost 90% of the respondents preferred landraces to modern varieties [53].

3.2.3. Biodiversity Richness and Pollination

Biodiversity richness (n = 1) and crop pollination (n = 1) are neglected topics and information about comparing landraces against modern varieties is missing.

3.2.4. Landrace Promote Regulating Ecosystem Services

Overall, we detect a positive effect of local landraces on regulating ecosystem services. They are a valuable source for resistance genes (like indirect plant defense mechanisms), which may have become lost during crop breeding [44,45,53], and are better adapted to local climate conditions [17]. Landraces are often cultivated in complex landscapes (riparian strips, forest remnants, single big trees, hedgerows, orchards, etc.), which may further improve the local biodiversity and its functional benefits such as regulating ecosystem services.

3.3. Cultural Services

According to the MEA (2005), cultural ecosystem services are the “nonmaterial benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreating, and aesthetic experiences” [19]. Within the reviewed literature, five publications are directly relating to cultural services (four surveys among small-scale farmers, one experiment). All publications state a positive influence of choosing landraces over modern varieties on providing people with cultural ecosystem services. These services include traditional values, cooking characteristics, nutritional values, as well as taste and color of harvested crops or prepared dishes.

(1) Findings from farmer surveys

Farmers and related user groups deciding for or against a landrace in comparison to modern varieties link different functional preferences for landraces related to various cultural services. Li et al. [32] asked 162 farmers in semi-structured interviews the reasons maintaining landraces on their fields. One identified reason was pressure from the social environment (13% of respondents), meaning that the landraces play an important role within their traditional food culture. In a study from the Iberian Peninsula on the general use of landraces, the question “Why do you consider the conservation of landraces important?” [53] provided the following responses: (1) taste and the nutritional value (37.5%), (2) tradition and food security (25%), and (3) ideological reasons (16.7%), although the respondents also stated that extra work in making seedbeds is seen as an disadvantage of cultivating landraces (18.7%). The remaining three studies analyze the impact of choosing maize landraces over modern varieties in South America. In an example from Bolivia by Zimmerer (2014) [47], small-scale farmers state that varieties must be suitable for diverse food items such as maize beer (chicha), toasting, soup thickener, and further maize-based foods and drinks. Zimmerer (2014) [47] concludes that each landrace maintains certain cooking characteristics and that the high diversity of landrace varieties in the region is a major part of the overall agrobiodiversity. This example in Bolivia shows that a high degree of landrace diversity not only supports the production of local food types but also reduces the risk of crop failure through variety diversification.

(2) Findings from field experiments

In a study from El Salvador, Olson et al. (2012) [17] investigated different seed types in milpa pots to understand the value of "agroecological and livelihood variables". Farmers stated that farmers' seed markets (were landraces are traded), are more reliable concerning information about the varieties than the commercial seed market, allowing best fitting choices (see Figure 2). Additionally, seeds from the farmers' seed markets were lower in cost and can be re-produced. These findings are in line with the results from Mexíco by Moreno et al. [38], who found the main reasons for persisting local maize landraces in small-scale farming systems is their popularity and high value of cooking characteristics, nutritional values, taste, and color. Other farmers also stated that—although landraces are harder to process compared to modern varieties—they are much tastier. The recipes for their families' special maize dishes are even passed over the generations together with the according landrace varieties [48].

Figure 2. Diversity of potato varieties on a local market in Peru, October 2015.

Landrace Provide Cultural Ecosystem Services

Small-scale farmers in many developing countries still prefer local landrace varieties because they fill social and cultural niches that modern varieties are lacking [20,47,63,64]. Cooking characteristics are a classical example for these cultural services [47,53]. In our review we found primary scientific evidence from South America concerning maize landraces. But the role of traditional farming practices including traditional varieties like landraces as providers for cultural services is becoming increasingly recognized globally. In conclusion, the use of landraces is a potential way to achieve social-ecological resilience, i.e., the capacity of human-environment systems to absorb shocks induced by changes, so that the system continues to support human well-being [65,66]. Adapted varieties in turn play a key role for socio-ecosystematic processes within small-scale farming systems [67]. In conclusion in-depth knowledge of the cultivation and cooking characteristics of landraces can therefore be seen as fundamental for biocultural diversity as it interlinks biodiversity knowledge with the diversity of cultures and human societies [68].

4. General Conclusions

The results of this review show that small-scale farmers evaluate a multitude of crop features before deciding for or against a given variety. From crop yield to resilience toward environmental changes to taste or storage characteristics and finally family traditions, landraces represent a portfolio of desired plant performances. With this review, we illustrate that local landraces are in many cases better adapted to local farming conditions, do not need as much agrochemical resource input compared to modern varieties, and maintain a diversity of regionally and/or personally specified performances. In some cases, modern varieties become replaced again by landraces due to their higher resistance to pests, diseases, and abiotic stresses, which may help to meet the needs of sustainable agriculture systems facing global climate change. As a part of traditional agricultural systems landraces continue to evolve and adapt to changing social, ecological, and environmental systems. Embedding variety decision in the ecosystem service framework of the Millennium Ecosystem Assessment illustrates that landraces can provide farmers and related user groups with high provisioning services under changing climate conditions because of their resilience under sub-optimal farming conditions. In comparison to modern varieties, landraces are often a trusted source for small-scale farmers globally, achieving stable crop yield with longer storability of the harvest. With specialized resistance genes and other features such as indirect plant defense mechanisms these varieties also provide farmers with regulating services that may be lacking in many cases of modern plant breeding. With regard to food security, landraces are in many cases better adapted to local, environmentally diverse farming conditions and require less artificial resource input compared to modern varieties. With that, they are a valuable component of agrobiodiversity that decreases the vulnerability of agroecosystems to global change. Our results underline the significance of landraces for provisioning and regulating ecosystem services, which needs to be better acknowledged by regional and global authorities.

In addition, small-scale farmers often prefer local landraces to modern varieties due to typical cultural features like family traditions and cooking characteristics for special dishes. In many cases, farmers recognize the role of landraces for the fulfillment of personal non-agronomic features. The diversity of landraces is therefore a viable part of various ways of living and farming, sustaining vivid cultures. Our review shows that genetic diversity and freedom to choose from a large variety pool is a substantial part of cultural ecosystem services and sovereign food production. Unfortunately, cultural ecosystem services are often neglected, but need to be much better acknowledged as a vital part of satisfying living standards.

Last not least, the current legal framework regulating seed usage and variety protection needs to be taken into account. Since seeds and varieties are the foundation for food production, their free access—including the right to save and replant seeds, the right to share seeds and the right to use seeds to breed new varieties—is often considered as a mandatory part for sovereign agriculture and nutrition [69]. Landraces are often maintained and developed in informal, commons-based seed systems, such as participatory breeding arrangements [70,71] and seed exchange systems [72,73]. Such systems need to be acknowledged by national and international authorities to provide small-scale farmers with a stable and independent livelihood—an essential part toward food sovereignty.

Supplementary Materials: The following are available online at http://www.mdpi.com/2071-1050/10/8/2834/s1, Table S1: List of included 41 publications comparing landraces against other variety types.

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