



An updated checklist of plant agrobiodiversity of northern Italy

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Abstract Northern Italy is an area particularly suitable for the cultivation of different crops. It used to be characterized by a high agrobiodiversity. However, it is estimated that over the last decades, this area experienced a genetic erosion of more than 90%, resulting in the loss of many traditional plant genetic resources (PGR). Nevertheless, recent surveys found an unexpectedly high agrobiodiversity which remains. The presented study aims to provide a complete overview

of plant agrobiodiversity (in terms of crop landraces, old cultivars and neglected crops) in northern Italy using a mixed approach of literature research and ethnobotanical field surveys. In addition, this paper aims to investigate on farm and ex situ conservation activities performed in the study area. 810 entities were found, of which 26 were identified as neglected crops, 377 as landraces (plus 124 doubtful landraces) and 99 as old cultivars (plus 184 doubtful old cultivars). 248 entities were here recorded for the first time through field surveys. It clearly emerges that by using an ethnobotanical approach, several PGR can still be found in the study area especially in small farms and home gardens. We describe hotspots of crop diversity and areas in which there is still a lack of knowledge of local agrobiodiversity. Only 43% of the PGR recorded are conserved long-term in seed banks, underlying the fact that great efforts are needed to ensure the ex situ conservation of PGR in northern Italy. Careful interventions are needed to enhance the on-farm conservation status of the crop diversity reported here by enhancing its demand and its accessibility.

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Introduction

Plant agrobiodiversity is defined as the diversity of crop species used in different agro-ecosystems as well as the genetic diversity within and among crop and crop wild relatives (Last et al. 2014). The conservation of traditional agrobiodiversity is fundamental for plant breeding to broaden the eroded gene pool of modern crop cultivars (Guarino and Lobell 2011; Vincent et al. 2013; Warschefsky et al. 2014). Keeping this diversity available could allow to select the improved crop cultivars of the future, capable to cope with the challenges that global food security is facing (e.g., a growing human population, changing diets, extreme climate conditions, lower availability of natural resources, soil degradation) and with the need for a more sustainable agriculture (Godfray et al. 2010; Asseng 2015). The bulk of genetic diversity in crops is found in landraces (Thormann et al. 2014). Landraces are defined by Camacho Villa et al. (2005) as “dynamic populations of a cultivated plant that have historical origins, distinct identities and lack formal crop improvement, as well as often being genetically diverse, locally adapted and associated with traditional farming systems”.

Landraces are not only important as sources of useful traits for crop breeding but also for reasons of cultural and local identity, being associated with traditional food products and superior sensory properties (see e.g. Barcaccia et al. 2015; Ardenghi et al. 2018; Orsenigo et al. 2018; Guzzon et al. 2019). Beside landraces, two additional categories of plant genetic resources for food and agriculture (PGRFA) are considered being particularly important for food security, breeding and conservation, namely neglected crops and old cultivars. Neglected and underutilized species (NUS), also referred to as underutilized or orphan crops, are defined as “crop species that have been ignored by science and development but are still being used in those areas where they are well adapted and competitive” (Hammer et al. 2001). Within NUS it could be possible to recognize different landraces which are poorly known due to the lack of characterization studies. Neglected crops are also linked to traditional recipes and sensory properties (see e.g. Ardenghi et al. 2017). An increased use of neglected crops is of key importance to diversify human diets that currently rely on an extremely reduced number of crop species (Li and Siddique, 2018; Conti et al.

2021). Another category of PGR of great value for breeding and conservation are old cultivars (Spataro and Negri 2013, also sometimes referred to as obsolete cultivars). Old cultivars are cultivated entities which have fallen into disuse (Food and Agriculture Organization (FAO) 1983). Unlike landraces, old cultivars had been subjected to formal crop improvement but were replaced by more productive, modern cultivars. They are considered being of great importance for cultivation since many old cultivars figure in the pedigrees of modern cultivars (see e.g. Lupton 1987). Moreover, old cultivars are often associated, like landraces, with food products with higher sensory properties and/or with traditional agricultural systems (Acquistucci et al. 2020). In this scenario it is of key importance to conserve and keep accessible agrobiodiversity (landraces, NUS and old cultivars) in the long-term. Furthermore, the conservation of PGRFA is fundamental to achieving target 9 of the 2011–2020 Global Strategy for Plant Conservation (and subsequent updates) and target 13 of the Convention on Biological Diversity’s Aichi Biodiversity Targets.

Two main strategies are used to conserve plant genetic resources, *ex situ* conservation in gene banks (i.e., the collection, transfer and storage of a population sample of a certain species away from its original location) and *in situ* conservation (the designation, management and monitoring of a population at the location where it is currently found and within the community to which it belongs). The *in situ* conservation of landraces (but also of old cultivars and neglected crops) is known as on farm conservation which is defined as the sustainable management of these entities by farmers within traditional agricultural systems (Veteläinen et al. 2009). While *ex situ* conservation, especially in terms of seed collections of orthodox seeds, has many advantages for the conservation of crop diversity for the long-term (Li and Pritchard 2009), it must be complemented by on farm conservation, since the genetic diversity of on farm populations is higher than that of accessions conserved *ex situ*. Moreover, on farm populations can continue evolving in order to adapt to changing environmental conditions and under the effect of farmer’s selection (Thomas et al. 2012). Additionally, landraces, old cultivars and NUS are linked to the cultural heritage, especially in terms of local food products, of the people cultivating them.

In many parts of the world, traditional plant genetic resources got lost due to their substitution with high-yielding modern cultivars (van Heerwaarden et al. 2009; van de Wouw et al. 2010). This is particularly evident in those areas which are characterized by intensive agriculture like in northern Italy. Hammer et al. (1996) estimated a genetic erosion for northern Italy of more than 90% over the last 50–60 years. Despite, several unique genetic resources, linked to unique food products, are still present in northern Italy. They are particularly suited for organic agriculture and they characterize different agroecosystems. Over the last few years, several traditional plant genetic resources from northern Italian regions, previously unknown to scientific literature, were described through ethnobotanical field surveys (i.e. on farm surveys on crop diversity employing questionnaires for farmers in order to investigate the history and use of each entity, see e.g. Hammer et al. 1999; Ardenghi et al. 2017, 2018; Manfrinato et al. 2019; Rossi et al. 2019), pointing towards the assumption that several neglected crops and landraces, still unknown to the scientific community, might still exist in this area. Currently, only few inventories of landraces are available for individual administrative regions and provinces of northern Italy (see e.g., Rossi et al. 2019 and Giupponi et al. 2020 for Lombardia region; Guzzon et al. 2019 for Pavia province), while little is known about other provinces, and the overall picture for the whole area is unclear. Recently, a landrace inventory, based on bibliographical data, was published by Giupponi et al. (2021), covering the entire country. This inventory showed that some northern Italian regions (e.g. Emilia-Romagna and Trentino-Alto Adige) are characterized by a relatively low diversity of landraces. It is not clear whether this low diversity is due to a real lack of crop diversity, the detrimental effects of genetic erosion in these regions, or due to a lack of knowledge on crop diversity that needs to be addressed by targeted field surveys. The publication of regional inventories of PGRFA is identified as a first key step in order to evaluate the threat of genetic erosion in a specific area and to develop an efficient system of conservation, both in situ (on farm) and ex situ.

The conservation and sustainable use of plant genetic resources, and the fair and equitable sharing

of the benefits arising out of the use of PGR, are the main objectives of the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA, FAO 2009). In this scenario, the main conservation tool for the European Union is represented by the Catalogue of Conservation Varieties, introduced by Council Directive 98/95/EC and improved through Council Directive 08/63/CE (see Bocci 2009; Spataro and Negri 2013 for an extensive analysis). According to this normative background, a “conservation variety” is a cultivated entity holding a clear link with a geographic area and being subject to a risk of genetic erosion. By today, only 19 of the 27 European Union countries have registered conservation varieties of agricultural crops. In Italy this process of valorisation has been underway for years, thanks to activities promoted by the Ministry of Agriculture (MIPAAF) and by the parliament itself, which passed a national law on this subject, Law no. 194/2015 (Ronchi and Brugna 2019). This was an important institutional process, which led to the issue of national guidelines for the conservation of plant agrobiodiversity. Italy is one of the major contributors to the Catalogue of Conservation Varieties in terms of number of entities registered, but its input is not even between different administrative regions (Santamaria and Ronchi 2016). In fact, the Italian contribution to the Catalogue depends on regional ad hoc normative, which is currently lacking in northern Italy, apart from the Emilia-Romagna Region. On the other hand, the normative background is well established in centre and southern Italy: various regions, primarily region Toscana since 1997, promulgated local laws to address PGR and agro-biodiversity conservation.

The current study proposes a list of PGRFA of conservation value in the eight administrative regions that constitute northern Italy. This list is obtained through a mixed approach of ethnobotanical field surveys, performed between 2013 and 2020, and bibliographic research. The aims of this paper are to, (1) provide a complete list of PGRFA of conservation value in the study area, (2) perform a gap-analysis of the PGR found in the study area that are conserved in ex situ conservation facilities, and (3) find hotspot of PGRFA diversity in the study area.

Materials and methods

Study area

Northern Italy comprises eight administrative regions (Emilia-Romagna, Friuli-Venezia Giulia, Liguria, Lombardia, Piemonte, Trentino-Alto Adige, Aosta Valley, Veneto). The total surface area is 120,260 km². The human population is almost 28 million people (ISTAT 2015), which translates to an average population density of 232.35/km², which is more than twice the mean average population density in the European Union (112/km²). Geographically, two mountain chains demarcate the study area: the European Alps in the north, and the Apennines in the south. The river Po is Italy's longest river and crosses the whole study area in a west–east direction. With its 114 tributaries, the Po created the most extended fertile quaternary alluvial deposit in Italy. The Po Plain represents one of the key areas for the development of agriculture in Italy. The cultivated land in the study area is 4,568,837 ha with a production value of €25.59 billion (ISTAT 2015). Currently, farms in the study area have got an average size (in terms of UAA, Utilised Agricultural Area; *Superficie Agricola Utilizzata*, SAU) of about 14.4 ha for north-west farms and 9.8 ha for north-east ones (ISTAT 2015).

Literature review

Agrobiodiversity of northern Italy was studied through both, a literature review and ethnobotanical field surveys carried out by the authors. The literature review took in consideration scientific papers about agrobiodiversity conservation as well as “grey literature”, such as regional registers and atlases, didactic materials of botanic gardens, reports on agrobiodiversity conservation projects and databases of genebanks. A selection of the most valuable literature sources used in this analysis (161 entries) is shown in Supplementary materials 1.

Field surveys

Field surveys took place between 2013 and 2020 in several locations of all eight administrative regions of northern Italy. Locations of the field surveys are shown in Fig. 1. Interviews using a semi-structured questionnaire (Supplementary materials 2) took

place on site. Interviews targeted both professional farmers and amateurs. As suggested by Vogl and Vogl-Lukasser (2004), we used a snowball sampling approach whereby the contact with an individual farmer in a new locality was often key to access a group of people with traditional knowledge about plants and germplasm. The participation of farmers and growers at the interviews was completely voluntary. Interviewees were asked (1) how many crop species, landraces and cultivars they grow, their local names, for how many years each entity has been cultivated, from whom the seeds had originally been obtained; (2) technical aspects of the cultivation such as, agronomical practices, selection and conservation of seeds, plant uses.

Samples of seeds were collected and are currently long-term preserved at the University of Pavia Plant Germplasm Bank according to FAO (2014) standards. Data associated with the seed samples, ethnobotanical interviews and related technical photographs (taken both, in the field and in laboratory) are stored in a database managed by University of Pavia Plant Germplasm Bank.

PGRFA categories

The current study is restricted to herbaceous crops for human consumption. Woody crops, ornamental, pharmaceutical or phytotherapeutic, fodder and other crop categories are not considered.

Entities recorded were attributed to one of the three following categories of PGRFA:

- Landraces of major crops: a dynamic population of a cultivated plant in which we considered the lack of formal improvement as the key feature (Camacho Villa et al. 2005; Ardenghi et al. 2018). Selection is farmers-driven, with no formal breeding activity (Food and Agriculture Organization (FAO) 1998). To consider a cultivar as a landrace we defined that it must have been cultivated for at least one human generation in the same area (≈ 30 years, as proposed by Louette et al. 1997) with no evidence of formal breeding.
- Old cultivars: cultivars undergone a varietal improvement through professional breeding in the past, but then abandoned by conventional seed companies in favour of more productive or resistant cultivars and now surviving mainly in tradi-

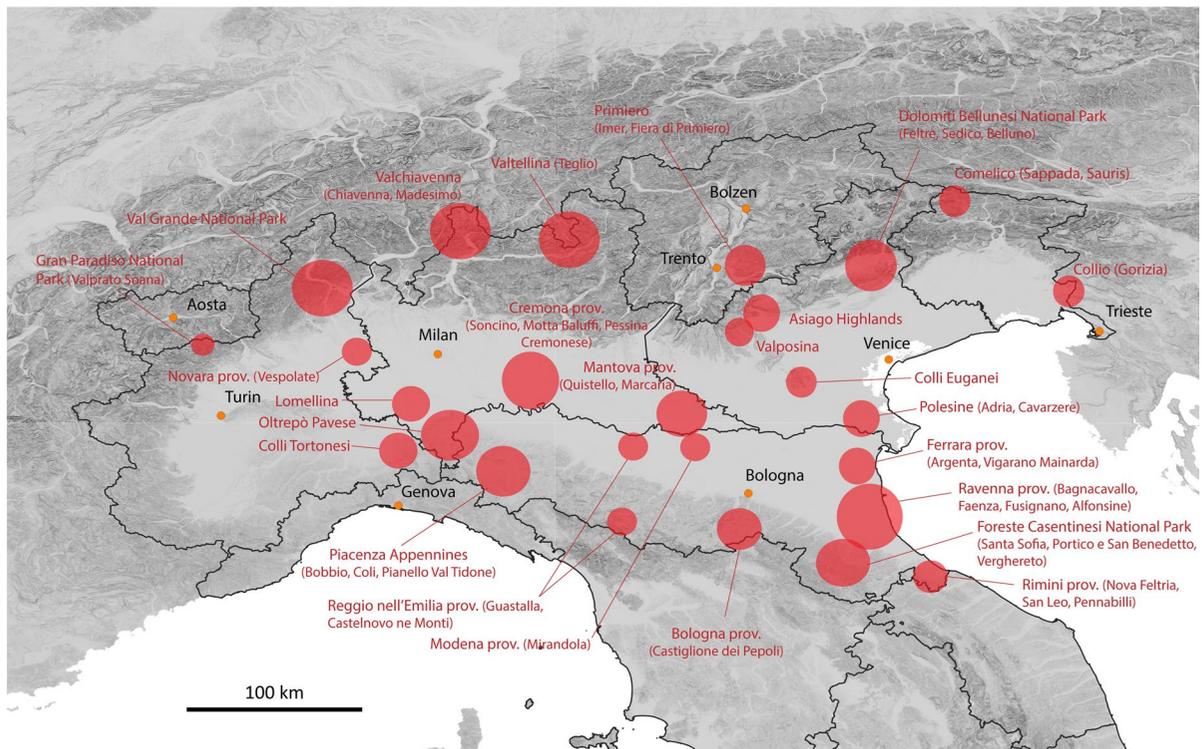


Fig. 1 Study area. Red circles indicate the localities targeted by field surveys. Black lines represent boundaries of Italian administrative regions

tional farming system. They are also known as obsolete cultivars (Food and Agriculture Organization (FAO), 1983; Skovmand et al. 2002), secondary landraces (Zaven 1998) or folk varieties (Berg 2009).

- Neglected and underutilised crops (NUS) sensu Hammer et al. 2001. Neglected and underutilized crops are: (1) important in local consumption, (2) cultivated mainly in marginal area, (3) cultivated and utilized drawing on traditional knowledge, (4) characterized by fragile seed supply systems (Padulosi and Hoeschle-Zeledon 2004). As NUS we decided to consider only crop species that are actively cultivated in the study area, not considering wild edible plants that are presently being considered for domestication (for example, *Cicerbita alpina* (L.) Wallr, see Palma 2020; Fusani, 2009). As highlighted above, it is possible that within a NUS, different landraces could be classified which are currently unknown or poorly known due to the lack of characterization studies. As an example, for some of the NUS in this paper (e.g.

Luffa aegyptiaca Mill.) several landraces are recognized in other cultivation areas (Kumari et al. 2019). Nevertheless, there is gap of knowledge on landraces classification in the study area, so we decided to consider them as NUS for northern Italy.

As shown in Supplementary materials 3, the border between PGRFA categories is sometimes unstable, especially between landraces and old cultivars, and between old and modern cultivars. The attribution of an entity to one category could not always be clear cutting for many reasons including information gaps, e.g., the breeding history is often missing and/or the involvement of professional breeders could not be verified. We marked such uncertain cases with “(?)”.

Geographical data and ex situ conservation

Entities grouped on a regional basis were used to design an heatmap on QGIS (2020), to visualize the

distribution of the PGRFA. For each entity, its availability in national ex situ collections was checked in the following research institutes: Plant Germplasm Bank of the University of Pavia (Pavia), ex Istituto di Genetica e Sperimentazione Agraria “N. Strampelli” (Lonigo, Vicenza), Crei-Cerzoo of Università Cattolica del Sacro Cuore (Piacenza), CREA-CI (Bergamo), Banca del Germoplasma Autoctono Vegetale (BaGAV, Università di Udine), Centro Ricerche Produzioni Vegetali (Bologna), Institute of Biosciences and Bioresources (IBBR) of the Italian National Research Council (CNR; Bari). Accessions were traced using the national database PlantARes (<http://planta-res.politicheagricole.it/pages/index.php>), gene bank internal databases and through personal communication with gene bank curators. The cultivar name(s) was the main descriptor used in this search.

Results

In our ethnobotanical and literature surveys, we found 810 entities (see Supplementary materials 1). Of these entities, 26 were identified as NUS, 377 as landraces (plus 124 doubtful landraces) and 99 as old cultivars (plus 184 doubtful old cultivars). Overall, 248 entities were recorded through the field survey. More than 50 interviews were performed. The number of these entities in each administrative province is shown in Fig. 2. The province with the highest number of traditional PGRFA was Forlì-Cesena with 62 entities, while in three provinces no entities were recorded (Lodi, Biella, Verbano-Cusio-Ossola).

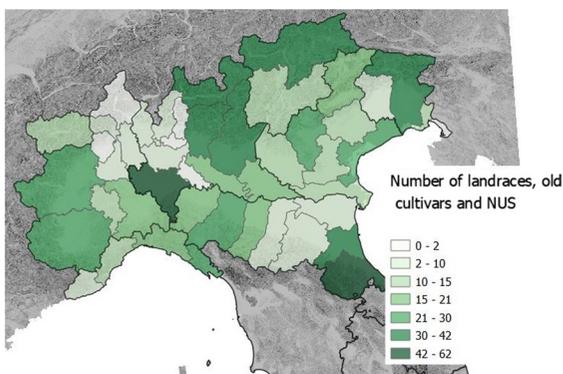


Fig. 2 Heatmap reporting the numbers of PGRFA found in each administrative province

Considering the number of traditional PGRFA grouped per administrative region, Emilia-Romagna has the highest number of entities recorded, while Valle D’Aosta the lowest (respectively 232 and 12 entities). The best represented botanical families were Poaceae, Fabaceae and Solanaceae, with respectively 224, 176 and 143 entities (Fig. 3). Of the 810 entities we found, 344 are currently long-term conserved in ex situ seed conservation facilities. Apart from few exceptions (*Allium sativum* L., *Allium oschaninii* O. Fedtsch., *Ipomoea batatas* L., *Solanum tuberosum* L.) the taxa are propagated by orthodox seeds (i.e., seeds that can tolerate drying to low moisture content and subsequent freezing).

Cereals and pseudocereals

Overall, concerning cereals (Poaceae) we found 127 old cultivars or landraces of maize, 22 of wheat, 14 of rice, 78 of rye, 5 of barley as well as 3 of the pseudocereal buckwheat (Polygonaceae). In the study area we found several examples of revival of cereal landraces or old cultivars, mainly known and commercialized as *grani antichi* (“ancient grains”), e.g. the maize ‘Spinato di Gandino’, the wheat ‘Gentil rosso’ and the rice ‘Bertone’.

Maize (*Zea mays* L. subsp. *mays*)

Maize has been cultivated in the study area since the second half of the XVI century. Northern Italy is considered a secondary centre of diversity of maize (Brandolini and Brandolini 2009). In our study we found 127 maize accessions belonging to seven racial complexes or cultivar groups: Eight rows flints, Conical flints, Microsperma flints, White flints, Semi flints, Insubrian flints (*sensu* Brandolini and Brandolini 2001, updated by Ardenghi 2019; Stagnati et al. 2021) listed in in Fig. 4. In addition, we found 8 landraces of popcorn maize (Everta Group) distributed in 4 regions (Emilia-Romagna, Lombardia, Trentino-Alto Adige, Veneto). Among the 8 popcorn landraces, 6 are cultivated on a horticultural scale by amateurs for personal consumption, while 2 landraces (white popcorn ‘Spose del Primiero’ and ‘Di Casola Valsenio’) are cultivated and also commercialized in

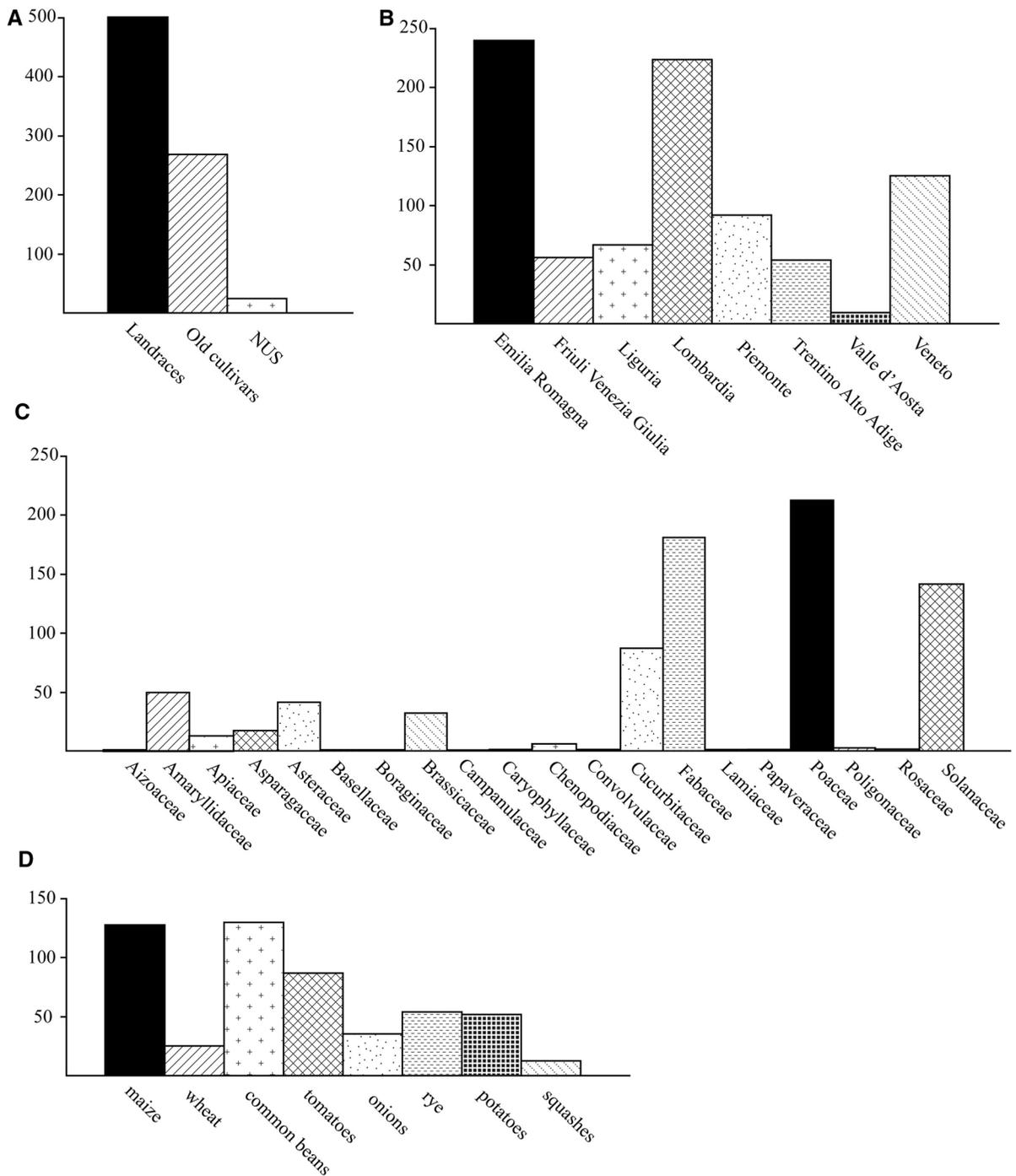
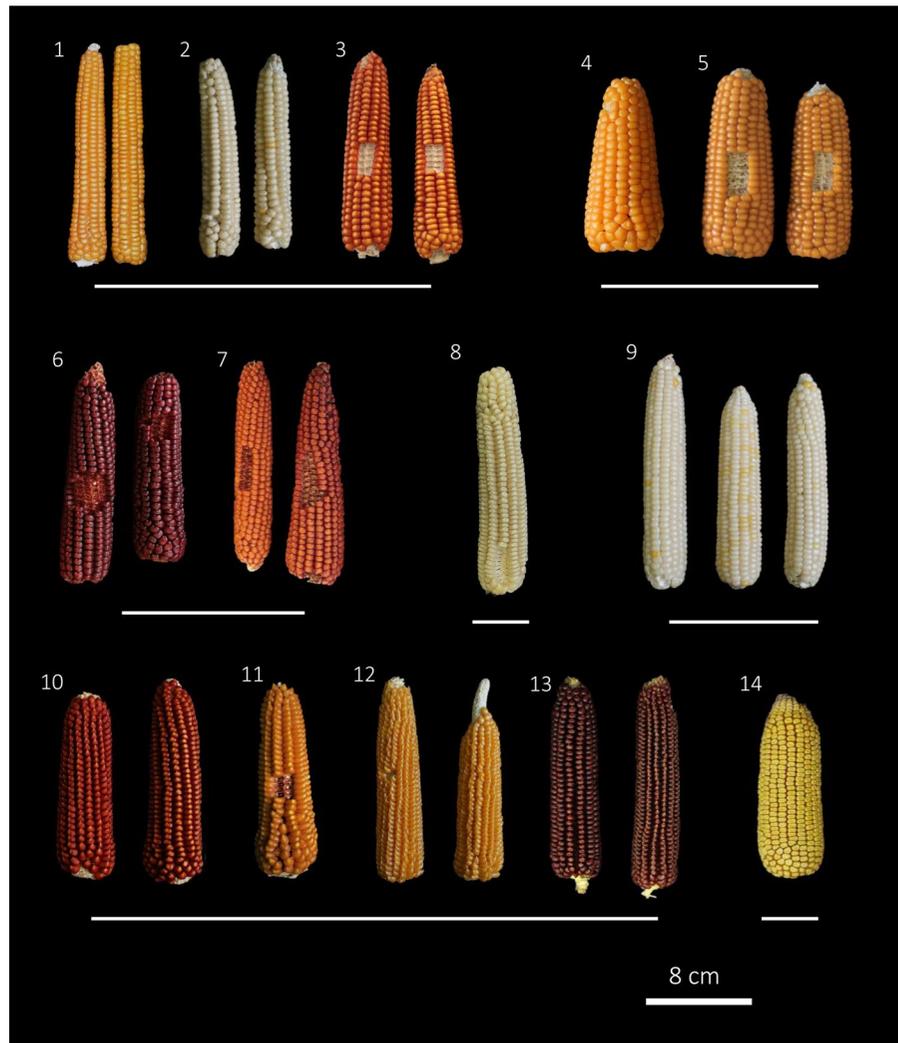


Fig. 3 Histograms reporting the number of entities recorded for PGRFA categories (A), administrative region (B), plant family (C), eight crops with the highest numbers of entities (D)

Fig. 4 Examples of maize ears collected during field surveys and grouped per racial complex. From the top left to the right; Eight rows flints: 1. ‘Ottofile Pavese’ 2. ‘Ottofile bianco’ 3. ‘Ottofile rosso’; Conical flints: 4. ‘Conico di Santa Sofia’ 5. ‘Sorc Dorotea’; Microsperma flints: 6. ‘Rosso di Rasora’ 7. ‘Cinquantino rosso di Ramiseto’; White dents: 8. ‘Dente di cavallo del Friuli Orientale’; Pearl white flints: 9. ‘Biancoperla’; Semi flints: 10. ‘Pignoletto rosso’ 11. ‘Spinato di Gandino’ 12. ‘Sponcio’ 13. ‘Rostrato di Valchiavenna’; Dents: 14. ‘Tagliolino’



small scale mountain agriculture (Stagnati et al. 2021, 2022).

Rice (*Oryza sativa* L.)

Documented Italian rice cultivation dates back to the second half of the XV century when the noble Sforza family promoted it in the wetlands of the Po Plain, where other cereals were difficult to grow (Mongiano et al. 2018). As reported by Cai et al. (2013), until the beginning of the XIX century all the rice cultivated in the study area belonged to ‘Nostrale’, a landrace highly affected by rice blast disease (*Pyricularia oryzae* Cavara). A heterogeneous corpus of rice blast-resistant cultivars was imported probably from

East Asia at different times, going under the name of ‘Chinese originario’. These cultivars represented the basis for further Italian rice breeding programmes, and since 1926 further improved cultivars have been commercialized (Ferrero and Vidotto 2019). In our survey we found 14 of these old cultivars.

Wheat (*Triticum* L. sp. pl.)

Landraces of wheat were widely cultivated in Northern Italy until the XIX century. Afterwards, the selection of local cultivars followed by crossbreeding and import of foreign germplasm resulted in the selection of more high-yielding cultivars that replaced the traditional wheat populations (Borghi 2001). We found

22 entities of wheat still in cultivation which belong to the following taxa, *Triticum aestivum* L. subsp. *aestivum*, *T. aestivum* subsp. *spelta* (L.) Thell., *T. monococcum* L. subsp. *monococcum*, *T. turgidum* L. subsp. *dicoccon* (Schrank) Thell., *T. turgidum* subsp. *durum* (Desf.) Husn. It must be underlined that wheat landraces were often cultivated across wider areas, encompassing several administrative provinces or even regions, unlike most other crop landraces that are linked to specific localities. This fact is probably due to the strong autogamy of wheat, that allows a high maintenance of the traits of a given landrace/old cultivar even when cultivated in proximity of other ones in a new area (Rigatti et al. 2018). In addition, it is important to note that some of the *Triticum* landraces are experiencing a re-appraisal of cultivation in several localities, mainly linked to organic farming and the revival of traditional products (see e.g. Migliorini et al. 2016). This is the case for the ‘Piave’ bread wheat which is the basis for several gastronomic products entirely composed of this old cultivar. Another, similar case is the old cultivar ‘Bianco delle Valli di Suvero’, a bread wheat which gained interest by a project of the municipality of Rocchetta di Vara (province of La Spezia), with the aim to encourage the revival of this old cultivar and the recovery of uncultivated land.

Rye (*Secale cereale* L. subsp. *cereale*)

In northern Italy, rye is mainly cultivated on the mountains, thanks to its resistance to low temperatures and marginal soils. In the XX century, its cultivation declined greatly (Peratoner et al. 2015). To the best of our knowledge there is no comprehensive catalogue of northern Italian cultivars. In two areas, individual studies had been carried out to describe landraces, 59 in Bolzano province (Peratoner et al. 2015) and 19 in Aosta Valley (Bassignana and Arlian 2013).

Barley (*Hordeum vulgare* L. subsp. *vulgare*)

In northern Italy, barley had been historically cultivated for both, human consumption and as animal fodder. We found information about only 6 landraces. In Veneto, the ‘Agordino’ landrace is still cultivated in valleys of the Dolomites mountain range (Andrich and Andrich 2015). The recent revival of ‘Agordino’

is also due to its use in local breweries. We recorded 4 barley landraces still cultivated in the mountainous areas of Sondrio (‘Pedenosso’, ‘Di Semogo’ and ‘Dumega’) and Brescia (‘Di Vezza’) provinces. An additional old cultivar was recorded in Emilia-Romagna (‘Leonessa’), which is cultivated in scattered localities across the region.

Buckwheat (*Fagopyrum* sp. pl.)

Cultivation of buckwheat is localized in mountain valleys of Lombardia and South Tyrol. In Lombardia two entities belonging the species *Fagopyrum esculentum* Moench were found (the landraces ‘Curunin’ and ‘Nustran’). The classical buckwheat area is Toglio in Valtellina (Sondrio province), where some farmers are still active and also mills and pasta craft workshops are here located. A third landrace named ‘Valtellinese’ belongs to the species *Fagopyrum tataricum* (L.) Gaertn.

Pulses

Common bean (*Phaseolus vulgaris* L. subsp. *vulgaris*) and runner bean (*Phaseolus coccineus* L.)

Santalla et al. (2002) proposed south western Europe as a centre of differentiation of common bean. Continued cultivation of landraces was documented in several areas of Italy (see e.g. Piergiovanni et al. 2000 for southern Italy, Negri and Tosti 2002 for central Italy). Common bean was introduced in Italy during the XVI century in mountain valleys of today’s province of Belluno (Piergiovanni and Lioi 2010). In this area, the best-established cultivar is ‘Lamon’, an old cultivar currently selected and commercialized. Nevertheless, the bean diversity of the whole mountain area of Veneto is remarkable. Here, we found and collected 14 landraces as e.g. the small sized ‘Gialèt’; the round ‘Bala rossa feltrina’, or ‘Maselete rosse’ (characterized by two-coloured, half white and half red, seeds, leading to its expressive name translating as “red cheeks”). In Friuli-Venezia Giulia, 15 common bean landraces were detected and almost 200 accessions of common and runner bean are conserved by the University of Udine Plant Germplasm Bank (Zandigiacomo et al. 2015). In the central parts of the Alps, we recorded 28 cultivars in the hotspots of Valchiavenna (Lombardia,

province of Sondrio), e.g., ‘Gabinón’, ‘Guàt giallo’, ‘Bobis della Val Codera’ and Valcamonica (Lombardia, province of Brescia), e.g. ‘Copafòm’, ‘Di Cevo’, ‘Di Garda’ (see Rossi et al. 2019). In Piemonte, the province of Cuneo is a source of several old cultivars, such as ‘Regina di Boves’, ‘Regina rossa di Centallo’ and ‘Borlotto di Entraque’. In the Apennines, we found landraces in Oltrepò Pavese (Lombardia, province of Pavia), where amateurs and small-scale farmers preserve ‘Rosso di Pietragavina’ and ‘Viola di Romagnese’. Overall, 24 entities of this crop were recorded in this area. Another pulse of minor economical value is the runner bean (*Phaseolus coccineus* L.). Its cultivation requires high daily temperature peaks and it is mostly limited to mountain valleys, cultivated usually at a domestic scale or in small farms (Rossi et al. 2019). However, we found 16 morphologically distinguishable entities of this crop, considered as landraces or doubtful landraces.

Cowpea (Vigna unguiculata (L.) Walp. subsp. unguiculata)

Even if the cultivation of cowpea landraces is more common in central and southern Italy (Polegri and Negri 2010), we found a total of 5 landraces in three different regions (Lombardia, Veneto, Emilia-Romagna). Some landraces are cultivated for the consumption of both, the long immature pods (Sesquipedalis Group, e.g. ‘A metro’ from Veneto), or the dark-eyed seeds (Melanophthalmus Group e.g. ‘Di Pietragavina’ from Lombardia).

Faba bean (Vicia faba L.)

Landraces of this crop were historically used in valleys of north-eastern Italy (Perco 1988). We found 8 landraces cultivated for personal consumption or small-scale markets in Veneto, Friuli-Venezia Giulia and Trentino-Alto Adige. We found that landraces with small seeds are used as animal fodder in many regions. However, we did not include these entities in our dataset as they are not used for human consumption.

Potato (Solanum tuberosum L.), tomatoes (Solanum lycopersicum L.) and other Solanaceae

PGRFA of Solanaceae in the study area were mainly represented by landraces and old cultivars

of potato (*S. tuberosum* L.), tomato (*S. lycopersicum* L.) and pepper (*Capsicum annuum* L.). Potatoes (42 entities) are widely grown in the study area where this crop have had a great importance for food security for several centuries, and where it is connected to many traditional food products. Tomato (80 entities) is mostly grown in Emilia-Romagna and Lombardia, whose plains are particularly suitable for its cultivation. Sweet pepper (19 entities) is cultivated in the study area in the southern part of the Po plain from Piemonte to Emilia-Romagna.

Leafy vegetables

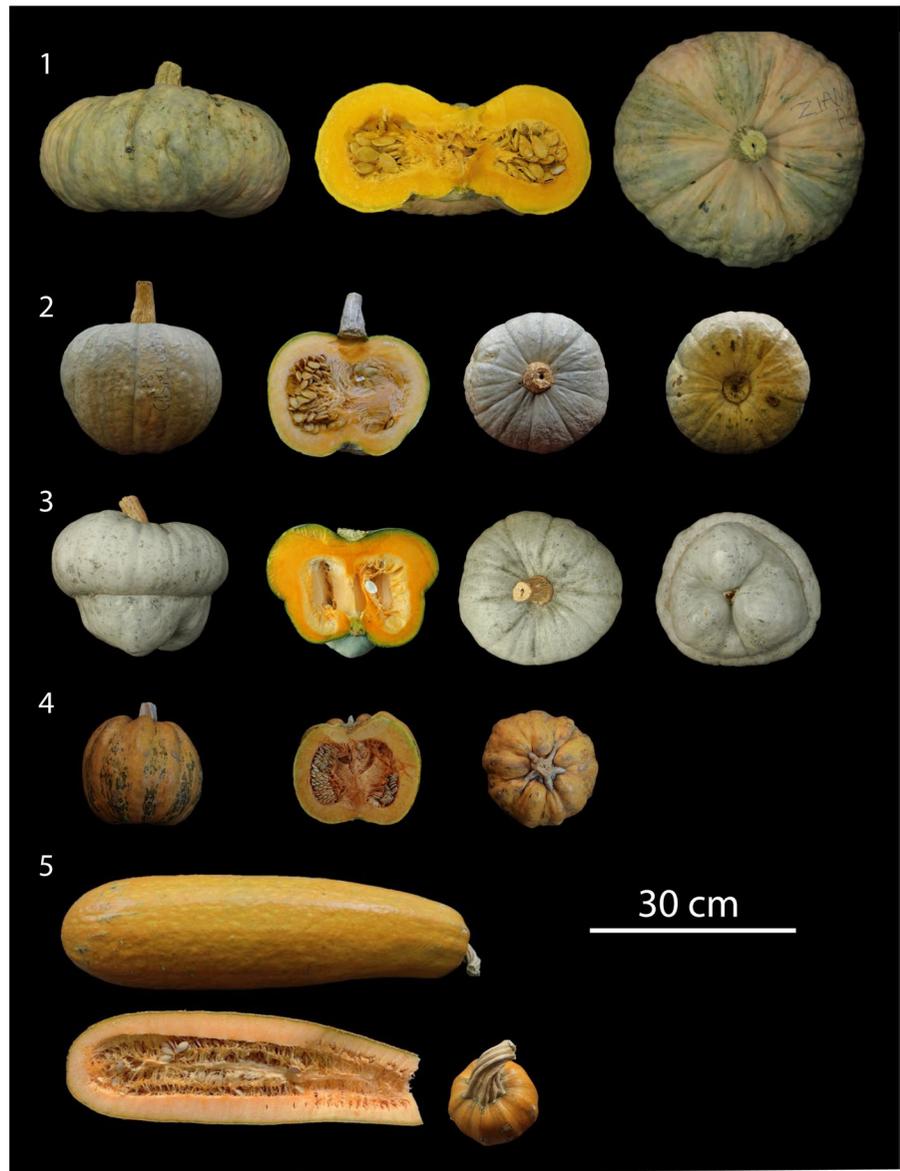
Among the leafy vegetables, we noticed a remarkable richness in radicchio (*Cichorium intybus* L.), a bitter leafy vegetable eaten usually boiled or grilled but also raw in salads. We recorded 19 old cultivars distributed in north-eastern regions (Veneto and Friuli-Venezia Giulia), where red-leaved cultivars are preferred. The most likely hypothesis is that all cultivars of red radicchio in the area were selected from ‘Rosso di Treviso’ (Pimpini et al. 2001). Some cultivars were obtained through mass selection as happened for the ‘Di Verona’ radicchio, while spontaneous hybridization with *Cichorium endivia* L. var. *latifolium* led to the ‘Di Castelfranco’ cultivar.

Cucurbits

Winter squash (Cucurbita maxima Duchesne subsp. maxima)

The introduction and spread of winter squash in Europe during the XVI and XVII centuries are well documented through pieces of art and naturalists’ descriptions (Formiga and Myers 2020). Among the 19 entities collected in this study, all main fruit-shape morphologies (based on Ferriol et al. 2004) were noticed, flattened, globular and turbinate (Fig. 5). We found that in northern Italy, the turbinate morphology is the most recurrent in landraces of winter squash. Good examples are ‘Cappello da prete’ cultivated in Emilia-Romagna, ‘Berrettina di Lungavilla’ and ‘Bertagnina di Dorno’ in Lombardia (Orsenigo et al. 2018). We noted also that ‘Marina di Chioggia’ is cultivated both, in turbinate and flattened phenotypes.

Fig. 5 Examples of fruit morphology in the genus *Cucurbita*. 1. flattened squash ‘Dell’orologio’, 2. globular squash ‘Di Castelvetro’ 3. turbinate squash ‘Di Dorno’ 4. pumpkin ‘bomba d’America’ 5. vegetable marrow ‘Da Tortelli’



Pumpkin, marrow and zucchini (Cucurbita pepo L. subsp. pepo)

16 entities were recorded among the pumpkins and marrows (summer squashes). The cultivar groups recorded are pumpkin (8 entities), marrow (4) and zucchini (4). Some of these entities have different

uses due to the maturation stage of the fruit, e.g., the fruits of ‘Da Tortelli’ from Forlì-Cesena province (Fig. 5, based on Paris 1986) are consumed like zucchini when unripe, while their pulp is used to stuff a local type of pasta (known as “tortelli sulla lastra”) when ripe (Rossi et al. 2019).

Watermelon (*Citrullus lanatus* (Thunb.) Matsum. & Nakai), *bitter melon* (*Citrullus amarus* Schrad.), *melon and cucumber* (*Cucumis* sp. pl.)

5 entities of watermelon, 13 entities of bitter melon and 17 entities of melon and cucumber (*Cucumis* sp. pl.) have been recorded. Such entities are traditionally cultivated in the southern Po Plain River, from Piemonte to Emilia-Romagna and Veneto. The sandy soils in these areas are particularly suitable for the cultivation of these crops.

Onion (*Allium cepa* L.)

32 old cultivars and landraces of onion were found. Even if this crop is common in all regions (except for Aosta Valley and Trentino-Alto Adige), its cultivation is localized due to the specific growing conditions required, e.g. sandy substrates. Many entities are cultivated in very limited areas and they are currently preserved by custodian farmers or cooperatives. The names of the cultivars usually refer to the colour of the skin, the area of origin ('Di Santarcangelo'), bulb shape ('Fiascona', meaning "big flask"), or more often to a mix of them ('Paglierina di Sermede', 'Rossa di Breme', 'Rosa di Bassano' 'Piatta di Bergamo' etc.).

Garlic (*Allium sativum* L.)

14 old cultivars and landraces of garlic were found in all regions (except for Aosta Valley and Trentino-Alto Adige) Some of these varieties are locally important such as 'Aaglio di Resia' in Friuli Venezia-Giulia (Palma 2020). Some garlic varieties carry a designation of origin (DOP) given by the EU (e.g. IGP, DOP), as in the case of 'Aaglio Bianco Polesano' (Rovigo) and "Aaglio di Voghiera" (Ferrara).

Neglected and underutilized species (NUS)

As part of our study, we found 26 NUS. During the last decades, the cultivation of some "minor" species were abandoned, and these species are currently collected in their natural environment as 'wild edible plants' (WEP, Hammer et al. 1999). Some prominent examples are *Blitum bonus-henricus* (L.) Rchb., *Glebionis coronaria* (L.) Fourr., *Reichardia picroides* (L.) Roth, *Rumex scutatus* L., *Smyrniium olusatrum* L.

(Ardenghi et al. 2017; Hammer et al. 1999). On the other hand, some taxa which used to be harvested as WEP for personal consumption are currently cultivated in a domestic-horticultural regime to standardize production, facilitate harvesting and/or allow local commercialization. This is the case for e.g. *Atriplex hortensis* L. subsp. *hortensis*, *Papaver rhoeas* L. subsp. *rhoeas* and *Silene vulgaris* (Moench) Garcke subsp. *vulgaris*. Other NUS are linked to local traditions and products and their cultivation is limited to extremely reduced areas. In some cases, a species is cultivated only within a given community, as it happens for *Artemisia genipi* Weber ex Stechm. cultivated in Maira valley (Piemonte, province of Cuneo, Laghetti et al. 2012) and *A. dracuncululus* L. in Sappada/Plodn (Friuli Venezia-Giulia, Manfrinato et al. 2019). In addition, some other crops are considered neglected in the study area while they are widely cultivated in other countries. This is the case for chayote (*Sicyos edulis* Jacq.), probably introduced in Lombardia by migrants from southern Italy during the XX century and now rarely cultivated in Lombardia, but widely grown in other parts of the world (Newstrom 1990; Rossi et al. 2019).

Ex situ conservation

To the best of our knowledge, 350 entities have at least one seed accession stored in a long-term storage facility, which represent the 43.2% among the total number of entities detected. Accessions are distributed as follows, 268 for the University of Pavia Plant Germplasm Bank (UNIPV), 24 for Banca del Germoplasma Autoctono del Friuli-Venezia Giulia (BaGAV), 5 for the CREA – unità di ricerca per la maiscoltura (CREA-Mac), 42 for the Centro di Sperimentazione Laimburg, 11 for the ex Istituto di Genetica e Sperimentazione Agraria "N. Strampelli" (Lonigo, Vicenza).

Discussion

Despite the dramatic changes due to industrialisation and introduction of modern cultivars that occurred in agricultural systems in northern Italy during the last decades, valuable PGRFA still persist, as previously showed for other European regions countries (Veteläinen et al. 2009). In the presented study, we found

810 entities, categorised as 26 NUS, 377 landraces (plus 124 doubtful landraces) and 99 old cultivars (plus 184 doubtful old cultivars). This high number of uncertain attributions is due to the lack of historical information for many cultivars connected with several crop breeding activities that had been carried out in the study area, especially since the beginning of the XX century (Zapparoli 1939; Brandolini and Brandolini 2006), which often makes it problematic to distinguish between landraces and old cultivars. This amount of uncertain attributions is sometimes also due to mixing and farmer breeding among landraces and cultivars. Moreover, information gaps on the breeding history of a given entity make sometimes impossible a certain attribution to landrace or cultivar categories. The amount of agrobiodiversity by looking at the names, historical data and morphology could be subject to over- or underestimations. This could be for example due to the use of different names for the same entity. Sadiki et al. (2007) showed how names could change more rapidly than crop traits from one area to another. This is the case of many pulses we found, which were morphologically very similar to one another, but which were identified by different names depending on the locality. As an example, the variety ‘Maselete rosse’ of Feltre (Veneto) mentioned above features the same bi-coloured beans as the ‘Della rama’ bean which we found in Santa Sofia (Emilia-Romagna), and both are similar to ‘Cappellette di Vallepietra’ of the central Italian Lazio region. In other cases, heterogeneous groups of cultivars possess the same common name, usually in combination with adjectives like *nustran* or *nostran* (meaning “local”). Given this situation, further analyses which should involve in-depth morphological characterizations and genetic analyses (see e.g. Barcaccia et al. 2015; Cassani et al. 2017) are needed to provide better classification systems of particularly complicated groups of Italian old cultivars and landraces, such as for example for squashes and pulses.

In accordance with previous studies, we could show that many landraces can still be found in northern Italy using an ethnobotanical survey approach, irrespective of the fact that this area experienced severe genetic erosion (Hammer et al. 1996) and was investigated previously through several PGR collecting missions (Hammer et al. 1999; Giupponi et al. 2020). This is largely due to the interviews conducted with owners of home gardens, managed by elderly

people for personal consumption or small scale markets (restaurants supplies, local fairs or gastronomic events) who over time, however, abandon this practice and the ancient seeds (Galluzzi et al. 2010).

With regard to the plant families, Poaceae, Fabaceae and Solanaceae were shown to be the best represented plant families in terms of recorded entities. One possible explanation for this is the traditional rural economy of the study area during the past centuries, in which maize, rice and wheat in the plains, and beans and potatoes in the mountainous areas were the most cultivated crops, used as a local source of carbohydrates and proteins (see e.g., Gasparini 2002; Perco 1988). The most diverse crop in term of number of entities found in our study were common bean (129) and maize (127). At least for maize, the allogamous pollination seems crucial in generating new morphologies, grain types and colours, and other plant traits leading to different cultivars. PGRFA of Solanaceae in the study area were mainly represented by 143 entities mainly of tomato, potato and sweet pepper. The high number of tomato entities can be related to the development in the northern Italy of the canning industry since the 1930s, with the development of cultivars later abandoned in the 1960s. These cultivars in many cases are still cultivated in home gardens (Ragazzi 1958).

The field survey and the bibliographic analysis pointed towards hillsides and mountainous areas as centres of agrobiodiversity which are therefore considered to be of particular interest for on-farm conservation of PGRFA: e.g. Apennines in the Forlì-Cesena province and Oltrepò Pavese (Pavia), Alps in provinces of Sondrio, Bolzano, Brescia, Bergamo and Udine. Our finding that mountain areas possess a high crop diversity confirms the results of previous studies in northern Italy that showed mountain areas as refugia of crop landraces (see e.g. Giupponi et al. 2021). Nevertheless, several entities were unexpectedly recorded in particularly diverse plains, too, such as in the provinces of Venezia, Cremona and Mantova. The southern part of Po Plain and the eastern parts of Emilia-Romagna are historically suited for the cultivation of different horticultural species (Castello e Monfroni 2009), linked to traditional food products and characterized by particular organoleptic properties (see e.g. Orsenigo et al. 2018 and Bionet 2014). This is often related to particular edaphic or climatic features of a given area, for example highlighted by

the diversity of carrot, radicchio and squash cultivars in coastal Veneto (an area characterized by moist, sandy soils). In these hotspots of agrobiodiversity, it would be important to promote farmers' conservation of traditional PGRFA through the formation of farmers consortia which could boost the production up to a market scale level, as it has already happened for some entities (see e.g. Da Deppo et al. 2013 for pulses in Belluno province). Custodian farmers are depositaries of plant propagation material and traditional knowledge which are essential to avoid the loss of a given PGRFA and its connected cultural heritage (Guzzon et al. 2021). To enhance the cultivation and therefore on-farm conservation of the crop diversity found in this study, the collaboration between different actors and stakeholders (i.e., farmers, consumers, breeding and research centres, policy makers, food manufacturing sector) is required. Actually, since the genetic resources are considered a public good by European laws, conservation actions are needed to make the cultivation of these entities profitable for custodian farmers. This could be done by increasing the demand for these entities (e.g. strengthening market opportunities) and their accessibility (e.g. making germplasm easily accessible for farmers through local germplasm banks, Bellon 2004). Such measures should also be supported by public interventions, for example in the form of payments for ecosystem services (PES) (Drucker and Ramirez 2020).

In this sense, several farmers in Northern Italy have already received seeds from family gardens and are now cultivating many of these recovered varieties, with a relatively good commercial success (Miceli and Peresson 2001). Examples of farmers who commercialize local varieties recovered from hobbyists and family gardens are available throughout the study area (<https://www.stuard.it/> in Emilia-Romagna; <https://www.terrevillane.it/> in Lombardia; <https://bellunodolomiti.voximprese.it/aziende/azienda-agricola-biasiotto-sags> in Veneto). As these farmers are professional farmers, they have access to funds from the EU common agricultural policy (*Piano di Sviluppo Rurale* (PSR) in Italian), which is supporting, at least in Italy, more and more agrobiodiversity conservation projects.

The low number of PGRFA in some areas of northern Italy could be explained by a lack of agrobiodiversity in these areas. Nevertheless, it is also possible that the low number of PGRFA detected

might be also due to knowledge gaps more than actual low levels of agrobiodiversity. The latter becomes evident in the case of Valle d'Aosta where 19 landraces of rye were found in bibliographic sources, while information on other crops were lacking. Areas where only a low agrobiodiversity was found (i.e., mountain areas: western Liguria, northern Piemonte; plain areas: provinces of Rovigo, Ferrara, Lodi, Milan and Como) need to be scrutinised by additional field surveys in order to strengthen the knowledge about their traditional PGRFA.

In the last decades, many cases of rediscovery and revival of traditional plant genetic resources, connected to traditional food products, were not communicated in the scientific literature but published in magazines, local newspapers, technical reports, websites and even social media (see e.g. Castello and Monfroni 2013; Bionet 2014; Consorzio agrituristico mantovano 2015). In our study, grey literature was a valuable source of information, especially to establish contacts with farmers or local keepers of PGRFA and traditional plant knowledge. Publicly available lists of local PGRFA as in our study or as the plant agrobiodiversity mapping system by Università degli Studi di Milano (Unimont 2021), are particularly important to complete the view of these entities within a particular geographical area. Searchable databases, grouping together the results of field surveys and grey literature, are particularly important to increase future conservation measures of crop diversity. In this study we detected several examples of successful revivals of traditional PGRFA and examples of their renewed commercialization. The extent of this revival phenomenon, its implication for on-farm conservation and potential ways to support it, deserve to be studied further.

268 entities collected during the field survey and described in this paper are stored at the Pavia Plant Germplasm Bank. Overall, only 350 (=43.2%) of all PGRFA that we identified as part of this study are conserved in six long-term seed conservation facilities. Often, the potential of these collections is diminished by inadequate accessibility of the seed accessions (due to the lack of publicly accessible databases and on-line seed ordering tools) or by incomplete passport data. Additionally, several entities are conserved with very few accessions (often only one); ex situ collections should aim at sampling the largest genetic diversity within an entity (McLean-Rodríguez

et al. 2021). It is very likely that several of the varieties and NUS that are already conserved will need further collecting missions to better sample and long-term conserve the genetic diversity of different populations. An Italian national programme for the long-term conservation of traditional PGRFA is urgently needed to avoid the loss of the priceless agronomical, biological and cultural diversity connected to these genetic resources (legge ‘Cenni’ n. 194/2015; Ronchi and Brugna 2019). In addition, not only germplasm needs to be collected, stored in the long-term and kept available for users but also the traditional plant knowledge (TPK, defined as a collective body of information, actions and beliefs dealing with wild plant and crop systems, Berkes and Folke 2002; Berkes and Turner 2006) needs to be recorded and preserved as part of PGRFA conservation activities. A good example of the collecting of TPK could be represented by the maize ‘Sorc Dorotea’ in Trentino-Alto Adige, mentioned above. For ‘Sorc Dorotea’, not only seeds were collected and conserved, but also a testimony of the last custodian farmer was recorded, including his detailed report of the traditional techniques of cultivation, harvesting, exsiccation of ears and seed selection. Currently, in addition to the revival of ‘Sorc Dorotea’ in two farms located in the original area of cultivation of this landrace, the local ethnographic museum keeps and divulges the TPK connected with the landrace (Stefani 2007).

Finally, the fragmented approach of conservation measures among administrative regions and provinces must be overcome. Common rules should be applied at national level, to solve the currently observed unbalanced situation in terms of PGR in situ conservation.

Conclusion

Northern Italy is richer in terms of crop diversity when compared to the most recent surveys (see e.g. Giupponi et al. 2020, 2021), even after decades of intensive agriculture and genetic erosion. Indeed, our paper shows that an ethnobotanical approach (i.e. on farm surveys coupled with the analysis of the history and traditional use of each entity) can be successfully used to identify previously unknown or lost PGRFA, even in an area that had been subjected to several previous surveys. The results of this paper are important

to guide the conservation of PGRFA as recommended by the European Union. The revived cultivation of several landraces, often connected to a speciality market, found in this paper deserves further scientific attention, since strengthening the value chains of these cultivars can represent the main strategies to enhance their on-farm conservation (Guzzon et al. 2021). Finally, further efforts are needed in order to: (1) further characterise, morphologically and genetically, some closely related landraces and old cultivars reported in this paper, also to facilitate their registration in lists of interest from a regulatory point of view (2) improve the ex situ conservation and accessibility of germplasm of PGRFA in northern Italy (3) apply locally the national rules (Italian Law no. 194/2015), overcoming the current diversification.

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Declarations

Conflict of interest The authors do not have any conflicts of interest.

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