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RESEARCH ARTICLE

Crop landraces inventory for Portugal

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Abstract The threats to agrobiodiversity ultimately affect our future food security. Countries bonded to national or international biodiversity conservation legislation should conserve and sustainably use their agrobiodiversity. Landraces are a key element of agrobiodiversity which is largely endangered due to lack of their systematic conservation, and partially due to obstacles in developing inventories which may be assigned to the difficulties in applying a standard landrace' definition and to complications associated with nomenclature (synonyms/homonyms). Effective national conservation of landraces can be best achieved with a comprehensive inventory. In this paper, we developed a comprehensive inventory of food and other Portuguese agricultural landraces by surveying literature, local media, and farms. Farms were selected based on knowledge of experts and using an ecogeographic diversity approach based on Geographic Information Systems. We compiled 14,813 records of 7492 different landraces. Grape vine (*Vitis vinifera* L.), common beans (*Phaseolus vulgaris* L.), and maize (*Zea mays* L. subsp. *mays*) have the highest number of landraces in Portugal according with the gathered data. Bragança and Faro are the districts with more records of landraces. The landrace inventory for Portugal that we developed is a first iteration of such kind and should be updated systematically.

Keywords Agrobiodiversity · Ecogeographic land characterization (ELC) maps · Inventory · Landraces · Conservation · Management

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Introduction

Despite their value to farmers and plant breeders, crop landraces are disappearing rapidly. The genetically diverse landraces are being replaced by more productive, but genetically uniform cultivars (e.g., Negri 2005; Negri et al. 2009) throughout Europe and Portugal is not an exception (Veloso, 2008). Their active conservation is required to maintain the wealth of genetic diversity they possess that is the foundation of much global plant breeding. Landraces public good value is recognised by the Convention on Biological Diversity (CBD) and the International Treaty

on Plant Genetic Resources for Food and Agriculture (ITPGRFA), both emphasizing the need to develop inventories of the plant genetic resources (PGR), including landraces, as the first step towards promoting PGR conservation and sustainable use (Negri et al. 2009; INIAV et al. 2015).

An inventory of landraces catalogues the existing landraces present in a particular geographic region and their associated knowledge and can be used as a basis for planning efficient conservation actions (Maxted et al. 2013). The associated knowledge should contain ecogeographic information of the site where it is cultivated, details about the farm and the farmer that grows them, nomenclature, cultivation and habits, and distinctive traits (Maxted et al. 2009). Farmers are normally interviewed using a questionnaire that aims at collecting relevant data associated with the landraces they cultivate, and samples of the landraces grown are collected. The selection of farmers and/or sites to survey can be based on the knowledge gathered from the literature, experts, or can be based on an ecogeographic diversity approach. The latter assumes that different landraces are cultivated in areas with different environmental characteristics. It involves the development of an Ecogeographic Land Characterization (ELC) map to identify diverse environmental areas, with distinct abiotic features (Parra-Quijano et al. 2012). Thus, each area can be visited and sampled systematically with less effort, saving time and resources.

Portugal is located in southwest Europe in the west of the Iberian Peninsula; it includes continental Portugal, the Azores and Madeira autonomous island Regions in the Atlantic Ocean and has a total area of 92,212 km^2. Portugal is divided into 7 territorial regions (NUTSII): North, Centre, Lisbon Metropolitan area, Alentejo, Algarve and the Autonomous Regions of Azores and Madeira. The main annual and perennial crops cultivated in Portugal are listed in Supplementary Table S1 and include several cereals, horticultural crops, tubers, and a great diversity of fruits. Additionally, there are several minor crops that are mainly used for local consumption such as various subtropical root crops (e.g., taro) in Madeira (Carvalho 2008; INE 2017). Portugal's ecogeographic settings along with the diverse traditional agricultural characteristics allowed the development of a significant range of landraces of numerous cultivated crops (Carvalho 2008; Veloso 2008; Veloso et al. 2008).

There are three main institutions in Portugal maintaining ex situ collections of PGR and landraces collections: *Banco Português de Germoplasma Vegetal* (BPGV) in Braga, mainland Portugal, *Banco de Germoplasma ISOPlexis* (ISOPlexis) in Madeira and *Banco do Centro de Biotecnologia dos Açores* (BCBA) in the Azores. The BPGV has the most comprehensive collection, comprising more than 70% of national collections. In total, landrace material accounts for around 35% of Portuguese gene bank collections, with cereals and grain legumes having the highest representation (Barata et al. 2008). Field collections are held by INIAV—the *Coleção Ampelográfica Nacional* with the largest grape vine collection; by DRAPC—the *Estação Agrária de Viseu* and DRAPN—*Centro de Formação Profissional de Vidago* which have the main *Malus* and *Pyrus* collections; and *Direção de Agricultura e Pescas do Algarve* (DRAPAlg) which has the main *Citrus* collection alongside other fruit trees such as carob and fig trees, loquat and pomegranates. DRAPN and DRAPAlg also maintain almond field collections and DRAPN has the national collection of apricot (INIAV et al. 2015).

There are field collections of vineyards in the Azores archipelago, namely the varieties *Terrantês*, *Verdelho* and *Arinto dos Açores* in S. Miguel, Graciosa and Pico islands, respectively (Jorge, Sousa and Paulos, personal communication 2017). There are also *Citrus* field collections in Pico and Terceira islands in the Azores (Jorge, personal communication 2017). In the Madeira archipelago, the *Direção Regional de Agricultura, Madeira* (DRA) holds apple, pear, abacate, custard apple, chestnut, cherry, sour cherry and sweet potato field collections of local varieties in several experimental stations. The *Centro de Desenvolvimento e Inovação Sociocultural e Agroflorestal* (CDISA), in Jardim da Serra, holds field collections of chesnut, sour cherry and apple and maintain the on-farm conservation of several landraces. The experimental field stations of Cardais, São Vicente and Arco de São Jorge, Santana, from the *Instituto de Vinho, Bordado e Artesanato da Madeira* (IVBAM) maintains the field collections of traditional and certified varieties of Madeira and table wine of Madeira Protected Designation of Origin (PDO), including *Sercial*, *Boal*, *Malvasia*, *Verdelho*, *Tarrantês*, *Tinta Negra*, *Carracol* and *Listrão*. The *Centro Experimental do Farrobo,* in Porto Santo promotes the multiplication of cereals varieties of wheat,

oat, barley, and rye (Freitas, personal communication 2017). A major part of these genetic resources, including the field collections of fruit trees are inventoried through the Information and Documentation System (SID) of ISOPlexis, (http://isoplexis.uma.pt/gringlobal/search.aspx).

Concerning on-farm conservation of landraces, there is no formally recognized active on-farm conservation of LR in Portugal, although VASO (Sousa Valley) Project (Mendes Moreira et al. 2009) presents a participatory plant breeding project where landraces have been valued. However, Portuguese farmers maintain an exceptionally wide array of landraces of vineyards and olive trees, that are highly cultivated and economically relevant (e.g., Veloso et al. 2008; Cardoso and Maxted 2009).

The EU policy on product quality certification is also applied in Portugal. Protected Designation of Origin (PDO) and Protected Geographical Indication (PGI) have been assigned to some products produced with landraces, stated as Class 1.5. and 1.6. (European Commission 2017; and see https://www.iniav.pt/divulgacao/publicacoes-bd/inventario-portugues-de-variedades-locais-landraces) and wine products (IVV 2016). There are 55 crop certified products out of which 32 and 23 are PDO and PGI certifications, respectively (IVV 2016; European Commission 2017). The certification entities were contacted to ascertain the commercialization of products under the quality seal. From 12 obtained answers, 10 products remained certified and sold and 2 are no longer commercialized with the quality label. The certified wine products continued to be commercialized as PDO and PGI (IVV 2016). The necessary conditions to have quality certification may change and a product might be granted or withdraw from it.

In this paper we present the results of a national survey of landrace diversity based on the landraces recorded in national ex situ collections, literature, and field surveys. The results may form the basis for the development of a national strategy for the conservation of Portuguese landraces.

Materials and methods

Landrace working definition

The definition of a landrace applied in the project was that proposed by Camacho-Villa et al. (2005), with LR distinguished based on nomenclatural difference and BPGV experts' opinion: landraces with the same name and same collecting site were assumed to be the same landrace, whereas landraces with different names or same name but different collecting sites were assumed to be different landraces.

Landrace survey and data collection

Landrace diversity was identified using published and "grey" literature, relevant websites (see https://www.iniav.pt/divulgacao/publicacoes-bd/inventario-portugues-de-variedades-locais-landraces for the list of references used), and field, with a questionnaire applied to farmers. The USDA, ARS, GRIN (2017) platform was used to standardize crop nomenclature as well as to obtain the accessions conserved in Portuguese gene banks (BPGV and ISOPlexis) (up to March 16th, 2017). The national catalogues, *Catálogo Nacional de Variedades* (CNV 2016) and *Catálogo Nacional de Variedades—Fruteiras* (CNVF 2016) were also considered, and the varieties registered as *conservation* or *traditional varieties* were added to the inventory. Landraces were excluded if they did not have collection site or date of collection. The data recorded were landrace names, crop scientific names, collection site and year of collection, mode of consumption and other available remarks as for example adaptation to altitude and drought.

Selection of sites

Field work was carried out in April and between July and September 2015 and a total of 165 farms were surveyed (Supplementary Figure S1.). The aim was to collect information to complement the one gathered from literature and genebanks. Thus, data from all LR's crops were collated from the 165 farms, throughout a questionnaire. In Madeira and the Azores Autonomous regions, experts from Madeira University (ISOPlexis Genebank) and from the Azores Agricultural Departments of each island were consulted to help identify field sites to be visited. Given the national importance of common bean (Martins et al., 2006), and the broader area to assess, a more targeted field survey for common bean landraces was carried out in mainland Portugal. In order to select the target sites, an ecogeographic diversity approach was carried out using the CAPFITOGEN

tools version 2.0 (Parra-Quijano et al. 2016). An Ecogeographic Land Characterization (ELC) map was developed for common bean landraces in Portugal based on ecogeographic variables selected using a two-step process: the ecogeographic variables of each component (bioclimatic, edaphic and geophysical) that best influence common bean landrace distribution were selected by BPGV experts, and a Random Forest (RF) statistical method, implemented in the SelecVar tool of the CAPFITOGEN tools (Parra-Quijano et al. 2016), was subsequently applied to select the final set of variables (Supplementary Table S2). The ELC map presented 22 different ecogeographic areas and a degree of resolution was 1 × 1 km cell size (30 arc-sec) (Fig. 1).

Results

The results of the field survey, obtained from the questionnaire applied to farmers, are comparable with other works (e.g., Negri 2003, 2005), regarding farmers' age, landrace's consumption mode, reasons for maintaining the landraces and decline. Throughout the Portuguese territory, most landrace maintainers are over 65 years old, and farmers maintain landraces due to maintenance of traditions (e.g., gastronomical traditions) and perceived superior flavour compared to commercial varieties. Landraces are cultivated predominantly for self-consumption, in backyards or small gardens, and less frequently in small farms (up to 0,5 ha). Farmers observed a decline on landrace cultivation in recent years, as they become older, they are physically unable to keep cultivating landraces and their children have other occupations, and generally lack the knowledge and time to maintain landrace

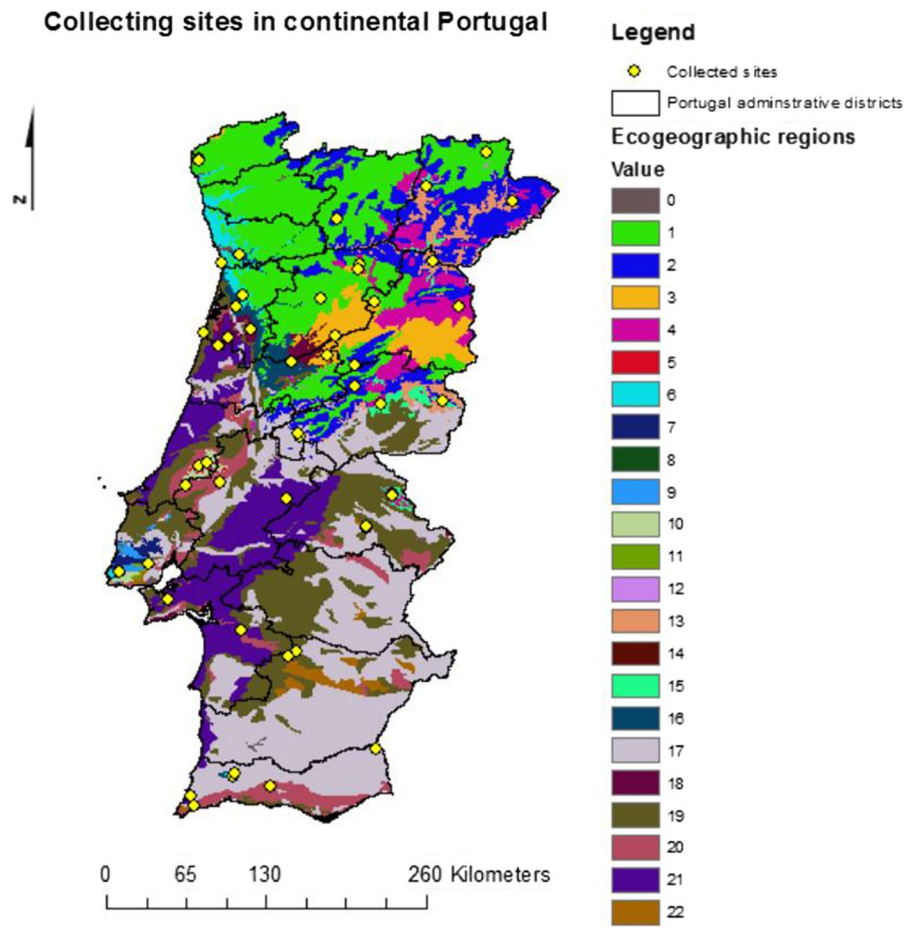

Fig. 1 Ecogeographic Land Characterization map for common beans in mainland Portugal with the sites where field survey was carried out. Different colours refer to different ecogeographic categories

cultivation. Nonetheless, there is still a good range of LR diversity requiring strong conservation measures.

The *Portuguese Inventory of Food and Other Agricultural Crop Landraces* (made available at https://www.iniav.pt/divulgacao/publicacoes-bd/inventario-portugues-de-variedades-locais-landraces) contains 14,813 landrace records that correspond to 7492 unique landraces after applying the landrace working definition. These landraces are grouped within 36 plant families, 88 genera, 130 taxa and 123 crops. The four families with highest number of landraces were the *Fabaceae*, *Vitaceae*, *Poaceae* and *Rosaceae*, the four genera with the highest number of landraces were *Vitis*, *Phaseolus*, *Zea* and *Brassica*. The numbers of landraces within all 130 crop taxa are listed in Table 1. Some landraces could only be identified to the genus level, and these are listed in Table 2. The taxa with the largest number of landraces are grapevine (*Vitis vinifera* L.), beans (*Phaseolus vulgaris* L.) and maize (*Zea mays* L. subsp. *mays*).

In the Portuguese mainland, the districts with the highest number of crop genera are Aveiro and Évora (43), Bragança and Faro (42), Santarém (39) and Setúbal (38) and the highest number of LR are recorded in Bragança (855), Faro (555), Aveiro (537) and Viseu (467) districts (Fig. 2 and Supplementary Table S3). Some records in the inventory were not included in our analysis because geographic information was inaccurate (Supplementary Table S4 and S5). Beans and grapevine are the most common crops in continental Portugal, while in the Azores and Madeira archipelagos, beans, sweet orange, and sweet potato are the most common crops (Fig. 3).

Discussion

NEGRI and Torricelli (2015) developed an inventory of landraces that are still cultivated on-farm comprising 2365 landraces belonging to 329 crops. In this paper, we cannot report on the number of extant landraces. The inventory that we prepared includes landraces that are conserved ex situ, those that are maintained on-farm and those that are referred in literature (potentially including many landraces that are no longer cultivated).

Lack of detailed information regarding landrace diversity and their characteristics, as well as the threats they face in today's agro-ecosystems, their level of erosion and extinction hampers their active conservation and use, both by farmers and in crop improvement. Existing information on Portuguese landrace diversity is diffuse and its collation is time consuming, but this base study intended to produce a first iteration of the Portuguese inventory of landraces which currently includes 14,813 landrace records. The methodology used to collate the inventory data, combining literature, media surveys, and field work based on an ecogeographic diversity analysis, proved to be generate a comprehensive inventory and such approach could be applied in other countries and regions, where information is dispersed, and time is limited. It was noticeable that all farmers visited immediately grasped the value of the study in the preservation of agricultural heritage once the aims were explained. The farmers were generous with their time and always tried to provide samples for ex situ backup. The districts with the highest number of crop genera, in mainland Portugal Aveiro and Évora (43), Bragança and Faro (42), Santarém (39) and Setúbal (38) and with the highest recorded number of LR, Bragança (855), Faro (555), Aveiro (537) and Viseu (467) districts, should be extensively monitored. Thus, threat assessments and implementation of conservation measures could be developed and applied. Nevertheless, the value of the less LR diverse areas should not be discard.

Agrobiodiversity inventories are a "snapshot" of landrace diversity of a certain geographic region; the diversity described is partially defined by the techniques applied and resources available, but the critical point is that such inventory should be periodic and iterative, repeated regularly to provide time series data and thus allow monitoring and changes to management if required (Maxted et al. 2009). Subsequent surveys can extend the range of landraces recorded; thus, each survey and revised inventory builds toward a more complete picture of the magnitude of landrace diversity and how it changes over time (Maxted et al. 2009). The inventory of landraces (a) is a useful tool for conservation planning (Veteläinen et al. 2009; Maxted et al. 2009) as it helps future collecting missions to be more systematic, addressing possible gaps and plan on-farm conservation projects, but also (b) provides a means of monitoring landrace diversity with possible triage identification of threats to landraces and threatened landraces, and (c) promotes

Table 1 Number of landraces per crop (species and/or infra-specific taxa level) in the Portuguese territory (mainland and the Azores and Madeira archipelagos)

Crop	Number of landraces	Crop	Number of landraces	Crop	Number of landraces	Crop	Number of landraces
*Vitis vinifera**	1470	*Prunus dulcis*	38	*Eriobotrya japonica*	7	*Lathyrus tingitanus*	2
*Phaseolus vulgaris**	1358	*Cucurbita moschata*	37	*Juglans regia*	7	*Morus nigra*	2
Zea mays subsp. *mays*	585	*Linum usitatissimum*	32	*Avena strigosa*	6	*Ocimum basilicum*	2
Malus domestica	264	*Colocasia esculenta*	30	*Brassica oleracea* var. *capitata*	6	*Ornithopus compressus*	2
Solanum lycopersicum var. *lycopersicum*	246	*Lathyrus sativus*	29	*Capsicum chinense*	6	*Physalis peruviana*	2
*Pyrus communis**	227	*Prunus persica**	29	*Setaria italica**	6	*Prunus cerasus*	2
*Lactuca sativa**	142	*Lolium multiflorum*	27	*Triticum aestivum* subsp. *compactum*	6	*Solanum betaceum*	2
*Brassica rapa**	137	*Capsicum frutescens*	26	*Brassica*o *oleracea**	5	*Vicia ervilia*	2
*Pisum sativum**	125	*Prunus avium*	24	*Capsicum baccatum**	5	*Ananas comosu* var. *cayene*	1
*Allium cepa**	124	*Raphanus sativus**	24	*Diospyrus kaki*	5	*Apium graveolens**	1
Ficus carica	124	*Hordeum vulgare* subsp. *vulgare*	23	*Psidium cattleyanum**	5	*Asparagus officinalis*	1
*Capsicum annuum**	121	*Coriandrum sativum*	22	*Arachis hypogaea*	4	*Cajanus cajan*	1
*Allium sativum**	114	*Cucurbita ficifolia*	22	*Brassica oleracea* var. *sabauda*	4	*Camellia sinensis*	1
*Cucurbita pepo**	106	*Lagenaria siceraria*	21	*Helianthus annuus*	4	*Cichorium endivia*	1
*Vicia faba**	103	*Brassica napus**	18	*Holcus lanatus*	4	*Cichorium intybus*	1
*Vigna unguiculata**	100	*Corylus avellana*	17	*Ornithopus sativus*	4	*Foeniculum vulgare**	1
*Olea europaea**	95	*Petroselinum crispum**	17	*Passiflora edulis**	4	*Glycine max*	1
Brassica rapa subsp. *rapa*	91	*Vigna unguiculata* subsp. *sesquipedalis*	16	*Solanum melongena*	4	*Lathyrus cicera*	1
*Cucumis melo**	89	*Triticum turgidum* subsp. *durum*	15	*Vicia sativa**	4	*Laurus nobilis*	1
Brassica oleracea var. *acephala*	86	*Citrus limon*	14	*Brassica oleracea* var. *italica*	3	*Lolium perenne*	1
Triticum aestivum subsp. *aestivum*	73	*Punica granatum*	14	*Lens culinaris**	3	*Luffa aegyptiaca*	1
*Prunus domestica**	72	*Beta vulgaris* subsp. *vulgaris*	13	*Portulaca oleracea*	3	*Melissa officinalis*	1
Citrus sinensis	68	*Solanum tuberosum**	13	*Prunus armeniaca*	3	*Nicotiana tabacum*	1

Table 1 (continued)

Crop	Number of landraces	Crop	Number of landraces	Crop	Number of landraces	Crop	Number of landraces
Brassica oleracea var. *costata*	59	*Castanea sativa*	12	*Saccharum officinarum*	3	*Origanum vulgare* subsp. *virens*	1
Citrullus lanatus	56	*Citrus reticulata*	12	*Satureja hortensis*	3	*Oryza sativa*	1
*Cucumis sativus**	56	*Spinacia oleracea*	11	*Allium ascalonicum*	2	*Panicum miliaceum**	1
*Ipomoea batatas**	49	*Lepidium sativum*	10	*Allium schoenoprasum*	2	*Passiflora ligularis*	1
*Secale cereale**	49	*Lupinus luteus*	10	*Annona cherimola*	2	*Persea americana**	1
*Cucurbita maxima**	48	*Nasturtium officinale*	9	*Arbutus unedo*	2	*Plantago lanceolata*	1
Avena sativa	47	*Sorghum bicolor**	9	*Carica papaya*	2	*Sinapis alba**	1
*Phaseolus coccineus**	47	*Cydonia oblonga*	8	*Ceratonia siliqua*	2	*Triticum turgidum* subsp. *turgidum*	1
Cicer arietinum	46	*Daucus carota**	8	*Cucumis melo* var. *reticulatus*	2	*Vicia articulata*	1
Lupinus albus	38	*Allium ampeloprasum**	7			Total	7200

*Crop species that present infra-specific taxa but for which taxonomic identification was not possible

Table 2 Number of landraces only identified to the genus level of the crop

Genus	Number of landraces	Genus	Number of landraces	Genus	Number of landraces
Cucurbita spp.	96	*Lathyrus* spp.	5	*Mentha* spp.	2
Brassica spp.	69	*Vicia* spp.	5	*Coffea* spp.	1
Triticum spp.	62	*Lupinus* spp.	3	*Ornithopus* spp.	1
Musa spp.	12	*Ocimum* spp.	3	*Phaseolus* spp.	1
Capsicum spp.	8	*Passiflora* spp.	3	*Physalis* spp.	1
Lolium spp.	8	*Allium* spp.	2	*Raphanus* spp.	1
Avena spp.	7	*Medicago* spp.	2	Total	292

utilization of landrace diversity by farmers and breeders (Maxted et al. 2009).

We should acknowledge the importance of the non-professional-based conservation, i.e., landrace farmers are not conservationists and are likely to have other priorities, habits, and traditions related to the landraces they grow, rather than ensuring unique alleles are maintained (Maxted et al. 2002; Camacho-Villa et al. 2005). All of which make enforcing standards in landrace definition, threat assessment and conservation methodologies and nomenclature synonyms problematic. Further, are we certain all entries included in the Portuguese inventory of landraces are indeed landraces and are they distinct landraces? Are they all still extant in the country? To ensure precision, these questions require additional field work and extensive phenotyping and genomic analyses. Nevertheless, our results show that landrace diversity in Portugal is still extensive compared to other countries and is seriously threatened (Veloso, 2008). The fires that took place recently in Portugal have further impacted farms and farmers and undoubtedly led to further landrace extinction. Waiting until enough resources are available for the necessary genomic analyses, means that significant Portuguese landrace diversity will

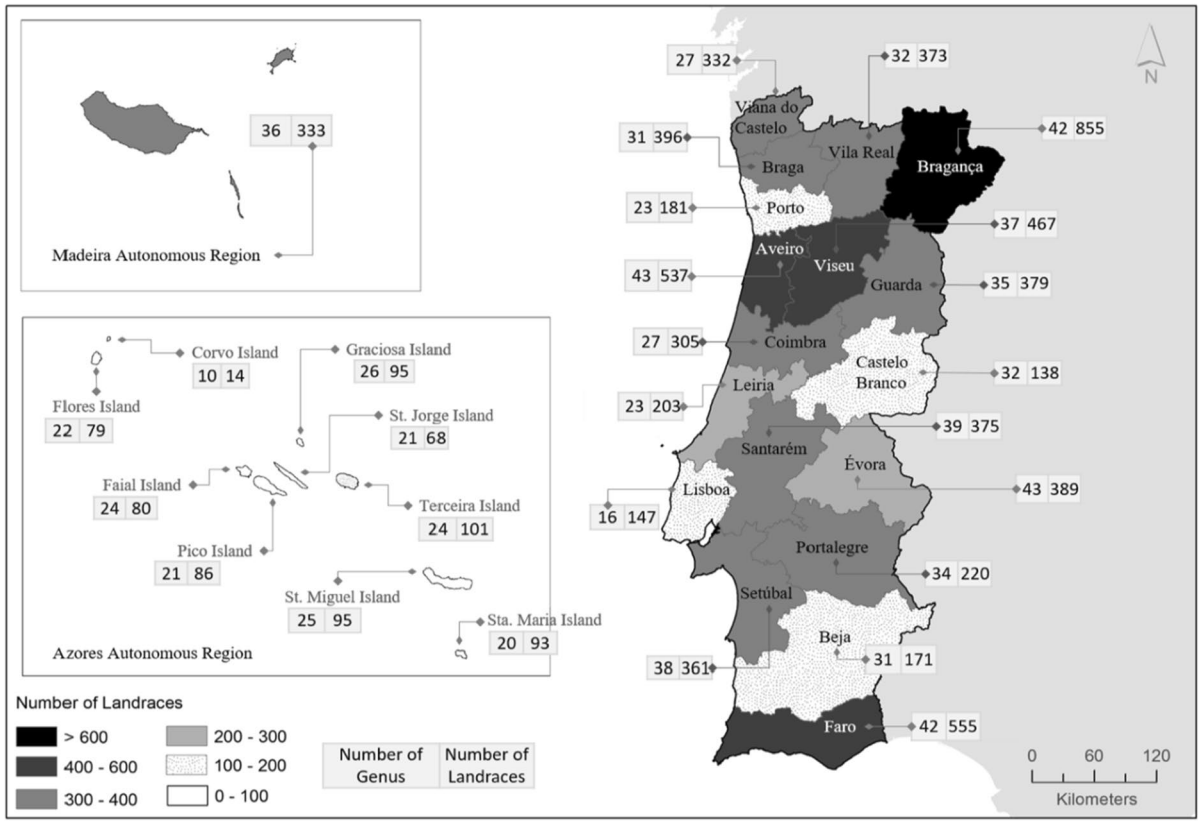

Fig. 2 Distribution of landraces in the Portuguese territories. Numbers indicate number of crop genera and number of landraces per territory

be surely lost. This has significant implications for future food security particularly giving the growing human population and environmental instability. Through the bibliographic survey and collation of farmer's knowledge, a significant step has been taken to plan landrace conservation more systematically and so avert landrace loss.

A recent study found the Mediterranean basin (including the south of Portugal) is an important hotspot for globally important crop wild relative diversity (Vincent et al. 2019) and it has also been highlighted that Portugal is also a hotspot for landrace diversity (Barata et al. 2008; Veloso 2008; Veloso et al. 2008; Cardoso and Maxted 2009; CNV 2016; CNVF 2016; Raggi et al. 2022). Our results (7492 unique landraces representing 123 crops) confirm that this is the case.

Finally, we want to stress that an inventory is a work in progress, with a requirement to be web enabled, repeated, and expanded periodically to have maximum it's use potential. The information contained in the inventory is expected to contribute to a National Agrobiodiversity Conservation and Use Strategy that aims at maximising complementary conservation of this unique resource and ensure the diversity contained underpins future national and regional food security.

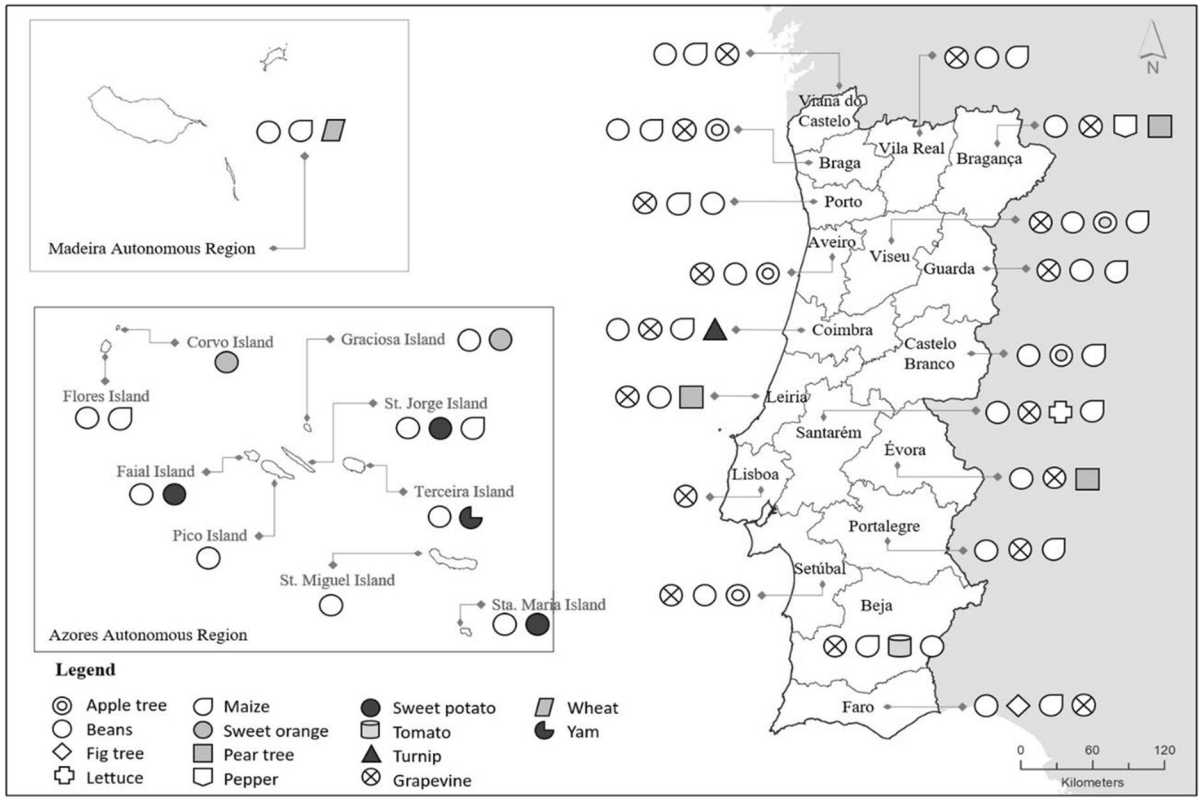

Fig. 3 Distribution of common crops in Portuguese territories

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Authors contributions MJA, AMB, JMB and NM contributed to the study conception and design. Material, preparation, data collection and analysis were performed by MJA, as well as the first draft of the manuscript. All authors commented on previous versions of the manuscript, read and approved the final manuscript.

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Data availability The dataset generated and analysed in the current study are available at https://www.iniav.pt/divulgacao/publicacoes-bd/inventario-portugues-de-variedades-locais-landraces, and are accessible from the corresponding author upon reasonable request.

Declarations

Conflict of interest The authors have no relevant financial or non-financial interests to disclose.

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