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REVIEW

Landrace legislation in the world: status and perspectives with emphasis in EU system

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Abstract Crop landraces are genetically variable populations of agricultural plant species that through natural evolution and farmers' selection and continuous cultivation have been adapted to the environment of their origin or cultivation. To be used and officially traded, there are more lax or strict registration schemes throughout the world concerning the application of distinctiveness, uniformity, stability (DUS) system. This review discusses the legislative framework of various countries worldwide and evaluates its application efficiency with a detailed focus on European Union (EU) experience. Especially in EU, landraces must be registered as conservation varieties in the European Catalogue of Varieties. A total of 313 agricultural and 173 vegetable conservation varieties were registered in the European Catalogues from 2013 to 2021. However, it is not clear how many of these registries are landraces because obsolete varieties are also included under the term conservation varieties. Moreover, our review reports the importance of landraces for the FAO (Food and Agriculture Organization of the United Nations) and EU strategies, namely 'Farm to Fork' and 'Biodiversity'.

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Additionally, the DUS criteria were evaluated for their use when a crop landrace is registered taking into consideration the genetic structure of a landrace. Furthermore, the connection of landraces with Farmers' Rights, their appropriateness for organic agriculture, and trade issues are discussed. Finally, the new proposal of European Commission on Plant Reproductive Material concerning landraces is critically reviewed and improvements are suggested.

Keywords Conservation varieties · Crop landraces · European catalogue of varieties · Genetic resources · Seed legislation · Seed registration

Introduction

Defining landraces

There are several definitions of the term landrace (Zeven 1998; Villa et al. 2005; Negri et al. 2009; Casañas et al. 2017). According to FAO (2019a), landraces are often "genetically and phenotypically heterogeneous, adapted to the environmental conditions of their cultivation areas, suited to the production systems and local culinary preferences and are generally associated with traditional farming systems". They are the product of breeding or selection carried out continuously, deliberately, or otherwise, by farmers over many generations. Landraces tend not to be genetically uniform and contain high levels of genetic diversity (FAO 2019a). Landraces are also known as indigenous varieties, native varieties, traditional varieties, local varieties, autochthonous varieties, folk varieties, heirloom varieties, local cultivars, and farmers' varieties (Adhikari 2019). Crop landraces are practically covering all agricultural species, annual and perennials, and they relate to crop domestication (Meyer 2012; Purugganan 2019).

Why, how, and where landraces are maintained

Before the extensive use of cultivars (scientifically improved varieties) in the twentieth century the crop production relied exclusively on landraces (Casañas et al. 2017). The gradual use of cultivars, during the industrialization and intensification of agriculture with the prospect of the economic profit, caused the reduction or even in some countries the disappearance of thousands of landraces which inevitably led to genetic erosion both at interspecies and intraspecies level (Hammer and Teklu 2008; Ford-Lloyd et al. 2009).

Landraces (including both annual and perennial species) originated after the domestication of wild species and creation of agricultural primitive forms all over the world (Byrne et al. 2020). Their populations spread through human movements, trade, and environmental changes in the new lands of cultivation and the new farmers' choices were among the key components of landraces diversification in the new areas that were transferred (Harlan 1992; Casañas et al. 2017).

Despite the immense changes brought about by the introduction of cultivars under the Distinctiveness, Uniformity and Stability (DUS) system (for "cultivar" definition please see Section "The history of landraces legislation") and the dramatic reduction of landraces, several of them particularly of certain agricultural species are still cultivated and play an important role for local or national economies, the latter applies particularly for underdeveloped countries. A recent review of the European cultivated agrobiodiversity situation showed that there are 19,335 geo-referenced landrace cultivation sites and 141 herbaceous and 48 tree species cultivated as landraces (Raggi et al. 2022). But genetic erosion has dramatically reduced landraces diversity, like in Southwest China, where from 1998 to 2008 the households using maize landraces were reduced by 56% in Guangxi and 66% in Yunnan provinces respectively (Li et al. 2012; Ficiciyan et al. 2018).

Landraces are frequently cultivated in diverse environmental and marginal lands under various management practices, under organic and low input systems contributing to the income of farmers who

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work in harsh conditions where conventional agriculture cannot be easily carried out (Ceccarelli 1994; Bencze et al. 2020; Raggi et al. 2021). In fact, due to their cultivation for many centuries in various microclimates and under specific cropping practices such as rainfed and polyculture farming, landraces, present adaptive traits to various abiotic stresses such as water deficiency, salinity, low chemical inputs (Pinheiro de Carvalho et al. 2003, 2004; Ganança et al. 2007, 2015, 2018; Gouveia et al. 2020a; Ntanasi et al. 2023).

Landraces of olive trees, fig trees, grapevines, pulses, and other crops flourish in Mediterranean countries, or in Canary Islands and contribute to their economy (Negri 2003; Thomas et al. 2012, 2013; Casañas et al. 2017; Pinheiro de Carvalho et al. 2019, 2022; Antunes et al. 2021; Giupponi et al. 2021; Raggi et al. 2021, 2022). Value-added landrace products, such as the product "Farro" from "Monteleone di Spoleto", named after the town, an old landrace of emmer wheat (*Triticum dicoccum* L.), cultivated in Umbria, central Italy, costs about 10 euros €/kg in town markets (Negri 2003). Santorini fava that is produced from a Spanish vetchling (*Lathyrus clymenum* L.) landrace costs 20 €/kg (Ralli et al 2020). The economic analysis on certain agricultural holdings, proved that the cultivation of landraces can provide both economic and environmental sustainability even for small farm sizes (Karanikolas et al. 2017). In Madeira, Island of Portugal, the sweet potato, corn, common bean, grapevine and apple-tree landraces are cultivated in small farms and some of their products are protected by Demarcated Region (DR), Protected Denomination of Origin (PDO) or Protected Geographic Indication (PGI) and constitute local brand, i.e. the Madeira Wine, Madeira cider or sweet potato bread (Pinheiro de Carvalho et al. 2019; Antunes et al. 2021). In a EU survey carried by Caproni et al. (2020) found that 54% of landraces' products are sold in local markets, 21% at national level, and 4% at international level. On other regions of the world, landraces are still playing important role on people's nutrition for example corn (*Zea mays* L.) in Mexico (Guzzon et al. 2021), taro (*Colocasia esculenta* L. Schott) in Côte d' Ivoire (Koffi et al. 2021), potato (*Solanum tuberosum* L.) in Andes (de Haan et al. 2019) or African yam bean (*Sphenostylis stenocarpa* Hochst. ex A. Rich. Harms) in Central Africa (Konyeme et al. 2020) and many other examples.

Besides advantages related to specific adaptation to biotic and abiotic stresses and farming practices, landraces have often been maintained in cultivation due to their cultural value for farmers and local communities owing to their tastes, shapes, and colours and or use in special dishes or occurrences. Literature reports that even feasts on occasion of particular religious celebrations (e.g. Saint Patron, Saint Donato in Lefkada-Greece) and contests for the best landrace product can contribute to keep a particular landrace in cultivation in Europe (Papa 1996, 1999; Castellini 2005; Stavropoulos et al. 2008; Ralli 2010; Ralli et al. 2011; Negri 2012; Mendes Moreira et al. 2014), as reported also in other continents (Bellon and Brush 1994; Deepak 2010).

In other words, cultural differences among people of the European melting pot also account for the numerous landraces still cultivated (Galluzzi et al. 2010). In this respect traditional uses and production of high-quality food is certainly among the main factors that allowed the maintenance of landraces in Europe and elsewhere despite the wide diffusion of cultivars. The analysis of a collection of 95 case studies of both garden and open field landraces (Raggi et al. 2021) also showed that actions of landrace products promotion can significantly affect the landrace added value and maintenance on the territory.

The history of landraces legislation

Until the beginning of the twentieth century, that landraces were the dominant cultivated genetic resource, there was no system for variety registration. With the intensification of agriculture, the plant breeding industry developed and created a system to protect its intellectual rights (Plant Breeder's Rights-PB Rights) and to ensure the final users (i.e. the farmers) about seed quality and compliance with the declared traits of a variety. This can be achieved through a legislation system that requires the cultivar registration and fulfilments of the DUS and VCU (Value for Cultivation and Use) testing. The first report of cultivated varieties (synonym cultivar) regulation is dated on the 1st of August 1905 in France (Dupont 1960; Revilla et al. 2022). In 1942, the Permanent Technical Committee on Seeds, consisted of seed industry representatives and government scientists, determined the DUS criteria for defining the cultivars (Chable et al. 2009). The introduction of PB Rights increased further the

importance of within-variety uniformity since 1940s leading to the harmonisation with the International Convention on the Protection of New Varieties of Plants (UPOV) in 1961 (Louwaars 2018). International Convention for the Protection of New Varieties of Plants (UPOV 1961) includes in Article 1 the definition of variety as a plant grouping within a single botanical taxon of the lowest known rank, which grouping, irrespective of whether the conditions for the grant of a breeder's right are fully met, can be:

- Defined by the expression of the characteristics resulting from a given genotype or combination of genotypes,
- Distinguished from any other plant grouping by the expression of at least one of the said characteristics and
- Considered as a unit with regard to its suitability for being propagated unchanged

and in Article 5 clearly states that: The breeder's right shall be granted where the variety is:

(i) new, (ii) distinct, (iii) uniform and (iv) stable. This definition is further clarified by the Explanatory Notes of UPOV (2010) which also states that: A variety which fulfils the DUS criteria will meet the definition of variety. According to the International Code of Nomenclature for Cultivated Plants (ICNCP) "The basic category of cultivated plants whose nomenclature is governed by this Code is the cultivar" and "A cultivar, as a taxon, is an assemblage of plants that (a) has been selected for a particular character or combination of characters, and (b) remains distinct, uniform, and stable in these characters when propagated by appropriate means" (Brickell et al. 2016). So, the above definitions include the DUS criteria but they use different terms (variety and cultivar). For other authors (Rey et al. 2021), such as in LIVESEED project, they are proposing a broader "cultivar" definition: "The term 'cultivar' is used, as defined in the LIVESEED project, as the generic term of reference for any crop, including therefore 'heterogeneous cultivars' that fall into the category of organic heterogeneous material (OHM)." The introduction of Plant Breeder's Rights increased further the importance of within-variety uniformity since 1940s leading to the harmonisation with the International Convention on the Protection of New Varieties of Plants (UPOV) in 1961 (Louwaars 2018). According to the same author 'plant breeding intends to combine as many 'favourable traits' as possible in one genotype or maximise the presence of such traits in one population. Diversity within the variety is thus reduced. 'Conventional' Plant Breeding usually, although depending on the method used on a certain crop, can be a major driver of uniformity in a farmer's field. In 1966 the Common Catalogue was created by European Community in which about 20,000 cultivars were registered (Chable et al. 2008).

With this background the first initiations for landraces' registration were take place in Italian Regions where they started quite early to protect their local genetic resources, and landraces in particular, by law (the first Italian regional law dated 1997, i.e. Tuscany Law no. 50/1997), these laws were then followed by a specific Italian national law (i.e. law no. 194/2015, December 1st). In 1998, for the first time, the European Directive 98/95/CE (EC 1998) mentioned the essentialness to ensure the conservation of genetic resources and the necessity to introduce a legal basis to that end to permit, within the framework of legislation on the seed trade, the conservation, by use in situ, of varieties threatened with genetic erosion. The next important step was on 20 June 2008 with the Commission Directive 2008/62/EC (EC 2008) "providing for certain derogations for acceptance of agricultural landraces and varieties which are naturally adapted to the local and regional conditions and threatened by genetic erosion and for marketing of seed and seed potatoes of those landraces and varieties" and successively the Commission Directive 2009/145/EC (EC 2009). Those two European Directives include under the term "conservation varieties" both landraces and obsolete varieties (cultivars or improved varieties of recent past). The second European Directive introduces, besides the conservations varieties, also the category of "Varieties developed for growing under particular condition" (VDGuPC), varieties with no essential value for commercial agriculture but developed for growing under particular conditions. Moreover, the reference to landraces is included in EU recent documents, like Farm to Fork Strategy (COM/2020/381) (EC 2020) and EU Biodiversity Strategy for 2030 EC (2021a, b) and resilience (EC 2021c). Other countries in the world have also their own laws concerning landrace registration, use and trade (Perera and Adhikari 2019; Shrestha 2019; Kuhlmann and Dey 2021). Thus, landraces

have been recognized by the European Union (EU) as well as other countries by the application of special legislations.

Here we examine the genetic structure of landraces as fundamental criterion for the appropriateness of different legislation systems regarding landrace registration. Also, landraces' mixtures are presented as a farmers' practice that it is applied still nowadays. We are reviewing different legislation systems all over the world and we are emphasizing on the EU legislation system searching for the connection with EU policies and the progress that has been achieved from the previous review of Spataro and Negri (2013) as well as the constraints and the delays that have been raised. Finally, we discuss how these systems can be improved formulating proposals in general and specifically for the new EC proposed Regulation on Plant Reproductive Material with the aim to protect landraces which are important genetic resources with on farm conservation and to ensure farmers' rights connected with their cultivation and trade.

Landraces' genetic structure

Many studies highlight the phenotypic diversity and heterogeneity among landrace populations, as indicated in Table 1 while others underline also the within population heterogeneity. The results of an experiment with 215 Ethiopian durum wheat landraces evaluated for their genetic diversity using SNP (single nucleotide polymorphisms) markers highlighted a high genetic diversity within population of landraces and that the total variation within accession was higher than the total variation among populations (Negisho et al. 2021).

Research evaluating onion landraces found that a great genetic variation existed within populations (Rivera et al. 2016; Ricciardi et al. 2020). These findings concerning between and within landraces populations diversity are also supported by the study of 52 wheat populations (dos Santos et al. 2009, 2012), 50 common bean (Freitas et al. 2011; Gouveia et al. 2014) and 43 corn (Pinheiro de Carvalho et al. 2008) populations from Madeira. In Portugal landraces of other crops such as apple-tree, taro and sweet potato are still used as dynamic populations continuously selected for their production or quality traits exhibiting great inter and intra-populations variation in specific traits (Ganança et al. 2018; Pinheiro de Carvalho et al. 2018, 2019; Gouveia et al. 2020b, c). Interestingly Pagnotta et al. (2005) found that the Syrian landrace Haurani has high genetic polymorphism for glutenins and RFLPs, both between (60%) and within (40%) sampling locations and genetic diversity is also related to the geographic distance between the collection sites.

Bulgaria is characterized as one of the richest countries with plant diversity in the Balkans. During the expedition, carried out in 2019–2021 with the support of the Bulgarian Ministry of Education and Science under the National Research Programme "Healthy Foods for a Strong Bio-Economy and Quality of Life", 85 accessions from different species (cereals, legumes, vegetables, and medicinal plants) were collected and stored at Sadovo Gene Bank species (Velcheva et al. 2022). High variability based on agronomical traits was observed in most of the collected accessions. For example, the diversity in Bulgarian faba bean (*Vicia faba*) landraces studied was due to their different geographical origin (the country contains three phyto-climatic areas: Central-European, Mediterranean, and Euro-Asian steppe and forest regions). The high genetic diversity in the collection among the accessions of faba bean landraces was influenced by the significant variability in some morphological traits (Velcheva and Petrova 2020). In twenty local and introduced lupin (*Lupinus albus*) genotypes the estimated broad sense heritability and expected genetic advance were higher for some of the traits (Petrova 2022a). The genetic diversity within the local Bulgarian accessions of grass pea (*Lathyrus sativus*) was proved through the variability of the studied traits (Petrova 2022b).

Research in tomato (Terzopoulos and Bebeli 2008a, 2010; Terzopoulos et al. 2009), pepper (Ralli et al. 2011) and cowpea (Lazaridi et al. 2017a, b), through the study of their phenotypic diversity, highlights the high genetic variability between and within landraces. Cowpea mixtures of different morphotypes found recently in Tinos Island (Supplementary Fig. 1). In Uzbekistan, an inventory conducted in 2010–2013 from the 30 wheat landraces collected showed that 10 were mixtures of different morphotypes (Baboev et al. 2021).

Caproni et al. (2020) drew the conclusion that landrace populations—either predominantly autogamous or allogamous species—retain remarkable

Table 1 Phenotypic variation and heterogeneity among and within landraces populations in some crops

Genus species	Common name	Examined populations	Pv[a]	HaP[b]	HwP[c]	References
Abelmoschus esculentus (L.) Moench	Okra	50	n/a[d]	Yes	n/a	Kyriakopoulou et al. (2014)
Allium cepa L.	Onion	31	n/a	Yes	n/a	Rivera et al. (2016)
		13	n/a	n/a	Yes	Ricciardi et al. (2020)
Allium sativum L.	Garlic	31	Yes	n/a	n/a	Polyzos et al. (2019)
		29	Yes	n/a	n/a	Avgeri et al. (2020)
		27	Yes	Yes	Yes	Papaioannou et al. (2023)
Anethum graveolens L.	Dill	33	Yes	Yes	n/a	Ninou et al. (2017)
Apium graveolens L.	Celery	6	Yes	Yes	Yes	Torricelli et al. (2013)
Brassica oleracea var. *capitata* L.	Cabbage	21	Yes	n/a	n/a	Padilla et al. (2007)
		n/a	n/a	Yes	n/a	Chiang et al. (1993)
		5	n/a	n/a	Yes	Dias et al. (1994)
Capsicum annuum L.	Pepper	5	n/a	Yes	Yes	Lanteri et al. (2003)
		139	Yes	Yes	n/a	Ralli et al. (2011)
Cicer arietinum L.	Chickpea	1082	Yes	n/a	n/a	Vishnyakova et al. (2017)
		202	Yes	n/a	n/a	Awol and Bulti (2019)
Citrullus lanatus L.	Watermellon	82	Yes	n/a	n/a	Singh et al. (2018)
Cucumis melo L.	Melon	6	Yes	Yes	Yes	Somma et al. (2021)
Cucurbita moschata D.	Winter squash	27	Yes	Yes	Yes	Lorello et al. (2020)
Cucurbita pepo L.	Summer squash	36	n/a	Yes	n/a	Dakir et al. (2002), Xanthopoulou et al. (2015)
Hordeum vulgare L.	Barley	120	Yes	n/a	n/a	Gadissa et al. (2021)
Lathyrus sativus L.	Grasspea	25	n/a	Yes	n/a	Mekonen et al. (2022)
Lactuca sativa L.	Lettuce	51	Yes	n/a	n/a	Šuštar-Vozlič et al. (2021)
Lens culinaris Medik	Lens	40	n/a	Yes	n/a	Gleridou et al. (2022), Sharma et al. (2022)
Nicotiana tabacum L.	Tobacco	53	Yes	Yes	n/a	Ralli et al. (2012)
Oryza sativa L.	Rice	33	n/a	n/a	Yes	Pusadee et al. (2009)
		24	n/a	Yes	Yes	Pusadee et al. (2019)
Petroselinum crispum (Mill.) Nyman ex A.W. Hill	Parsley	24	Yes	Yes	n/a	Boutsika et al. (2021)
Phaseolus vulgaris L.	Common bean	33	n/a	Yes	Yes	Lioi et al. (2005)
		5	Yes	Yes	Yes	Tiranti and Negri (2007)
Pisum sativum L.	Pea	120	n/a	Yes	n/a	Lázaro and Aguinagalde (2006)
Solanum lycopersicum L.	Tomato	34	Yes	Yes	Yes	Terzopoulos et al. (2009), Terzopoulos and Bebeli (2008a; 2010)
		25	Yes	Yes	Yes	Mazzucato et al. (2010)
		9	Yes	Yes	Yes	Cattáneo et al. (2020)
		64	n/a	Yes	Yes	Caramante et al. (2023)
Solanum melongena L.	Eggplant	36	Yes	Yes	n/a	Ganopoulos et al. (2015)
Triticum aestivum L.	Bread wheat	52	Yes	Yes	Yes	dos Santos et al. (2009)
		380	n/a	Yes	Yes	Pascual et al. (2020)
Triticum durum Desf.	Durum wheat	215	Yes	Yes	Yes	Negisho et al. (2021), Pagnotta et al. (2005)
		58	Yes	Yes	n/a	
Vicia ervilia (L.) Wild	Bitter vetch	49	Yes	Yes	Yes	Livanios et al. (2017)

Table 1 (continued)

Genus species	Common name	Examined populations	Pv[a]	HaP[b]	HwP[c]	References
Vicia faba L.	Faba bean	54	Yes	Yes	n/a	Terzopoulos et al. (2003), Terzopoulos and Bebeli (2008b)
Vicia sativa L.	Common vetch	503	Yes	Yes	n/a	De la Rosa et al. (2021)
Vigna unguiculata (L.) Walp.	Cowpea	23	Yes	Yes	Yes	Lazaridi et al. (2017a), Lazaridi et al. (2017b), Zafeiriou et al. (2023)
		3	Yes	Yes	Yes	Polegri and Negri (2010), Tosti and Negri (2005)
Zea mays L.	Corn	43	Yes	Yes	Yes	Pinheiro de Carvalho et al. (2008)

[a]Phenotypic variation

[b]Heterogeneity among populations

[c]Heterogeneity within populations

[d]n/a: not studied

levels of genetic diversity. Most of the research mentioned above, as well as others, underline that there is great inter and intra population diversity in landraces (Table 1). Other research using molecular methods highlights that there is a great genetic diversity among and within landraces (Arca et al. 2021; McLean-Rodríguez et al. 2021). These findings emphasize even more that landraces are a dynamic genetic resource consisting of various genotypes and/or populations and even sometimes of species that change over time under various pedoclimatic conditions and farmers' choices.

The application of DUS legislation system on landraces

When the Directives for the landraces's registration were written, the diversity status of landraces was ignored or underestimated and therefore landraces were considered as uniform varieties. Following the gradual realization that, despite the immense genetic erosion, landraces still exist and present genetic and economic value, the need to include them in a registration system was recognized. Some countries, like India, Peru (Kuhlmann and Dey 2021), and Switzerland (Batur et al. 2021) have more flexible approaches on landraces registration, or in the case of Brazil the informal sector is recognized (Kuhlmann and Dey 2021). Other countries including EU countries, and some African countries (ibid.), instead of creating an appropriate legislation system for landraces, examined them for registration with the DUS system. In a review on seed policies by Commission on Genetic Resources for Food and Agriculture (FAO 2019b) from a sample of 94 countries, it was found that 69% of them are using DUS criteria, 37% applied the Cultivation and Use of VCU system and 24% did not indicate any registration requirements or other than DUS or VCU testing The application of VCU requests an added value usually in terms of yield in comparison to other registered varieties which is not a safe criterion of landraces (ibid.) because it cannot be fulfilled. As for DUS system, also previously mentioned, is not appropriate for landraces, in the scale of Uniformity and Stability due to their genetic diversity. Instead of creating a suitable system for landraces registration, the insertion of derogations and exceptions was invented to provide a solution. As Spataro and Negri (2013) comment "Directive derogations in relation to uniformity are severe for those landraces with a very high morphologic variability". Trying to restrict landraces in Uniformity and Stability rules, a paradox is emerging, as described by Adhikari et al. (2022), that landraces, the outcome of centuries of crop selection and breeding by farmers, were included in inappropriate formal legal system. In parallel, farmers' questions on landraces legislation should be taken into consideration. Brazilian farmers concerned about 'freezing varieties in time and space and undermining seed evolution and adaptation, as well as granting

private ownership rights over shared and community resources' (AHTEG 2019).

The appropriateness of DUS system for landraces

Since landraces are dynamic (Villa et al. 2005) and genetically diverse populations (Lodhi et al. 2020) they are based on large genepools (Lioi et al. 2005; Terzopoulos et al. 2008, 2009; Mazzucato et al. 2010; Terzopoulos and Bebeli 2010; Lazaridi et al. 2017a, b; Casañas et al. 2017; Cattáneo et al. 2020; Ricciardi et al. 2020; Negisho et al. 2021) indicating the need for considering the appropriateness of the application of DUS system for their registration. On the one hand, most landraces' plants are characterized by certain unique morphological traits or a combination of them by which are recognized initially by farmers and then by scientists as different varieties of the same species, meaning that they present Distinctiveness. As an example, only in central Italy 31 common bean landraces were recorded on-farm by Negri and Tosti (2002). Interestingly, Gibson (2009) introduced the term "perceptual distinctiveness", as the traits that farmers recognize and denominate individual landraces that contribute to the creation and management of their diversity and the transfer of knowledge. He also points out, that when individual landraces are not distinct with clear morphological differences, farmers fail to maintain each of them as separate landraces (ibid.) and they treat them as the same.

On the other hand, landraces show lack of Uniformity (see Table 1) and also Stability as the result of the multiple selection pressures to which they are, and have been, exposed by farmer management and changing environment across cultivation years. They are populations always under evolution (Negri 2005; Hufford et al. 2019). We then see that Uniformity and Stability are inappropriate terms for landraces and wonder, as also Winge (2015), if these requirements may act as barriers for landrace registration.

Landraces' mixtures

Another method that the farmers used to overcome the stresses arose from harsh pedo-climatic conditions was using mixtures of either different species or plant populations of the same species. The practice of planting mixtures is widespread in subsistence agriculture, which is in contrast with industrial agriculture where genetic monocultures are the norm (Hufford et al. 2019). So here we are referring to mixtures created by farmers and not by scientific research (Ceccarelli and Grando 2020; Timaeus et al. 2022).

Papadakis (1929) highlighted that some wheat landraces were mixtures of both *Triticum aestivum* L. and *Triticum turgidum* L. subsp. *durum* (Desf.) Husn. varieties. Farmers' mixtures are still cultivated on farm as it has been observed in recent collecting expeditions. The cultivation of wheat and barley in mixture is referred to Lemnos Island (Thomas et al. 2012) and even nowadays in Patmos Island, Greece (Supplementary Fig. 2). The Greek wheat landrace "Leventis" (originated in west Peloponnese and collected few years ago by Agricultural University of Athens team) was a mixture of three wheat species (*Triticum turgidum* subsp. *polonicum* (L.) Thell., *Triticum turgidum* L. subsp. *durum* (Desf.) Husn., and *T. aestivum*) (Thanopoulos and Bebeli, unpublished data). Mixture of Cyprus vetch (*Lathyrus ochrus* (L.) DC) and pea (*Pisum sativum* L.), with the former as dominant was found in cultivation in Lemnos Island (Thomas et al. 2012). Farmers were choosing the cultivation of crop mixtures so as to have a sufficient production result according to the weather conditions which favor the one of the two species or to achieve better organoleptic characteristics of the final products.

Examples of legislation on seed production and marketing systems from the world

Legislation systems concerning landraces from different countries and continents of the world are presented alphabetically aiming at an integrated presentation of the issue and the trends. Seed systems in Africa can be divided into two types, the formal and informal systems. Even though the informal systems serve small farming seeds saving use and exchange does not comply with many seed laws (Munyi 2022). In 2013 a group of African countries, the Southern Africa Development Community (SADC) created a Harmonised Seed Regulatory System (SADC HSRS) (ibid.). SADC HSRS is not an obligatory system that provides among others a framework for the release of varieties also

landraces, even though detailed rules have not yet been developed. Landraces, local varieties, and farmers' varieties registration is expected to follow Quality Declared Seed (QDS) and field tests (ibid.).

In Algeria a National plant variety Catalogue registration of plant varieties requires DUS uniformity (Assabah 2001; Bishaw and van Gastel 2009), however it also includes a section for farmers' varieties. This has allowed the registration of non-uniform populations (landraces) in the National Catalogue without changing the law (Louwaars and Burgaud 2016).

In Benin landraces can be registered in the National Catalogue, multiplied, and sold under the up-to-date legislative framework. There are three types of lists within the National Catalogue, (1) those that should be tested for DUS and VCU criteria, (2) those that should be tested only for DUS criteria (can be multiplies exclusively for exports) and (3) those that are comprised by traditional varieties and landraces and should be tested only for VCU criteria, can be produced and sold (Herpers et al. 2017).

In Bolivia landraces and farmers' varieties cannot be registered in the National Registry of Varieties (NRV) by any official system and formal seed production must follow rules (De Jonge et al 2021). However, several potato, peanut and maize landraces have been included in the NRV by the allowance of the INIAF (Instituto Nacional de Innovación Agropecuaria y Forestal) exempting them from DUS testing due to reports presenting sufficient distinctness, uniformity and stability in different locations and years (ibid.). Also, after 2008 the use of descriptors not included in the UPOV list that were more prompt for the diverse colors and shape of potatoes was negotiated. Therefore, INIAF allowed the use of the International Potato Center regarding descriptors that were not included in the UPOV list (ibid.).

In Brazil if seeds of local, traditional varieties, landraces or creole varieties are used, traded, or exchanged among family farmers, agrarian reform settlers or indigenous people, is not needed to be registered in the National Catalogue of varieties (requiring homogeneity and stability criteria) (Santilli 2015) but there is also an exclusion for family farmer organizations, which can only distribute, and not sell, seeds of local, traditional varieties.

In Chile crop species varieties cannot be registered without abide by the DUS rules, however foreign DUS certifications can be used. Additionally, there are farmers' exceptions in the use of non-uniform accessions such as landraces, although the material cannot be advertised or transferred via any seed title (Venturelli and Lazcano 2022).

In China registration of a plant variety according to the up to 2012 legislation is allowed only after passing DUS and VCU testing, and landraces or farmers varieties can seldom pass these tests (Li et al. 2012). According to the Chinese legislation it is illegal to produce on-farm seeds that are not officially released (ibid.).

In India farmers' varieties are those that "have been traditionally cultivated and developed by farmers in their fields, … or landraces about which farmers possess common knowledge" (Agrawal 2019). These landraces can be defined as intellectual property and marketed in India under the *Protection of Plant Varieties and Farmers' Rights Act* as extant varieties (ibid.). Extant varieties including farmers' varieties, should imply to distinctness, uniformity, and stability (DUS) criteria, if it does, then after a series of evaluation processes it is registered, and the owner of the variety rights can produce and market the landrace exclusively for 15 years (annual crops) or 18 years (trees and vines) (Lushington 2012). To facilitate the registration of farmers' varieties, a new act (*2009 Protection of Plant Varieties and Farmers' Rights Regulations*) loosened the measures regarding uniformity and stability requirements, such as one year of stability testing instead of two (Agrawal 2019). More specifically any person that is selling, importing, or exporting seeds is characterized as a seed dealer and they are obliged to comply with the Seeds Act (1966), Seeds Control Order (1983), and the New Policy on Seeds Development (1988) legislation. To do so they must have a license (valid for three years) (Kuhlmann and Dey 2021). However, farmers in India can sell seeds in the market if the seeds are not sold under a brand name, and they can use their own varieties without obligation of compulsory registration (ibid.). On the contrary if a seed dealer wants to commercialize a farmers' variety, they have to take permission of the farmer or the community that owns this landrace (Lushington 2012).

In Indonesia farmers varieties are grown mainly for self-consumption (Almekinders and Hardon 2006). Since 2014 DUS criteria should be fulfilled for the official registration of varieties, while plant

variety protection can be applied for all plant species (Khadijah 2021).

In Nepal, seeds are certified by authorized agencies as either breeder seeds, foundation seeds, certified seeds, or improved seeds. Producers are obligated to apply for truthful labelling for non-certified seeds (Kuhlmann and Dey 2021). However, plant genetic material can be considered as a variety, multiplied, or traded legally only if it is noted in the Gazette (the Catalogue of Nepalese varieties) (De Jonge et al. 2021). A variety can be included in the Gazette either by "registration" of local or foreign varieties or by "releasing" a local variety (ibid.). Since 2013 seed regulation was modified to enable the registration of landraces in the National Catalogue of crop varieties (Joshi et al. 2017; De Jonge et al. 2021). The naming of the new variety or landrace can be the name of the geographical site that was collected, a Hinduism or Buddhism religion god name, production environment, grain type and color and functional traits of the variety. However, rice and maize varietal names should follow some specifications. The legislation regarding the maintenance of the landraces is not clear (Joshi et al. 2017; Recha et al. 2019). Tests regarding the DUS are required for registration in the National list of crop varieties (Joshi et al. 2017). To register a landrace, valid data for one season are sufficient, on the contrary, the registration of a scientifically bred variety requires three season's multilocation yield and other trials. Finally, value for cultivation and use (VCU) testing is not necessary for registration of landraces (ibid.).

The *Plant Breeders' Rights Act* that has been implemented in Pakistan since 2016, aims at the development of new varieties and the protection of the intellectual property of the breeders (Ahsan Rana and Adhikari 2019). However, there is no reference or discussion regarding the rights of farmers over their landraces (Aziz-ur-Rehman and Mubeen 2018). Additionally, under the *Plant Breeders' Rights Act* 2016 farmers could sell, exchange and use of seeds of a variety as far as it is not protected by the Act and exchange "reasonable" amounts of propagating material among other farmers (Yazdani and Ali 2017). Due to the UPOVs DUS criteria needed for seed registration the production and commercialization of landraces is not favoured.

The intellectual property of seeds in Sri Lanka is governed by the Draft Bill on the Protection of Plant Varieties (Breeder's Rights) of Sri Lanka. 2011. According to the bill farmer is he/she who:

- Grow crops by cultivating the land himself/herself.
- Oversees the cultivation of crops by another person.
- Is a "tenant cultivator"; or
- Preserves—whether individually or collectively—any wild species or traditional variety or adds value to these plants through the selection and identification of useful properties (Perera and Adhikari 2019).

This bill allows farmers to 'save, use, sow, resow, exchange, share or sell their farm product including the seed of a protected variety'. Additionally, farmers are protected from penalties regarding seed intellectual property rights. However, there is no mechanism that protects farmers' varieties, and plant breeders could use them without any consent to the farmers (ibid.).

According to Batur et al. (2021) in Switzerland, landraces, as sub-category, are included in the "niche varieties". In this case the application should present a description of the landrace, an indication of the area of origin and a declaration that the landrace is not the same to any other variety neither in Switzerland nor abroad. Commercialization of landraces' seed is permitted without the need of official tag but writing that "approved niche variety, seeds not certified" (ibid.).

Thailand, after the Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS), has implemented a National law (Plant Variety Protection Act B.E.2542 1999) for the protection of intellectual property. The Thailand law for the protection of intellectual property presents an innovation regarding UPOV, that is the protection of different categories of plant varieties (1) new plant

varieties, (2) local domestic plant varieties, (3) general domestic plant varieties and (4) wild plant varieties[1] (Lertdhamtewe and Jefferson 2019). The act also defines a plant variety as "a plant grouping of similar or identical genetic or botanical characteristics, with particular features which are uniform, stable, and distinct from other grouping[s] in the same species of plant." And finally, the DUS requirements are re-inscribed based on UPOV (ibid.). All these differentiations enabled a looser legislation that allows the registration of domestic and wild species varieties.

The Island of Timor-Leste or East Timor, a country in the Indonesian Island complex, implements a two-way seed registration system; (1) State-run and controls the new seed registration, release, quality control and dissemination and the (2) farmer's seed system where farmers produce and circulate (exchange and sell) their own seeds at a community level. In the State-run system all seeds are produced controlled for their quality and after registration they are categorized according to their genetic purity (from higher to lower level) at breeder, foundation, certified, commercial, and community seeds. These seeds are then multiplied from various trained stakeholders undergo quality control test and are then released to the market. On the contrary, the farmer's seed system seeds include landraces, local varieties, adapted varieties, and new varieties that are produced, saved, used, exchanged, or sold within a particular community (family, neighbour, other farmers, and local markets) (Shrestha 2019).

The seed policy governance system of Uganda is comprised by formal and informal systems, the later concern only 20% of the National seed produced (Recha et al. 2019). On the contrary 80% of the National seed is produced by the informal system that is recognized by the National Seed Policy (2018) as important for the conservation of landrace biodiversity (ibid.). Additionally in Uganda the term "farmers' varieties" include both landraces and obsolete varieties (ibid.).

In the United States plant varieties can be applied to three different categories of intellectual property, the utility patents, Plant Variety Protection Act (PVP in 1970) and plant patents (Plant Patent Act since 1930). The utility patents can be granted invention including new plant varieties, the Plant Patent Act involves varieties that imply DUS criteria hence not the landraces (Lopez-Noriega 2016). The genetically variable landraces can be exchanged and marketed among farmers along with the certified uniform varieties, such cases are the non-profit organization "Seed Savers Exchange" that preserves rare, heirloom, and open-pollinated varieties. In other cases, registration is compulsory, and accessions should apply DUS criteria, in these cases landraces exchange or sell is prohibited (Louwaars and Burgaud 2016). The plant patent is the easiest way of granting intellectual property right over a plant variety that does not imply to the PVP requirements (Lopez-Noriega 2016). In conclusion variety registration is not mandatory for its commercialization in the United States (Blaustein 2016).

In Vietnam the registration of varieties is mainly conducted by seed clubs that are comprised by farmers' organizations and community level seed organizations (Kuhlmann and Dey 2021). Variety registration in Vietnam require DUS and VCU testing and multi-location trials (ibid.). The registration of varieties is required by the formal system, however since 2008 Government recognizes officially the informal seed system. Additionally, smallholder farmers can exchange their varieties legally, however they need to apply rules for the quality of variety and environmental sanitation (ibid.).

In Zimbabwe there is no legislative framework to allow farmers' varieties registration, production or marketing and the requirement is that varieties multiplied or sold as seeds should follow a DUS and value for cultivation and use (VCU) certification scheme (De Jonge et al. 2021). In a workshop for the registration of farmers' varieties, stakeholders concluded that the main factor limiting landraces from registration was the DUS and that other factors such as taste, cooking time, quality and storability should also be included in landraces certification scheme (ibid.). The Community Technology Development Trust (CTDT) and seed services prepared a draft for Local/Traditional seeds certification scheme, that proposed DCS (distinctness, consistency, and stability criteria, that could allow more heterogenous genetic material (ibid.)).

[1] The PVP Act defines 'wild plant variety' as a 'plant variety that currently exists or used to exist in the natural habitat and has not been commonly cultivated'.

The European Commission Directives for landraces

The basic structure of EU Directives

European Committee recognizing the importance of landraces published the Directives 2008/62/EC and 2009/145/EC referring to the "acceptance of agricultural landraces and varieties" and "marketing of seeds of those landraces and varieties" and hence their registration into the Common Catalogues of Varieties. The first Directive (2008/62/EC) refers to the Agricultural plant species (cereals, pulses etc.) as well as the Directives 66/401/EEC, 66/402/EEC, 2002/54/EC, 2002/56/EC and 2002/57/EC. The second one (2009/145/EC) refers to the vegetable species covered by Directive 2002/55/EC. Both Directives provide definitions of the content of the terms "conservation in situ", "landrace", "genetic erosion" and "seed", in their 1st chapter, Article 2. According to those Directives, landraces can be registered in the National Catalogues and then in the Common Catalogue as "conservation varieties" and "varieties developed for growing under particular conditions", under specific terms described in the Commission Directives of 2008 and 2009. The Article 1a summarizes the subject that deal with "Landraces and varieties which are naturally adapted to the local and regional conditions and threatened by genetic erosion" and "the marketing of seed" (Article 1b). The second chapter of the Directives deals with the requirements needed so that the conservation varieties can be accepted which are: "It shall present an interest for the conservation of plant genetic resources" (Article 4.1), and "respond to the DUS system" and also that "if the uniformity level is established based on off-types, a population standard of 10% and an acceptance probability of at least 90% shall be applied" (Article 4.2).

Article 5 states the procedural requirements for the acceptance (its description, and denomination, results of unofficial tests, knowledge from practical experience and other information). A "conservation variety" or "variety developed for growing under particular conditions"[2] shall not be accepted for inclusion if it is already listed in the common Catalogue, or it was deleted from the common Catalogue within the last two years (Article 6.1). This above-mentioned provision relates to cultivars and obsolete varieties. Article 7 sets the rules for the denomination of conservation varieties applying Regulation (EC) No 930/2000 (EC 2000) permitting derogations except if such derogations would violate prior rights of a third party. 'The denominations which were known before 2000, Member States may permit derogations from Regulation (EC) No 930/2000″ otherwise the Regulation should be applied, (Article 7). The Member State shall identify the region or regions in which the conservation variety has historically been grown and to which it is naturally adapted and will name it/them region/s of origin (Article 8). Chapter III refers to seed production and marketing and reports the requirements for certification (Article 10). The Member States shall ensure that seed of a conservation variety may only be produced in the region of origin (Article 11) and marketing takes place in its region of origin with derogation for additional regions (Article 13). Quantitative restrictions have been set for each crop (eg. 'Seed marketed does not exceed 0,5% of the seed of the same species used in that Member State in one growing season, or a quantity necessary to sow 100 ha') (Article 14) and sealing of packages and containers (Article 17). The Chapter III of the Directive 2009/145/EC deals with Varieties developed for growing under particular conditions.

Achievements in landraces registration in the EU common Catalogues (2013 vs 2022)

As it has been mentioned in the previous subsection, the two Directives are permitting the registration of conservation varieties, whereas the second one also includes the category of varieties developed for growing under particular conditions. These varieties' categories registered from the start of the Directives' application till now are presented in Fig. 1. In some countries the number of "varieties developed for growing under particular conditions" exceed dramatically the number of conservation varieties, like in France and Germany. It seems that "varieties developed for growing under particular conditions" are more common in Central and North Europe which have developed a tradition towards this category. Interestingly, some countries, like Cyprus and Malta

[2] In Article 22 is defined as a variety that it has been developed for growing under particular agro-technical, climatic or pedological conditions.

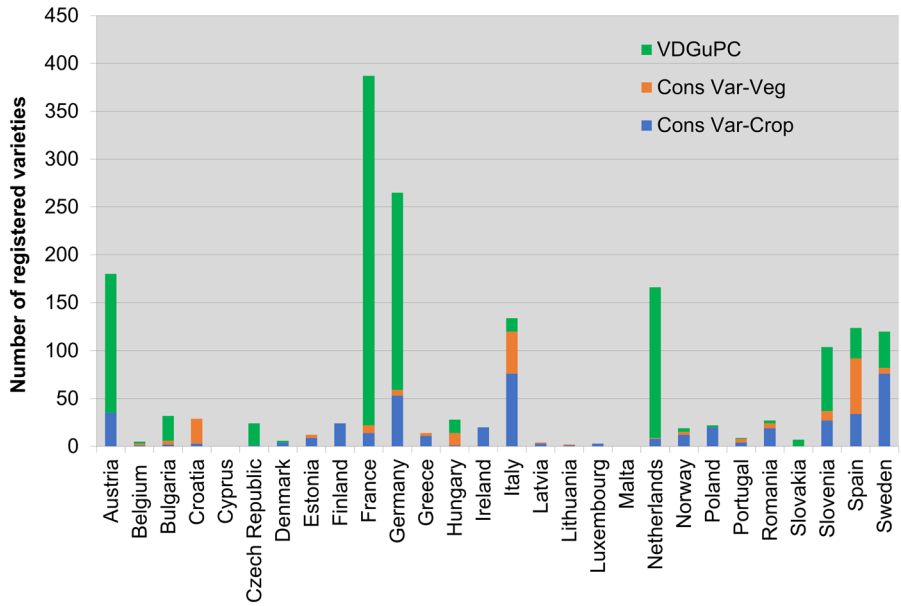

Fig. 1 Total number of conservation varieties for agricultural crops (Conservation Variety -Crop, Cons Var-Crop) and vegetables (Conservation Variety-Vegetables, Cons Var-Veg) and varieties developed for growing under particular condition (VDGuPC) registered in the European Common Catalogue during the application of Directives 2008/62/EC and 2009/145/EC based to the European Plant Variety Database, accessed at 23-2-2023 in https://ec.europa.eu/food/plant-variety-portal/

do not have any registrations. The ratio of registered conservation varieties of agricultural species against vegetables crops is higher for instance in Austria, Germany, Italy but not in Spain although in the case of Italy vegetables have a strong representation.

Conservation varieties registered per country and species

After four years of the implementation of both European Commissions' Directives 2008/62/EC and 2009/145/EC, 13 (Austria, Estonia, Germany, Finland, France, Italy, Latvia, Portugal, Romania, Slovenia, Spain, Sweden and UK) and 6 countries (Belgium, France, Italy, Portugal, Spain and Sweden) had registered various landraces as conservation varieties respectively for each Directive (Spataro and Negri 2013). After 2013 several countries registered more conservation varieties, while other countries that had not included their conservation varieties in 2013 registered them (Fig. 2). Due to the exit of the United Kingdom from the EU, the conservation varieties, that had been registered by UK, were deleted from the common Catalogue (EC 2021d, e).

In general, the number of conservation varieties of agricultural and vegetable species in the European Common Catalogue has been increased from 2013 to 2023 by 313 and 173 respectively (Fig. 2). The conservation varieties of agricultural species included in the Catalogue were comprised mostly of the following species, wheat and spelt wheat, potato and maize, while the less represented registered species are white clover (*Trifolium repens* L.), white lupin (*Lupinus albus* L.) and white mustard (*Sinapis alba* L.) (Table 2).

The Catalogue of vegetable conservation varieties included many species, with the most registered ones belonging to tomato (*Solanum lycopersicum* L.), common bean (*Phaseolus vulgaris* L.) and chili pepper (*Capsicum annuum* L.), while the ones with the less registrations belong to pumpkin (*Cucurbita maxima* Duchesne), butternut squash (*Cucurbita moschata* Duchesne), and watermelon (*Citrullus lanatus* (Thunb.) Matsum. & Nakai) (Table 3). The number of registered conservation varieties increased in all countries, mostly the southern European ones such as Italy and Spain.

In 2013 the countries with more than ten registered agricultural species conservation varieties were Sweden, Finland, Romania and Spain, while in 2023 their number doubled including Sweden, Italy, Germany, Spain, Finland, Slovenia, Ireland, Poland, France, Norway (Table 2, Fig. 2). Regarding vegetable varieties their registration as conservation varieties increased in the South and Eastern European countries. The countries with the most registered vegetable conservation varieties in 2013 were Spain and

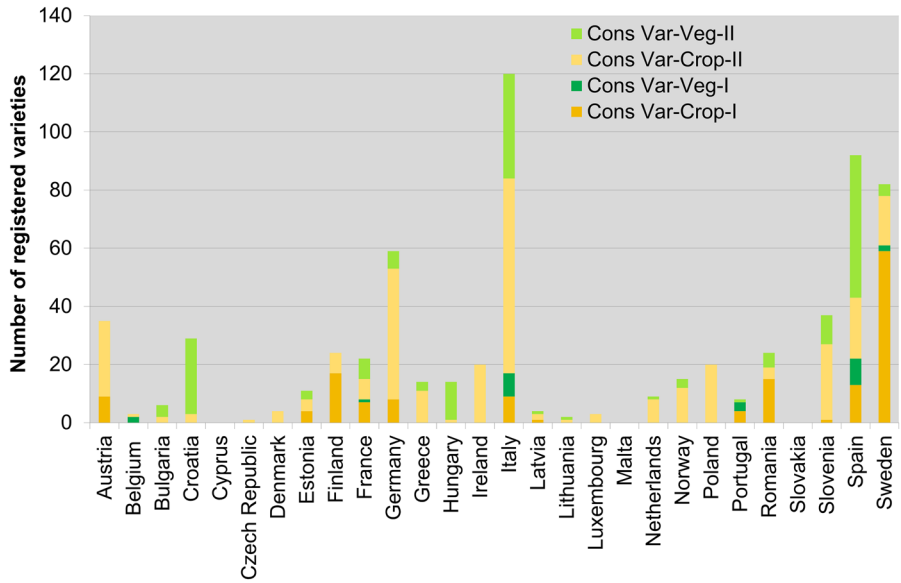

Fig. 2 Total number of conservation varieties for crops (agricultural species according the Directive 2008/62/EC) and vegetables from 2008 to 2013 (I) and from 2013 to 2023 (II) registered in the European Common Catalogue during the application of Directives 2008/62/EC and 2009/145/EC (Cons Var-Crop = Conservation Varieties for Crops and Cons Var-Veg = Conservation Varieties for Vegetables. Sources: Spataro and Negri (2013) and the European Plant Variety Database, accessed at 23-2-2023 in https://ec.europa.eu/food/plant-variety-portal/. The total of each category is resulting from the summation of the conservation varieties of each period without adding each variety twice

Italy, while in 2023 the same countries were the ones with the most registered vegetable varieties, while also Croatia and Hungary had more than ten vegetable conservation varieties registered (Table 3).

Landraces vs obsolete varieties

According to the two Directives 2008/62/EC and 2009/145/EC, the 'conservation varieties' include both landraces as well as cultivars deleted from the National Register (obsolete varieties) (Article 6 of the Directives). Incompletely the European Plant Variety Database (https://ec.europa.eu/food/plant-variety-portal/) is not providing information whether a variety is a landrace or an obsolete variety. Therefore, someone must search various databases to find out relevant information (Spataro and Negri 2013). Some examples can be quoted according to an investigation that was conducted. In Bulgaria the registered conservation varieties include *Lotus corniculatus* L. and *Trifolium repens* L. obsolete varieties and four vegetable varieties (pers. comm. VEMA LTD, Bulgaria 2023). In Estonia, out of the 11 conservation varieties, eight are obsolete varieties and three landraces (pers. comm. Külli Annamaa and Ilmar Tamm 2023). In Greece out of the 10 registered conservation varieties only one is obsolete variety. In Poland the 16 registered conservation varieties are all obsolete varieties (source: European Cultivated Potato Database-https://www.europotato.org/). In Portugal out of eight conservation varieties of European Database (https://ec.europa.eu/food/plant-variety-portal/) seven are landraces and one wheat obsolete "Pirana" variety. Additionally, two conservation varieties of chickpea (*Cicer arietinum* L.) and pumpkin (*Cucurbita pepo* L.) registered in the national Catalogue (Catálogo Nacional de Variedades, DGAV 2023) do not appear in the European database. In Spain among 92 registered conservation varieties, 15 were certainly identified as landraces, mostly vegetables, (pers. comm. Jaime Prohens 2023) while 2 were common bean (*Phaseolus vulgaris* L.) obsolete varieties (pers. comm. Antonio M. De Ron 2023). In Italy the great majority of conservation varieties (78%) are landraces with impressive genetic diversity comprising 22 taxon, obsolete varieties are only found in *Oryza sativa*, *T. aestivum* and *T. durum* (Dr. Oriana Porfiri, personal communication 2023), all the other registered conservation

Table 2 Conservation varieties of agricultural crop species registered by crop and country from 2008 to 2023 based on European Plant Variety Database accessed at 23-2-2023 in https://ec.europa.eu/food/plant-variety-portal/, nomenclature according to the European Common Catalogue

Scientific name	Common name	Uses	Austria	Belgium	Bulgaria	Croatia	Czech Republic	Denmark	Estonia	Finland	France	Germany	Greece	Hungary	Ireland
Avena nuda L.	Naked oat	F[a]	3												
Avena sativa L.	Oat	F	1			1				1		2			
Beta vulgaris L. ssp. *vulgaris* var. *alba* DC.	Beetroot	F							1						
Brassica napus L. var. *napobrassica* (L.) Rchb.	Swede	F	1								1				
Brassica napus L. var. *napus*	Rapeseed	F													
Cannabis sativa L.	Hemp	Ph													
Dactylis glomerata L.	Orchard grass	P													
Glycine max (L.) Merr.	Soybean	F,A													
Helianthus annuus L.	Sunflower	F,B	1												
Hordeum vulgare L.	Barley	AF	2					3		3		4	1		7
Linum usitatissimum L.	Linseed	F	1									1			
Lotus corniculatus L.	Birdsfoot Trefoil	P			1										
Lupinus albus L.	White lupin	F,A													
Oryza sativa L.	Rice	F	3												
Papaver somniferum L.	Opium poppy	Ph													
Pisum sativum L.	Pea	F,A										2	1		1
Secale cereale L.	Secale	AF	4				1			10		5	1		
Sinapis alba L.	White mustard	F								1					

Table 2 (continued)

Scientific name	Common name	Uses	Austria	Belgium	Bulgaria	Croatia	Czech Republic	Denmark	Estonia	Finland	France	Germany	Greece	Hungary	Ireland
Solanum tuberosum L.	Potato	F	4						4		10	8			12
Sorghum bicolor (L.) Moench. subsp. *bicolor*	Sorghum	A	1												
Trifolium hybridum L.	Alsike clover	P								1					
Trifolium pratense L.	Red clover	P	1							7	1	1			
Trifolium repens L.	White clover	P			1										
Triticum aestivum L.	Bread wheat	F	9					1	1	1		20	1		
Triticum aestivum L. subsp. *spelta* (L.) Thell.	Spelta wheat	F	1	1								4			
Triticum durum Desf.	Durum wheat	F											3		
Triticum monococcum L. subsp. *monococcum*	Einkorn wheat	F											1		
Triticum turgidum ssp. *dicoccum*	Emmer	F											2		
x Triticosecale Wittm. ex A. Camus	Triticale	F													
Vicia faba L. var. minor Harz.	Faba bean	F,A							1			1			
Vicia sativa L.	Common vetch	A							1						
Vigna unguiculata L.	Cowpea	F											1		

Table 2 (continued)

Scientific name	Common name	Uses	Austria	Belgium	Bulgaria	Croatia	Czech Republic	Denmark	Estonia	Finland	France	Germany	Greece	Hungary	Ireland
Zea mays L.	Maize	F	3			2					2	5		1	
Total by country			35	1	2	3	1	4	8	24	14	53	11	1	20

Scientific name	Common name	Uses	Italy	Latvia	Lithuania	Luxembourg	Netherlands	Norway	Poland	Portugal	Romania	Slovenia	Spain	Sweden	Total by species
Avena nuda L.	Naked oat	F[a]													3
Avena sativa L.	Oat	F					3				2			5	15
Beta vulgaris L. ssp. *vulgaris* var. *alba* DC.	Beetroot	F													1
Brassica napus L. var. *napobrassica* (L.) Rchb.	Swede	F					1	1						10	14
Brassica napus L. var. *napus*	Rapeseed	F										1			1
Cannabis sativa L.	Hemp	Ph		2								2			4
Dactylis glomerata L.	Orchard grass	P										1			1
Glycine max (L.) Merr.	Soybean	F,A										1		1	2
Helianthus annuus L.	Sunflower	F,B													1
Hordeum vulgare L.	Barley	AF					1	1			2		1	7	32
Linum usitatissimum L.	Linseed	F										5			7
Lotus corniculatus L.	Birdsfoot Trefoil	P													1
Lupinus albus L.	White lupin	F,A										1			1
Oryza sativa L.	Rice	F	13										1		17
Papaver somniferum L.	Opium poppy	Ph										1			1
Pisum sativum L.	Pea	F,A			1									25	30
Secale cereale L.	Secale	AF	1			1		1				1			25

Table 2 (continued)

Scientific name	Common name	Uses	Italy	Latvia	Lithuania	Luxembourg	Netherlands	Norway	Poland	Portugal	Romania	Slovenia	Spain	Sweden	Total by species
Sinapis alba L.	White mustard	F													1
Solanum tuberosum L.	Potato	F	1			2	2	3	16				12	14	88
Sorghum bicolor (L.) Moench. subsp. *bicolor*	Sorghum	A										2			3
Trifolium hybridum L.	Alsike clover	P													1
Trifolium pratense L.	Red clover	P											1		11
Trifolium repens L.	White clover	P													1
Triticum aestivum L.	Bread wheat	F	21				1	6	4	1	12		2	14	94
Triticum aestivum L. subsp. *spelta* (L.) Thell.	Spelta wheat	F										5	3		14
Triticum durum Desf.	Durum wheat	F	27							1		2			33
Triticum monococcum L. subsp. *monococcum*	Einkorn wheat	F													1
Triticum turgidum ssp. *dicoccum*	Emmer	F													2
x Triticosecale Wittm. ex A. Camus.	Triticale	F									2				2
Vicia faba L. var. minor Harz.	Faba bean	F,A		1								1	2		6

Table 2 (continued)

Scientific name	Common name	Uses	Italy	Latvia	Lithuania	Luxembourg	Netherlands	Norway	Poland	Portugal	Romania	Slovenia	Spain	Sweden	Total by species
Vicia sativa L.	Common vetch	A									1				2
Vigna unguiculata L.	Cowpea	F													1
Zea mays L.	Maize	F	13							2		4	12		44
Total by country			76	3	1	3	8	12	20	4	19	27	34	76	460

[a]F = Food-human, A = Animal feed, P = Pasture plant for grazing, Ph = Pharmaceutical plant, N = Nutrition, NF = Non food, B = Biofuel

varieties of both agricultural and horticultural species are true landraces. In Sweden, NordGen Växter registered 59 conservation varieties out of which 28 are landraces and 31 obsolete varieties (personal communication Michael Lyngkjär and Jan Svensson 2023).

The concept of area of origin

Regarding conservation varieties the Article 8 of the Directives 2008/62/EC and 2009/145/EC introduced the concept of region of origin. Thus, for each conservation variety an area where this variety should be cultivated and traded, will be claimed (Article 13). There are two basic categories about the use of this scheme. The one is when the area of origin of a conservation variety covers the whole country, something which happens in Austria, Croatia, Estonia, Finland, France, Slovenia and Sweden (Suplementary Fig. 3). The other case is when the area of origin of a conservation variety covers a part of the country (e.g. district, province), like in Greece, Hungary, Italy, Portugal and Spain. There are also cases that a conservation variety has its region of origin in more than one country, like the obsolete potato variety "Ackersegen" registered in Germany and Austria. In other cases, such as in Austria a *T. aestivum* conservation variety, namely "Laufener Landweizen" is registered at national level in Austria) as well as at regional level in Germany (Oberbayern, Niederbayern). Additionally, several (16) crop conservation varieties are registered by Poland with origin at national level, and five at regional level (Supplementary Table 1). Out of the total registered conservation varieties, 45% have as area of origin a restricted area.

The crop conservation varieties registered in National level are 60.8% and the rest 39.2% at regional level, whereas in vegetable conservation varieties was the opposite, 40 and 60% respectively. The above-mentioned is related to their country of origin as most of the vegetable conservation varieties (66.0%) originate from southern European countries while most of the crop conservation varieties from northern-central European countries (65.7%) (Supplementary Table 1).

Denomination of landraces

Another interesting issue is the denomination of landraces. Again, the denomination system used is that

Table 3 Vegetable conservation varieties and varieties developed for growing under particular condition registered by species and country based on the European Plant Variety Database, accessed at 23-2-2023 in https://ec.europa.eu/food/plant-variety-portal/, nomenclature according to the European Common Catalogue

Scientific name	Common name	Austria	Belgium	Bulgaria	Croatia	Czech Republic	Denmark	Estonia	France	Germany	Greece	Hungary	Italy	Latvia
Allium cepa L. var. *aggregatum* G. Don.	Potato onion	(1)[a]							**1**/(3)					
Allium cepa L. var. *cepa*	Onion	(2)		(3)	**5**				(3)	(2)	**1**	(1)	**5**	
Allium fistulosum L.	Welsh Onion	(1)								(1)				
Allium porrum L.	Leek		**1**						**1**/(2)	(1)			**1**	
Allium sativum L.	Garlic	(3)			**6**	(2)				(2)		**2**		
Allium schoenoprasum L.	Chives									(1)				
Apium graveolens L. var. *dulce* (Mill.) Pers.	Celery		(1)										**1**/(1)	
Apium graveolens L. var. *rapaceum* (Mill.) Gaud.	Celeriac	(1)					(1)			(2)		(1)		
Asparagus officinalis L.	Asparagus								(2)					
Beta vulgaris L. ssp. *vulgaris* var. *conditiva* Alef.	Garden Beet	(1)		(1)					(1)	(4)				
Beta vulgaris L. ssp. *vulgaris* var. *flavescens* DC. f. *crispa*	Leaf Beet	(2)							(2)	(5)			**2**	
Brassica oleracea L. convar. *acephala* (DC.) Alef. var. *sabellica* L.	Curly Kale	(1)							(2)	(6)			**1**	
Brassica oleracea L. convar. *botrytis* (L.) Alef. var. *botrytis*	Cauliflower	(1)							(2)	(3)				
Brassica oleracea L. convar. *botrytis* (L.) Alef. var. *cymosa* Duch.	Broccoli									(5)				
Brassica oleracea L. convar. *capitata* (L.) Alef. var. *alba* DC.	White Cabbage	(2)		(1)	**4**		(1)		(2)	(1)		**1**/(1)		
Brassica oleracea L. convar. *capitata* (L.) Alef. var. *rubra* (L.) Thell.	Red Cabbage			(1)								(1)		
Brassica oleracea L. convar. *capitata* (L.) Alef. var. *sabauda* L.	Savoy Cabbage	(2)							**1**/(2)	(2)		(1)		
Brassica oleracea L. var. *gemmifera* Zenker.	Brussels Sprouts								(1)	(1)				

Table 3 (continued)

Scientific name	Common name	Austria	Belgium	Bulgaria	Croatia	Czech Republic	Denmark	Estonia	France	Germany	Greece	Hungary	Italy	Latvia
Brassica oleracea L. var. *gongylodes* L.	Stem turnip												**1**/(1)	
Brassica oleracea L. var. *palmifolia* DC.	Jersey kale								(1)	(1)			**1**	
Brassica rapa L. Emend. Metzg. ssp. *pekinensis* (Lour.) Hanelt	Chinese Cabbage	(2)												
Brassica rapa L. var. *rapa* (L.) Thell.	Turnip	(1)			**2**				**1**/(6)	**1**/(3)				
Capsicum annuum L.	Pepper	(34)		**2**/(11)	**4**	(2)			**1**/(6)	(11)	**1**	**1**/(5)	**3**	
Cichorium endivia L.	Escarole								(1)				**1**	
Cichorium intybus L.	Chicory		**1**						(1)	(2)				
Cichorium intybus L. var. *foliosum* Hegi	Salad Chicory	(1)							**1**/(1)				**1**	
Citrullus lanatus (Thunb.) Matsum. & Nakai	Watermelon			(1)	**1**				(4)	(5)				
Cucumis melo L.	Melon	(1)		(2)		(1)			(17)	(2)				
Cucumis sativus L.	Cucumber	(4)		**1**		(1)			(7)	**1**/(9)				
Cucurbita maxima Duchesne	Pumpkin	(2)	(1)	(1)		(1)			(20)	(11)			**1**	
Cucurbita moschata Duchesne	Butternut Squash													
Cucurbita pepo L.	Courgette	(3)							(23)	(16)			**1**	
Cynara cardunculus L.	Cardoon			(1)					(3)	(1)			**2**	
Daucus carota L.	Carrot	(2)		(1)		(2)			(6)	(10)				
Foeniculum vulgare Mill.	Fennel	(1)							(1)	(1)				
Lactuca sativa L.	Lettuce	(13)			**1**	(3)			(27)	**2**/(4)				
Petroselinum crispum (Mill.) Nyman ex A. W. Hill	Parsley	(1)		(1)	**1**	(1)				(2)				
Phaseolus coccineus L.	Kidney Bean	(1)								(1)				
Phaseolus vulgaris L.	Common bean	(8)			**1**				**2**/(26)	**1**/(7)		**2**	**18**	
Pisum sativum L.	Field pea	(2)				(2)		**1**	(1)	**1**/(3)			**1**	
Raphanus sativus L. var. *niger* (Mill.) S. Kerner	Black Radish								(4)	(4)				

Table 3 (continued)

Scientific name	Common name	Austria	Belgium	Bulgaria	Croatia	Czech Republic	Denmark	Estonia	France	Germany	Greece	Hungary	Italy	Latvia
Raphanus sativus L. var. *sativus*	Radish	(1)							(1)	(2)		(1)		
Rheum rhabarbarum L.	Rhubarb									(1)				**1**
Solanum lycopersicum L.	Tomato	(45)		**1**/(1)	**2**	(8)		**1**	(181)	(55)	**1**	**7**/(3)	**4**	
Solanum melongena L.	Eggplant	(2)		(1)					(4)	(7)				
Spinacia oleracea L.	Spinach	(1)												
Valerianella locusta (L.) Laterr.	Cornsalad								(1)					
Vicia faba L. var. *major* Harz	Broad Bean							**1**		(3)				
Zea mays L. convar. *microsperma* Koern.	Popcorn	(1)							(1)	(3)			(1)	
Zea mays L. *saccharata* Koern.	Sweet Corn	(2)								(6)				
Sum Conservation Varieties		0	2	4	26	0	0	3	8	6	3	13	44	1
Sum VDGuPC		145	2	26	0	23	2	0	365	206	0	14	14	0

Scientific name	Common name	Lithuania	Netherlands	Norway	Poland	Portugal	Romania	Slovakia	Slovenia	Spain	Sweden	Sum Conservation Varieties	Sum VDGuPC [b]
Allium cepa L. var. *aggregatum* G. Don	Potato onion								(1)		(6)	1	11
Allium cepa L. var. *cepa*	Onion								(1)	**4**		15	12
Allium fistulosum L.	Welsh Onion											0	2
Allium porrum L.	Leek											3	3
Allium sativum L.	Garlic	**1**							(4)			9	11
Allium schoenoprasum L.	Chives											0	1
Apium graveolens L. var. *dulce* (Mill.) Pers.	Celery											1	2

Table 3 (continued)

Scientific name	Common name	Lithuania	Netherlands	Norway	Poland	Portugal	Romania	Slovakia	Slovenia	Spain	Sweden	Sum Conservation Varieties	Sum VDGuPC [b]
Apium graveolens L. var. *rapaceum* (Mill.) Gaud.	Celeriac											0	5
Asparagus officinalis L.	Asparagus		(1)									0	3
Beta vulgaris L. ssp. *vulgaris* var. *conditiva* Alef.	Garden Beet											0	7
Beta vulgaris L. ssp. *vulgaris* var. *flavescens* DC. f. *crispa*	Leaf Beet		(3)									2	12
Brassica oleracea L. convar. *acephala* (DC.) Alef. var. *sabellica* L.	Curly Kale		(2)							**2**/(1)		3	12
Brassica oleracea L. convar. *botrytis* (L.) Alef. var. *botrytis*	Cauliflower		(1)									0	7
Brassica oleracea L. convar. *botrytis* (L.) Alef. var. *cymosa* Duch.	Broccoli		(1)									0	6
Brassica oleracea L. convar. *capitata* (L.) Alef. var. *alba* DC.	White Cabbage					(1)			**1**/(4)	**1**	**1**	8	13
Brassica oleracea L. convar. *capitata* (L.) Alef. var. *rubra* (L.) Thell.	Red Cabbage											0	2

Table 3 (continued)

Scientific name	Common name	Lithuania	Netherlands	Norway	Poland	Portugal	Romania	Slovakia	Slovenia	Spain	Sweden	Sum Conservation Varieties	Sum VDGuPC [b]
Brassica oleracea L. convar. *capitata* (L.) Alef. var. *sabauda* L.	Savoy Cabbage											1	7
Brassica oleracea L. var. *gemmifera* Zenker	Brussels Sprouts											0	2
Brassica oleracea L. var. *gongylodes* L.	Stem turnip		(1)									1	2
Brassica oleracea L. var. *palmifolia* DC.	Jersey kale											1	2
Brassica rapa L. Emend. Metzg. ssp. *pekinensis* (Lour.) Hanelt	Chinese Cabbage											0	2
Brassica rapa L. var. *rapa* (L.) Thell.	Turnip			**1**						**3**	**1**	8	10
Capsicum annuum L.	Pepper		(26)			**1**	**1**	(1)	(6)	**16**/(2)		30	104
Cichorium endivia L.	Escarole											1	1
Cichorium intybus L.	Chicory								**1**/(2)			2	5
Cichorium intybus L. var. *foliosum* Hegi	Salad Chicory		(2)						(1)			2	5
Citrullus lanatus (Thunb.) Matsum. & Nakai	Watermelon		(1)									1	16
Cucumis melo L.	Melon		(2)						(1)	**3**		3	29
Cucumis sativus L.	Cucumber		(7)						(2)		(2)	2	32

Table 3 (continued)

Scientific name	Common name	Lithuania	Netherlands	Norway	Poland	Portugal	Romania	Slovakia	Slovenia	Spain	Sweden	Sum Conservation Varieties	Sum VDGuPC [b]
Cucurbita maxima Duchesne	Pumpkin		(11)									1	48
Cucurbita moschata Duchesne	Butternut Squash									**1**		1	
Cucurbita pepo L.	Courgette		(13)			**1**				**1**		3	55
Cynara cardunculus L	Cardoon											2	5
Daucus carota L.	Carrot		(2)									0	23
Foeniculum vulgare Mill.	Fennel		(3)									0	6
Lactuca sativa L.	Lettuce		(2)				**1**	(1)	**1**/(12)	**4**		9	62
Petroselinum crispum (Mill.) Nyman ex A. W. Hill	Parsley				(1)			(1)				1	7
Phaseolus coccineus L.	Kidney Bean								(1)			0	3
Phaseolus vulgaris L.	Common bean		(12)			**2**	(1)		**3**/(15	**6**/(16)	**1**/(6)	36	92
Pisum sativum L.	Field pea		(1)	**2**/(2)					(1)	**1**	(21)	6	33
Raphanus sativus L. var. *niger* (Mill.) S. Kerner	Black Radish		(1)									0	9
Raphanus sativus L. var. *sativus*	Radish							(1)				0	6
Rheum rhabarbarum L.	Rhubarb											1	1
Solanum lycopersicum L.	Tomato		**1**/(52)	(2)	(1)		**3**/(1)	3	**4**/(14)	**13**/(13)		37	380
Solanum melongena L.	Eggplant		(11)							**2**		2	25
Spinacia oleracea L.	Spinach											0	1

Table 3 (continued)

Scientific name	Common name	Lithuania	Netherlands	Norway	Poland	Portugal	Romania	Slovakia	Slovenia	Spain	Sweden	Sum Conservation Varieties	Sum VDGuPC[b]
Valerianella locusta (L.) Laterr.	Cornsalad								(2)			0	3
Vicia faba L. var. *major* Harz.	Broad Bean		(1)							**1**	3/(3)	5	7
Zea mays L. convar. *microsperma* Koern.	Popcorn											0	6
Zea mays L. *saccharata* Koern.	Sweet Corn		(1)				(1)					0	10
Sum Conservation Varieties		1	1	3	0	4	5	0	10	58	6	198	–
Sum VDGuPC		0	157	4	2	1	3	7	67	32	38	–	1108

[a]The number in bold indicates conservation varieties and within the parenthesis indicates the varieties developed for growing under particular conditions registered in the European Unions' plant variety Catalogue

[b]VDGuPC = Varieties developed for growing under particular conditions

for cultivars (EC 1994; UPOV 2015). The names of landraces have sometimes a meaning for the local communities while cultivars could not. In the cultivars' case someone decides for the name according to the rules established by UPOV serving rightly the commercial interests. In the case of landraces, the name is an expression of community culture, which had chosen the name with simple or complex criteria (Halewood et al. 2006; Joshi et al. 2017). Thanopoulos et al. (2021) highlighted the landrace naming as a cultural heritage among different countries because farmers have named different landraces among different countries using similar meanings. In many cases the same landrace is called with several different names (Thomas et al. 2012, 2013; Douma et al. 2016) and landraces with same name are sometime different (Pagnotta et al. (2005). The same landrace maintained by different farmers may exhibit different genetic diversity level (Tosti and Negri 2005; Halewood et al. 2006; Tiranti and Negri 2007; Pusadee et al. 2019). Negri (2006) states that the landraces are recognized with local names and are strongly associated with the traditional uses, knowledge, habits, dialects, and celebrations of the people who grow them. For example, the name could be an idiomatic, or to indicate the geographic origin, or just the common name of the crop (Lazaridi et al. 2017b; Thanopoulos et al. 2021). Sathya (2014) writes about the art of naming as an ancient tradition in Tamil area where the 27.5% of naming is based on special traits (features of fruit, flower, seeds (of other plants), plants, trees, organs of animals, parts of birds, insects, musical instrument, weapon, etc.), 18% memory of great persons, 11% on color and 7% on shape. For example, the landrace name Muthu Valai means Pearl banana, and Maghudi is a musical instrument (ibid.). In Gambia rice landraces naming is based on particular morphological characteristic (husk color, plant height, presence of awns, grain size, or grain shape), agronomic and culinary traits (Nuijten and Almekinders 2008). In the case of UPOV denomination rules, as well as the EU's ones, landraces' naming faces several restrictions for example the names used should not be misleading or too generic as simply referring to traits such as a color or a sweet taste or a shape. The local names of landraces usually relate to a location origin, the environment it endures (tolerance to drought, or to frost), its post-harvest traits or an epithet describing its morphology (color, size, shape,

texture, etc.) (Thomas et al. 2012, 2013; Douma et al. 2016; Joshi et al. 2017). But epithets describing the morphology of landraces are not allowed under the EU's law (EC) 2100/94 because these names might be misleading (CPVO 1994; UPOV 2015). Several landraces include in their names adjectives that may be misleading as they describe also other landraces of the same species (e.g. Papadakis 1929). For example, the EU forbids the use of the common name of a crop or attributes like the epithet "black" which cannot be used for a wheat awn because it might imply that other awns are not black (UPOV 2015). "Marzal" is a barley landrace cultivated in Spain whose name means March implying that it is sown in March, this name is also considered a misleading name as it is not the only barley landrace sown in March (Martínez-Moreno et al. 2017). Another problem on denomination is that it cannot refer the common name of the crop, the geographic origin of the crop, the village, or the area of origin. The "Milho Branco de Santana", the common name of the corn Portuguese landrace from Madeira was obliged to change name in "Santana", during registration for misleading nomination (Pinheiro de Carvalho et al. 2004, see register in the European Plant Variety Database). Those names are established before the creation of the denomination of cultivars, and we should respect and recognize them as well as the Nepalese legislation does (Joshi et al. 2017). They are a cultural heritage that follows the landrace traits and should not be ignored (Karanikolas et al. 2017; Giupponi et al. 2021). Moreover, from the moment that a landrace's name has been used for denomination of a PDO or PGI product it cannot be used for the denomination of this landrace for registration, an approach that ignores the culture heritage. The registration in the National Catalogue and the PDO or PGI scheme are two complementary, not contradictory systems, because in both landraces can be the common ground, where the former deals with the recognition of the variety and seed trade and the latter with the processing and the production procedure.

Landrace seeds' trade

The trade of landraces' seeds is a controversial issue causing a lot of confrontations. Seed industry has doubts if through a more relaxed system cultivars will be traded illegally. Some countries have more flexible approaches in this issue like India, Peru, Thailand, Ethiopia, Malaysia, and Vietnam whereas others follow stricter approach like EU countries, some African countries without clear exemptions for farmers and the informal sector (Kuhlmann and Dey 2021). Some countries (e.g. India and Peru) recognize farmers' rights and may even allow protection for landraces (ibid). In France regulations for seeds marketing are quite strict, except for old vegetable varieties that can be marketed in, however, very small amounts only for home gardening to enhance their conservation. In Italy various ways have been implemented regionally to conserve the landraces, for example the use of regional Catalogues that allows the exchange of seeds in the region in the frame of a conservation network for on-farm and ex-situ conservation and finally the recognition of landraces as local community heritage. In The Netherlands special VCU rules have been used for "green varieties" that however were not successful. The marketing of these seeds was illegal, although the authorities did not act because they remained in the local market level (Louwaars and Burgaud 2016). In EU there are restrictions connected with the area of origin: the production should be taking place only in that area, the quantity of seed to be marketed yearly as percentage of cultivars quantity, and other restrictions related with seed packaging and phytosanitary measures (EC 2008, 2009; Spataro and Negri 2013). Such requirements make the trade of landraces' seeds quite difficult. Formal seed certification could be proved costly and time-consuming, even under collective schemes (Kuhlmann and Dey 2021). If someone wishes to apply this context, then farmers and their collective schemes should be supported with special policies as the Thessaloniki Declaration (2022) proposes. But it should also be taken in consideration that cause of spread of major pests throughout the world was due to introduction of genetic material, which hosts pests like phylloxera, *Daktulosphaira vitifoliae* (Tello et al. 2019), the intense modern trade of agricultural goods (e.g. South American tomato pinworm, *Tuta absoluta*) (Guedes et al. 2019), travelling, research (Pimentel et al. 2001) and not due to landraces that was traded and exchanged mainly locally. The enrichment of landraces diversity was achieved through many pathways. The keepers of cereal diversity are the farmers through seed exchanges with neighbours (Jensen et al. 2013). They select genetic materials with desired

traits and save seeds for subsequent growing seasons (Frankel et al. 1998). The exchange of seeds between farmers ensures the maintenance of the genetic heterogeneity of the landraces, which can contribute to the creation of new landraces (populations), as well as groups of interrelated landraces (which could be considered as meta-populations) (Zeven 1999). On the other hand, frequent seed exchanges between farmers can reduce the genetic variation in wheat as mentioned by Pagnotta et al. (2005). The question is if in our societies we realize this situation and if we are working to find positive solutions. In a joint letter to the European Commission on the EU Seed Marketing Legislation 37 NGOs support the development of cultivated plant diversity and "a clear exemption from seeds marketing regulation for all activities aimed at the conservation and dynamic management of cultivated plant diversity" (Seed Marketing EU legislation stakeholders 2023).

Use of landraces in organic agriculture

Another interesting issue is the possible connection of landraces to organic agriculture and their use. Regulation (EU) 2021/1189 (EC 2021f) characterises OHM for its 'high level of phenotypic and genetic diversity, and its dynamic nature to evolve and adapt to certain growing conditions'. Then Regulation 2021/1189 notes that 'In contrast of landraces as defined in Commission Directive 2008/62/EC and Commission Directive 2009/145/EC, OHM is intended to adapt to various biotic and abiotic stresses due to repeated natural and human selection and therefore is expected to change over time'. So, through this regulation, landraces seem to be 'freezed' and not able to change over time because Uniformity and Stability criteria are used for their inclusion in the National Registry. As it is extensively described, it is quite the opposite, and that shows an insufficient understanding of the genetic structure of landraces. Regulation 2018/848 (EU 2018) describes that OHM shall be generated with crossing of several different types of parental material and with on-farm-management practices, including selection, establishing, or *maintaining material, which is characterized by a high level of genetic diversity*. Even though OHM have not been conceived to re-use landraces but new populations created from combination of cultivars or landraces, the last phrase (in italics context) opens a window for the use of landraces per se for organic agriculture offering a wide range of cultivation opportunities to farmers in EU, but also offers a paradigm for other countries of the world.

Landraces and Farmers' Rights

Issues regarding Farmers' Rights and landraces have been extensively discussed in literature (Biber-Klemm et al. 2006; Bocci et al. 2011; Santilli 2016; Aziz-ur–Rehman and Mubeen 2018; Adhikari and Jefferson 2019; Tsioumani 2021). Several policies have been applied in different countries globally regarding the intellectual property of landraces, with "formal seed systems" comprised by both state-institutions and the private sector that are subjected to specific legislation regime (Kuhlmann and Dey 2021). The "informal seed systems" or "farmer seed systems" are including transactions between mostly small-scale farmers and are not generally characterized by a commercial purpose (ibid.). In many countries landraces are circulated via "farmer seed systems" that however allow only small-scale farmers to trade within the community (ibid.). In the context of formal seed systems, landraces are used as genetic material for improvement through private sector companies (Galluzzi et al. 2020); often landraces have been used without the consent of the community that created them, although the entry in vigor of the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) Plant Production and Protection Division (2009) tried to overcome this problem. Private companies do have more means to register a variety in comparison to the public sector or a single farmer or a farmers' community (Louwaars and Burgaud 2016; Kanniah 2019). Therefore, there is need to support the local seed systems (Kuhlmann and Dey 2021) with integrated policies.

Landraces belong to the community, and in the context of farmers' rights and fair and equitable sharing of the benefits, the community should have decisive role on how and where "its" landraces will be given, and its traditional name should be used taking into consideration that the use of landraces has economic purposes directly or indirectly. As a general worldwide 'rule' the inclusion of landraces in a Register can fortify the rights of the community better

than nothing. Additionally, the policy of areas of origin, which is applied in EU, can protect the landraces from uncontrollable cultivation outside the area of their origin.

In a general view of legislation, landraces should be registered in the National Register Catalogues under the special category of Landraces with main criterion the Distinctiveness using the descriptors of either UPOV/CPVO or IPGRI and clearly separated from obsolete varieties. Under the existing system, despite its weak points, dozens of landraces of cereals, pulses and vegetables crops were registered in EU and significant progress has been made as presented in the relevant chapter.

The proposed Regulation of European Commission on plant reproductive material

The European Commission recently proposed the Regulation on the production and marketing of plant reproductive material (PRM) EC (2023). In its introduction the role of conservation varieties, including landraces, is recognized, to support the conservation and sustainable use of plant genetic resources and contribute to agro-biodiversity by introducing looser and adapted rules on organic varieties, conservation varieties, seed conservation networks and exchange of seed in kind between farmers. In the preamble (29) a 'conservation variety' is defined as "(a) traditionally grown or locally newly bred under specific local conditions in the Union is presented and adapted to those conditions" and (b) as "characterized by a high level of genetic and phenotypical diversity between individual reproductive units". This Regulation applies to the genera and species listed for the respective uses referred to in Parts A to E of Annex I (Article 2). The delegated act shall add genera or species if they fulfil at least two of the following elements: "(a) represent a significant area of production of PRM and a significant value of marketed PRM in the Union, (b) are of substantial importance for the security of food and feed production in the Union…, and (c) are marketed in at least two Member States". Article 53 regulates the registration of conservation varieties under the conditions: "(a) it has an officially recognized description, specifying the characteristics that qualify it as a conservation variety, …., (b) it has an indication of its initial region of origin; (c) it bears a denomination …; (d) it is maintained in the Union". "The officially recognized description … shall be based on results of unofficial tests, knowledge gained from practical experience during cultivation, reproduction and use". The "officially recognised description' means a written description of a conservation variety, which has been recognised by a competent authority". Moreover, the application should include "information related to the production of an officially recognized description of the variety, a proof of that description and any document or publication supporting it'' (Article 56 (k)). Article 53, 3 describes when a conservation variety shall not be listed in the Catalogue, if: (a) it is already listed in the Union variety register with an official description, or it was deleted from the Union variety register as a variety with an official description within the last 2 years, or within 2 years from the expiry of the period granted pursuant to Article 71(2), or (b) it is protected by a Community or National plant variety right. The suitability for the denomination of all kinds of varieties is described in Article 54, where cases, like the name to be identical or confusing or misleading, …to the identity of the breeder, are listed as not suitable. In paragraph 4 (b) the Commission is empowered to adopt delegated acts by setting out specific criteria concerning the suitability of variety's denominations as regards their relation to geographical indications or designations of origin for agricultural products. The registration should be carried by a professional operator who is able to cover the requirements of Article 10. A variety cannot be listed in the National variety register as a conservation variety, if: "(a) it is already listed in the Union variety … or it was deleted from the Union variety register as a variety with an official description within the last 2 years, or within 2 years from the expiry of the period granted pursuant to Article 71(2), or (b) it is protected by a Community plant variety right …". According to Article 26 a conservation variety may be produced and marketed in the Union as standard seed, if it complies with all the requirements of Article 8. Article 20 refers to certification activities' costs, necessary to produce and market the respective seed as pre-basic, basic, and certified seed are proportionate: (i) to the purpose of ensuring food and feed security or (ii) ensuring the high value of industrial processing. The preservation mixtures are recognized when contribute to the conservation of genetic resources (Article 22). Farmers may exchange

seeds in kind (Article 30) in conditions such as: are produced in the respective farmer's own premises and harvest, are not connected with a professional operator performing seed production and the seed is used for dynamic management of farmer's own seed for the purpose of contributing to agro-diversity. In these cases, the seed should be limited to small quantities, free from pests and any defects likely to impact their quality as seeds, and with satisfactory germination capacity.

Comments on the proposed Regulation of EC on RPM

The definition of conservation varieties covers the concept of landrace on a satisfying level but is missing their cultural value (Negri et al. 2009). It seems that conservation varieties are including only landraces but reading Article 53 is described when a conservation variety shall not be listed in the Catalogue (see chapter 5.3) i.e.: "it was deleted from the Union variety register as a variety with an official description within the last 2 years, or within 2 years from the expiry of the period granted pursuant to Article 71(2)". It is clear that this item is referring to cultivars that may be erased from the National Catalogue and can be registered again. This is the case of obsolete varieties, and they should clearly be separated from landraces because, while the former can cover the DUS criteria and belong to an institution, the latter are genetically diverse and belong to the farmers. Therefore, either the conservation varieties should be divided into landraces and obsolete varieties, where a definition is needed, or the terms landrace and obsolete variety shall be used. From here onwards writing for conservation varieties, we are referring to landraces only. In the elements that should be fulfilled for the delegated act (Article 2) "the conservation and sustainable use of plant genetic resources and their contribution to agro-biodiversity" should be added. The same is true also for Article 20.2,b adding the standard seed for landraces. In the Annexes species like *Ipomoea batatas, Lablab purpureus, Lagenaria siceraria, Lathyrus clymenum, L. sativus, L. ochrus, Lens culinaris, Sesamum indicum, Trititcum monococcum, T. dicoccum, T. polonicum, Vicia ervilia, Vigna unguiculata, V. radiata* are not included and should be added. The conditions for the registration of a conservation variety (Article 53) need "an officially recognized description, specifying the characteristics that qualify it as a conservation variety". This "officially recognised description … shall be based on results of unofficial tests, knowledge gained from practical experience during cultivation, reproduction and use", and "information related to the production of an officially recognized description of the variety, a proof of that description and any document or publication supporting it" (Article 56 point k). The above requirements make the whole issue rather complicated and bureaucratic, but significant change in the DUS application on landraces should be recognized. The simplest way for the application is to include the morphological description with an officially recognized technical protocol, any experience gained, and possible historical records. The state authority will examine the file and define if more data are needed, or the file will be approved. Another condition is the initial region of origin which in this proposed regulation is not connected with any geographical restrictions on cultivation and trade as in the previous regulations. In the context of Farmers' Rights, the region of origin shall be retained for cultivation and seed production but not for trade, giving the local communities the right to decide the extent of the area of origin. The denomination of varieties is another positive element of the proposed regulation, which allows a more flexible approach. Nevertheless, it should be clearly referred to that landraces can follow their historical and traditional denomination, including the geographical origin, as an element of their cultural heritage (Sathya 2014). The Member State Commission also will consider the case of the suitability of variety denominations in relation to PGI or PDO for agricultural products. In the case of landraces, the denomination of the landrace and the PGI/PDO is essential because in both cases the tradition is applied and, this could be clearly written into the new Regulation. Article 53.2 of the new proposed Regulation on PRM also states "A conservation variety shall be registered in the national variety register upon application by a professional operator established in the Union". Here it seems that obsolete varieties are still considered, and this is a step backwards in comparison to the present regulation. Another disadvantage of the 'professional operator' concept is that he/she may

not be interested in the registration of neglected and underutilized landraces. Who other can be the applicant for a landrace than the farmers and the cooperatives who are managing it for hundreds of years? It is the responsible authority, a physical person (farmer, gardener) or legal entity (cooperative, municipality, research centre or university if needed) who should make the application for landrace registration and will be the maintainer, eventually following specific instructions for the allogamous and autogamous species (Caproni et al. 2020) and controlled by the National authorities. The maintainer of a landrace should be supported technically and economically to produce seed of high quality, devoid of pests (Article 8) and have more lax requirements for seed packing. Positively the proposed regulation recognizes the 'preservation mixtures' where farmers' mixtures can be included. The seed trade should be disconnected from professional operator from the moment that the maintainer is the farmer. Seed exchange in kind within the area of origin should be permitted independently of the quantity. The new proposed regulation combined with the experience gained from the application of the present Directives of EU, is a good paradigm for a concrete policy on legislation and can be used worldwide. In this context, the described proposals for the new Directive are presented in detail in Supplementary Table 2.

Landraces and goals of UN and EU

The present status of landraces should be regarded under the policies of big organizations like UN (United Nations) and EU. The contribution of landraces for the achievement of UN 17 Sustainable Development Goals like zero hunger, food security, improved nutrition, promoting sustainable agriculture, sustainable consumption and production patterns, mitigation of climate change and its impacts, mitigation of desertification, and halting and reversing land degradation and halting biodiversity loss (United Nations 2015) should be considered and highlighted. The importance of shorter and more sustainable supply chains and domestic supply preference has been reaffirmed during the recent COVID pandemic outbreak (European Parliament 2016; CIDSE et al. 2020; Hayakawa and Mukunoki 2021) but also war situations. Shorter and more local food chains could be a way for landraces to be included in the food systems because of their adaptability and sustainability to local pedoclimatic conditions (Stefani et al. 2017; Varia et al. 2021). Furthermore the irrational use of improved plant genetic material and agricultural chemical inputs (pesticides, antimicrobials, fertilizers) has resulted to both environmental pollution and also biodiversity loss (Beattie et al. 2005; EC 2021a, b). Landraces are usualy cropped under null or natural input agricultural systems in marginal lands while competing with the cultivars in terms of sustainable production (Suso et al. 2013). Within this framework landraces could play a crucial role as they exhibit drought resistant traits; they can grow in marginal lands where commercial and improved cultivars cannot grow properly with the use of minimum or no inputs (Cabello et al. 2012; Yahiaoui et al. 2014; Marone et al. 2021). Equally can contribute to EU policies like the Green Deal (EC 2019, 2022), Farm to Fork strategy (EC 2020), strategy for the adaptation to climate change (EC 2021c), EU Biodiversity Strategy for 2030 (EC 2021a, b, c). Most of the genetic diversity is presented in landraces but it is still less used and should be largely exploited for traits of interest (Marone et al. 2021). A recent study showed that 19,335 sites exist in Europe where landraces are cultivated and about twenty percent of these sites are in Natura 2000 areas (Raggi et al. 2022) which shows how EU policies, mainly aimed at protecting the wild part of nature, also had a great impact in protecting that cultivated part of nature whose evolution was driven by humans. In fact, in protected areas, organic or low input agricultural techniques are encouraged (EU 2018) and the best resources to carry out these production practices and techniques are landraces, due to their intrinsic diversity which counteracts the damages of pests. Also, to be noted, many Common Agricultural supportive Policies are linked to Natura 2000 farming systems. In addition, landraces relate to the production of quality products which in EU are protected with PDO (Protected Designation of Origin), PGI (Protected Geographic Indication), TSG (Traditional Speciality Guaranteed) quality labels thus facilitating the maintenance of some, at least, landraces in agriculture (Menapace et al. 2009; Raggi et al. 2021).

Conclusion

Taking into consideration the different approaches on landraces registration throughout the world we can conclude in some basic suggestions on the issue: (i) Landraces need their own legislation system for registration and marketing and should not be mixed with genetic material of different origin, like obsolete varieties. Such a system is also for the benefit of seed industry clearing any possible confusion. (ii) Landraces description can be based on the technical questionnaires of former IPGRI or UPOV to describe their distinctiveness, but uniformity and stability is not applicable. To the contrary less uniformity and stability are good indices that there is a landrace and not cultivar. (iii) Landraces denomination should follow the tradition and the perception of farmers, and the same name can be used for their processed products that take a quality designation (PDO or PGI). (iv) The area of origin, as EU Directives Designate, could be proved a very useful choice because landraces can be cultivated in this specific area, protecting farmers from any kind of bio-piracy while the product can be traded for consumption also in markets outside the region. In some countries the trade outside the area of origin is interpreted loosely and is permitted, like Italy, and in others, like Greece, is applied absolutely strictly. The areas of origin can possibly offer a solution also to the seed trade for cultivation and not for consumption, in other words the seed can be exchanged and traded with lighter requirements only in the area of origin. (v) Farmers' crop mixtures can also be registered describing the components of the mixture, their quantitative participation as percentage and taking in consideration that mixture can change in time.

Humanity faces many challenges with basic ones the hunger, poverty, climate change and biodiversity loss. Landraces had and could play an important role on those issues in the present and future. Because both biological and human-driven cultural evolution generates new resources for the future (Negri 2005). In this context it is needed a constructive discussion with scientific and social criteria to conserve on farm these unique and irreplaceable plant genetic resources with a distinguished load of cultivation, culture and history.

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Declarations

Conflict of interest All the authors declare that they have no conflict of interest.

Consent for publication All our authors have agreed to submit and publish this work in your journal formats, including print and digital platforms. All authors are acknowledged and permitted to publish this work.

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