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An inventory, threat and conservation assessment of UK wheat landrace diversity

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Research Article

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Abstract

In the early 20th century, agricultural production was mostly focused on traditional, low-input systems where seed was actively selected by farmers and then frequently saved on-farm for sowing in subsequent seasons. More recently, the replacement of diverse landraces (LR) with fewer genetically homogeneous, commercially bred cultivars has led to considerable genetic erosion and loss of valuable plant genetic resources. Without appropriate *in situ* and *ex situ* conservation, it is inevitable that genetic erosion will continue at an undesirable rate until the loss of these unique resources. Earlier projects to document and inventory LR cultivation in the United Kingdom (UK) provide some insights but were incomplete, leaving research gaps that still need to be addressed. This research provides information on the current status of UK wheat LR diversity and identifies the significant challenges associated with cultivating LR on-farm. A total of 50 farmer interviews were conducted between January and June 2024. It was found that the number of wheat LR maintained on-farm, and the scale at which these varieties are grown, has increased since 2009. There are now 27 varieties maintained over 700 hectares. However, lack of market demand and seed availability have been shown to limit the conservation of these varieties, and therefore, strategies should be implemented to overcome some of the challenges associated with the cultivation of LR. Recommendations are put forward to encourage their continued growing on-farm, and to safeguard important plant genetic resources for future generations.

Introduction

There have been substantial changes to the agricultural sector over the last century, where production has moved away from traditional cultivation methods and towards more intensive, mechanized systems (Dallimer *et al.* 2009; Kell *et al.* 2009). In the early 20th century, agricultural production was mostly focused on traditional, low-input systems where seed would have been actively selected by farmers from plants that performed well in their local environment and then saved for sowing in subsequent seasons (Veteläinen *et al.* 2009a; Maxted *et al.* 2014). Sowing, harvesting and saving seed on-farm through generations led to the evolution of landrace (LR) varieties and their acclimatization to local agro-environments, also commonly referred to as ‘traditional varieties’, ‘heirloom’, ‘heritage’, ‘garden’ and ‘farmer’s varieties’, that have high genetic diversity and are well adapted to growing in the local environment (Camacho Villa *et al.* 2005; Preston *et al.* 2012; Martin *et al.* 2023). However, modernization of the agricultural sector during the mid-1900s led to LR being largely replaced by much fewer, genetically homogeneous, commercially bred cultivars that were regularly superseded by novel cultivars with enhanced performance, yield or quality characteristics (Newton *et al.* 2009; Pingali 2012; Lopes *et al.* 2015).

The replacement of diverse LR with genetically homogeneous cultivars has led to considerable genetic erosion and loss of valuable plant genetic resources (PGRs) (Martin *et al.* 2023). Estimates suggest that 75% of genetic diversity in PGR and 90% of crop varieties were lost following the introduction of high-yielding varieties (FAO 2004). As it stands, food production is reliant on a relatively small number of cultivars that are vulnerable to extreme changes in climate conditions and new strains of pests and diseases due to the lack of their genetic adaptability. Crop breeders commonly utilize LR diversity in the development of new cultivars since LR, along with crop wild relatives, offer a unique source of adaptive traits for environmental tolerance, pest and disease resistance and nutritional quality (Camacho Villa *et al.* 2005; Almeida *et al.* 2024). However, without appropriate conservation, it is inevitable that genetic erosion will continue the loss of the unique genetic resource, resulting in a narrowing of the gene pool (Scott 2022).



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The conservation of LR, crop wild relatives and breeders' varieties *ex situ* in repositories, or Genetic Resource Centres, has been an important practice in the management of PGR since the mid-20th century (Aubry 2023; Salgotra and Chauhan 2023), although the amount of the genetic diversity conserved versus the genetic diversity that exists on-farm is poorly understood. Efforts to collect LR samples have increased since the 1960s as LRs were increasingly replaced by novel cultivars and agricultural, demographic and climate changes impacted on-farm conservation (Ramirez-Villegas *et al.* 2022). At the same time, interest in models and application of sustainable on-farm conservation methodologies has increased, but few models or exemplar studies have been developed and even fewer employed for the conservation of genetic diversity on-farm (Maxted *et al.* 2002). As a result, the vast majority of plant genetic resources for food and agriculture (PGRFA) are currently held *ex situ*. However, once PGRs are removed from their natural environment, their dynamic evolution is stopped, and adaptive potential is paused, only to be restarted once planted again. Complementary conservation strategies are therefore recommended to maximize conservation efforts of PGR on-farm and in their local environment, as well as in Genetic Resource Centres to facilitate access to the conserved resource (Maxted *et al.* 1997; Bellon *et al.* 2017).

Knowledge of on-farm LR conservation within the UK is limited; there are few case studies of UK LR varieties that have records showing continued cultivation on-farm over many generations. However, it has been found that LRs continue to be maintained in marginal environments where they are well adapted to local agri-environmental conditions, and therefore, are able to achieve yield stability and even outperform current cultivars (Camacho Villa *et al.* 2005; Raggi *et al.* 2021). Modern varieties perform well in conditions under which they were selected, such as high-input/high-yielding scenarios. While many growers are interested in reducing inputs, the current economic viability of the organic sector has not been sufficient to warrant large investment in developing and testing modern varieties that target the organic sector. Due to their adaptive trait diversity and inherent heterogeneity, LRs are able to maintain yield in low-input, organic systems where soil nutrient levels are often low, or where there are other biotic and abiotic pressures (Newton *et al.* 2009; van Bueren *et al.* 2011; Maxted *et al.* 2014). LRs are also maintained where they meet niche market demand. Traditionally, long-straw wheat varieties have been maintained on-farm for thatching material; thus, many traditional LRs are maintained (Scholten *et al.* 2009). There are, however, several factors that have contributed to the decline in the production and diversity of wheat LR in recent years. Where there were once 150 named LR wheat varieties in the 1830s (Ambrose and Letch 2009), a study by Scholten *et al.* (2003) found that only three LR varieties were being used for thatching at the time of the study.

Several international policies, including the Convention on Biological Diversity, the International Treaty on Plant Genetic Resources for Food and Agriculture and the Nagoya Protocol, have recognized the importance of PGRFA for future food security, and have implemented strategies to ensure the sustainable use and safe handling of PGR (Marden *et al.* 2023). This includes the fair and equitable distribution of PGR to plant breeders, growers and researchers across the globe (Dempewolf *et al.* 2023). In the UK, the legal marketing and sale of seed of old 'conservation varieties' is recognized and supported by legislation (The *Seed (Conservation Varieties Amendments) (England) Regulations 2009*; The *Seed Marketing Regulations 2011*). The 2020 UK Agriculture Act referenced the importance of PGR and, for the first time, 'the Secretary of State may give financial assistance for conserving

plants grown or used in carrying on an agricultural, horticultural or forestry activity, their wild relatives or genetic resources relating to any such plant' (Agriculture Act 2020). While this could provide farmers with the much-needed incentive to begin or to continue growing LR, there is very little information available on which LR varieties are maintained in the UK, where they are grown, for what purposes and at what scale. Without an understanding of the current trends in LR cultivation, it would be difficult, if not impossible, to implement strategies to conserve LR and their associated genetic resources (Raggi *et al.* 2022). While there have been some attempts to inventory UK LR, including a vegetable inventory completed by Kell *et al.* (2009), there are still research gaps that need to be addressed, especially for cereals. The primary aim of this research was to identify which wheat LR varieties are currently maintained in the UK, and to determine conservation priorities for the future. This involved specific research objectives that were: a) to compile gene bank accessions for UK wheat LR into a database, b) to record which wheat varieties are currently maintained on-farm and on what scale and c) to identify the most significant challenges of maintaining wheat LR on-farm.

Materials and methods

Defining LR

Harlan (1975) was one of the first to formally characterize LR, describing them as morphologically recognizable, locally adapted and genetically diverse populations that were the result of millennia of natural and artificial selection. Camacho Villa *et al.* (2005) identified six key characteristics of an LR that include historical origin, recognizable identity, lack of formal genetic improvement, high genetic diversity, local genetic adaptation and an association with traditional farming and/or cultural systems. Preston *et al.* (2012) later proposed a hierarchical structure for the classification of crop varietal diversity, including traditional and modern crop varieties, with the key distinction being whether they were bred with or without conventional plant breeding techniques. Within the structure, LR are classified as traditional varieties that are selected, developed and maintained without formal breeding methods, produced on a farm scale for commercial sale, and which have the characteristics described by Camacho Villa *et al.* (2005). More recently, authors have proposed that varieties that were formally bred should be included as LR if they have been maintained via grower selection and seed saving for ≥ 10 crop generation cycles (Kell *et al.* 2009; Maxted *et al.* 2020). For the purpose of this study, we used the following terminology to describe LR from traditional and modern crop varieties:

- **Traditional LR:** an LR that has not been formally bred and has historical origin, a distinct identity, is genetically diverse, locally adapted, linked to traditional farming systems and has a local cultural association.
- **Secondary derived LR:** an LR that was historically bred but has since been maintained on-farm through grower selection and seed saving for at least 10 generations after the initial sale.

Collection of data for wheat LR held in *ex situ* conservation

There are seven main Genetic Resource Centres in the UK, including Warwick Crop Centre, Aberystwyth University IBERS Biobank, Science and Advice for Scottish Agriculture (SASA), John Innes Centre (JIC), The James Hutton Institute, the wild

species focused the Millennium Seed Bank and the Nottingham Arabidopsis Stock Centre (JNCC 2018). Currently, more than 800,000 accessions are held in UK Genetic Resource Centres (ECPGR 2025; FAO 2025). However, not all Genetic Resource Centres maintain samples of wheat; most cereal accessions are held at JIC in the BBSRC Small Grain Cereal Collections and A.E. Watkins Historic Collection of Landrace Wheat. SASA maintains Scottish cereal LR in their collections and as part of the Scottish Landrace Protection Scheme (SLPS; SASA 2024).

An extensive desk-based search was conducted to identify wheat LR of UK origin maintained *ex situ* by JIC and SASA. All JIC germplasm-associated data are made available through the database, SeedStor (<https://www.seedstor.ac.uk/>; Horler *et al.* 2018; JIC 2024). In SeedStor, users have to select the following criteria as part of a phenotype search to identify wheat LR: first, select *Triticum* as the taxon name; then, select 'traditional cultivar/landrace' as the sample status; and finally, select the United Kingdom (GBR) as the country of origin. The steps listed above were repeated for England (GBE), Scotland (GBS) and Wales (GBW) as the country of origin to ensure all accessions had been included. SASA publishes information about the accessions they hold on their website (<https://www.sasa.gov.uk/variety-testing/scottish-landraces/scottish-landrace-protection-scheme-slps>).

For this research, accessions that have been classified as 'traditional cultivars', 'landraces' or 'land varieties' were included in data collection. It is common for LR to be mistakenly classified as modern or 'improved' cultivars in germplasm collections (Kell *et al.* 2009). Therefore, the JIC database was searched to identify any known English LR that have been classified as advanced cultivars, including former bred varieties that were once commercially bred but have since been maintained on-farm (Maxted *et al.* 2020; Almeida *et al.* 2024). Many of these varieties have been cultivated as part of growing demonstrations at JIC that aimed to raise awareness of old varieties and cereal LR that are available for use in thatching and milling (Ambrose 2005). The accessions identified were then checked against the Genesys PGR database (<https://www.genesys-pgr.org/>), a global portal that holds information on crop diversity maintained in Genetic Resource Centres.

Collection of data for wheat LR held in on-farm conservation

There is limited methodology for surveying and inventorying LR within the literature. Maxted and Scholten (2007) discussed methodologies for creating national/European inventories, focusing on LR diversity and suggested types of data to be collected for a national LR inventory, as well as how to collect information on LR diversity. A later publication by Maxted *et al.* (2009) suggested categories of information that might be included in an LR inventory but stated that the information collected would likely be dependent on the resources available and the level of knowledge already known about the LR. The work of other authors that have generated LR inventories in the past, including Scholten *et al.* (2003) and Kell *et al.* (2009), was used to inform the methodology of this research.

The internet was searched for information on growers of wheat LR, and contact via email or telephone was made with those whose information was publicly available online. The UK Grain Lab Interactive Map of alternative grain groups (http://www.bicga.org.uk/grain_map.php) was used to identify potential contacts throughout the UK. If growers recommended additional individuals or organizations, these too were added to the contact list. Several thatching associations and millers were also contacted. Virtual or face-to-face interviews were organized with individuals

who responded to initial contact via email between January 2024 and June 2024. A total of 50 interviews were conducted, of which 10 were in-person during farm visits. These semi-structured interviews with growers aimed to collect information about the current status of on-farm conservation by asking which LR varieties they grow and on what scale, how long they had been growing these varieties, what the biggest challenges associated with cultivating LR varieties were and how they obtain their propagation material. For this research, we were particularly interested in varieties that had been maintained on-farm for more than 5 years. Swedish farmers have stated that within 3–4 years varieties become noticeably adapted to the local environment (Ortman *et al.* 2023). Field notes were completed for each interview that summarized the key points, including any additional comments interviewees made beyond the questions asked to them. Full details of the interview protocol can be found in the Supplementary Material, Table S1.

Results

LR wheat of UK origin conserved *ex situ* in UK genetic resource centres

In total, 19 LR wheat varieties were identified as held *ex situ* in the JIC gene bank and further one held at SASA (Table 1). Red Standard, a square head type wheat variety first released in the early 20th century, was obtained by SASA in 1950 and has since been maintained as part of the SLPS, but there are no current records of Red Standard being cultivated in Scotland. In Table 1, 'Miracle' and 'Rivet' are listed twice with the same name but different accession numbers. This is likely due to the acquisition of material at different times or from different donors, representing two distinct samples. A further nine accessions of traditional cultivar/LR status were listed on the JIC database but had no variety name and were therefore not included in the data table.

Further to the accessions classified as traditional cultivar/LR, there are traditional LR varieties maintained in the BBSRC Small Grains Collection at JIC that have been classified as advanced/improved cultivars (Table 2). There are also varieties that were once formally bred but have since been maintained through grower selection and seed saving on-farm, especially for use in thatching. Like traditional LR, these varieties have important intrinsic genetic diversity and a long history of being cultivated in the UK prior to the introduction of modern, high-yielding varieties. We refer to these varieties as secondary derived LR. A full list of LR material maintained at JIC can be found in the Supplementary Material, Table S2.

Current status of on-farm diversity of LR wheat within the UK

A total of 50 interviews were conducted with growers who cultivate LR varieties for the thatching and milling industries. Growers reported maintaining 27 different wheat varieties on-farm (Table 3). Ten farmers reported growing one of the following wheat populations: Miller's Choice, Torth y Tir, Balcaskie and Cornovii. Balcaskie and Cornovii populations are mixtures of LR wheat varieties grown together with the resulting seed saved each year. Balcaskie is a mixture of three Scottish LR varieties: Rouge d'Ecosse, Golden Drop and Hunters (Scotland The Bread 2005). Cornovii population is a mixture of the following seven varieties: Hen Gymro, Holdfast, Old Devon Blue Rough Chaff, Percival's Blue Cone, Red Lammis, Wilhelmina and Yeoman (Turners of Bytham 2025). Miller's Choice and Torth y Tir are both wheat populations

Table 1. Traditional LR accessions maintained *ex situ* at John Innes Centre and SASA. These varieties are classified as traditional cultivar/landraces in the JIC database

Taxonomy	Variety	Accession code	Genetic resource centre	Country of origin
<i>Triticum turgidum</i>	Rampton Rivet	T1080057	GRU-JIC	GBR (UK)
<i>Triticum turgidum</i>	Matty	T1080062	GRU-JIC	GBR (UK)
<i>Triticum turgidum</i>	Miracle	T1080063	GRU-JIC	GBR (UK)
<i>Triticum turgidum</i>	Miracle	W1156	GRU-JIC	GBE (England)
<i>Triticum turgidum</i>	Paines Defiance	T1080064	GRU-JIC	GBR (UK)
<i>Triticum turgidum</i>	Early Red Cone	T1080065	GRU-JIC	GBR (UK)
<i>Triticum turgidum</i>	Early Cone	W0995	GRU-JIC	GBE (England)
<i>Triticum turgidum</i>	Rivet	T1080067	GRU-JIC	GBR (UK)
<i>Triticum turgidum</i>	Rivet	T1080069	GRU-JIC	GBR (UK)
<i>Triticum turgidum</i>	Percival's Blue Cone	W1022	GRU-JIC	GBE (England)
<i>Triticum aestivum</i>	Squareheads Master	WAT1190149	GRU-JIC	GBR (UK)
<i>Triticum aestivum</i>	Browick	WAT1190853	GRU-JIC	GBR (UK)
<i>Triticum aestivum</i>	ChidhamBlanc-de-Mars	WAT1190863	GRU-JIC	GBR (UK)
<i>Triticum aestivum</i>	Squarehead	WAT1190864	GRU-JIC	GBR (UK)
<i>Triticum aestivum</i>	Holdfast	WAT1190868	GRU-JIC	GBR (UK)
<i>Triticum aestivum</i>	April Bearded	WAT1190906	GRU-JIC	GBR (UK)
<i>Triticum aestivum</i>	Little Joss	WAT1190913	GRU-JIC	GBR (UK)
<i>Triticum aestivum</i>	Hen Gymro	W0498	GRU-JIC	GBW (Wales)
<i>Triticum aestivum</i>	Orange Devon Blue Rough Chaff	W10031	GRU-JIC	NLD (Netherlands) ^a
<i>Triticum aestivum</i>	Red Standard	SASAWH001	SASA	GBS (Scotland)

^aOrange Devon Blue Rough Chaff is an English landrace with a long history of cultivation in the UK. The country of origin is listed as the Netherlands because the accession held at JIC was requested from the Netherlands in 2010.

whose exact composition is unknown. Miller's choice is a population of long straw wheats created in 2010 (BICGA 2026). Torth y Tir is a mixed population of heritage wheat. There were also approximately 30 acres of 'Maslin' grown in 2024, although it is unclear how many growers. Maslin is an old medieval word for a mixture containing different varieties of wheat and rye. A main-tainer interviewed during this study reported that cultivation of maslin decreased considerably in 2024, although production is intended to be scaled up in coming years.

The varieties reported in Table 3 had been maintained on-farm for anywhere between 1 and 54 years. More than half of the varieties (17 out of 27) were being grown for use in the milling industry, with only two varieties grown for thatching and eight varieties being used for both industries. The great majority (24 out of 27) of wheat LR grown on-farm today are 'common' or 'bread' (*Triticum aestivum* L.) varieties. Einkorn (*Triticum monococcum* ssp. *monococcum*), spelt (*Triticum spelta*) and rivet wheat (*Triticum turgidum* ssp. *turgidum*) were recorded on-farm but on a much smaller scale. Percival's Blue Cone was the only rivet variety recorded during interviews, although it is also a component of the Cornovii population.

Interviewees were asked about the scale of production, and it was found that the varieties being maintained on-farm had a total cultivation area of 737.0 hectares. However, the production area of the UK wheat crop in 2023 was reported by the Department for Food, Environment and Rural Affairs (Defra) to be over 1.7 million hectares (Department for Environment, Food and Rural

Affairs (Defra) 2024). The reported area of LR cultivation therefore only represents approximately 0.043% of the total UK wheat production area. Figure 1 shows the scale of production for each of the LR varieties that are currently maintained on-farm in the UK. Öland is a traditional Swedish LR variety that has become a popular choice for milling wheat in the UK, especially for organic systems. Some growers report to have maintained this variety on-farm for 10 years, saving seed after each harvest.

In addition to the varieties listed in Table 3, four growers reported that they cultivate Wakelyns YQ, a composite cross population (CCP) developed in the UK by the JIC and Organic Research Centre (formerly Elm Farm Research Centre) during the early 2000s (Wolfe *et al.* 2006). Although not a traditional LR variety, Wakelyns YQ has been maintained on-farm for several generations, with cultivation is expected to increase in coming years, especially in low-input and organic systems. Identifying growers of CCPs was not one of the main objectives of this research; therefore, we anticipate that the current number of growers is much higher than we recorded.

The challenges of growing UK LR wheat varieties on-farm

During farmer interviews, individuals were asked about their experience of growing wheat LR, and the advantages and challenges associated with maintaining them on-farm. Most commonly, farmers reported that these LR varieties grow well in the

Table 2. Traditional and secondary derived LR of UK origin maintained at John Innes Centre as part of the BBSRC Small Grain Collections. These varieties are classified as advanced/improved cultivars in the JIC database

LR name	Sample year	Provenance	Accession code	Comments
April Bearded	1969	Historic English LR	W0002	
Red Lammas	1973	Historic English LR	W0987	Fradgley <i>et al.</i> (2019) recorded the year of release as 1750
Red Standard	1986	Historic English LR	W5623	
White Victoria	1973	Historic English LR	W1000	
Main's Standup	1973	Historic English LR	W1038	
Golden Drop	1952	Historic English LR	W0497	Fradgley <i>et al.</i> (2019) record year of release as 1836
Squareheads Master 13/4	1952	Bred variety from 1940s	W0511	Later selection from Squareheads Master
Benefactor	1973	Bred variety from early 20th century	W0976	1914–1925. Cited in Percival (1934)
Browick (Old True)	1973	Selection from Historic English LR Browick	W1001	Very old Norfolk variety from 1700s
Yeoman	1952	Bred variety from 1910s	W0517	
Redfast	1973	Bred variety from 1950s	W1206	Fradgley <i>et al.</i> (2019) record year of release as 1952
Victor	1952	Bred variety from early 20th century	W0514	Fradgley <i>et al.</i> (2019) record year of release as 1949. Peachey (1951) states 1908.
New Harvester	1973	Bred variety from 1970s	W1080	
Milns N59	1952	Bred variety from 1950s	W0505	Fradgley <i>et al.</i> (2019) record year of release as 1949
Aquila	1976	Bred variety from 1970s	W2214	Fradgley <i>et al.</i> (2019) record year of release as 1975
Maris Widgeon	1981	Bred variety from 1960s	W4114	Fradgley <i>et al.</i> (2019) record year of release as 1964. Recommended list in 1971.
Badger	1973		W1039	Cited in Percival (1934).
Cambridge Browick	1986		W6637	Bred by Rowland Biffen. Cited in Percival (1934)
Defiant	1952	Bred variety from 1940s	W0493	Fradgley <i>et al.</i> (2019) record year of release as 1946. Cited in Peachey (1951).
Essex Gladhof	1973		W1098	Fradgley <i>et al.</i> (2019) record year of release as 1886
Fenland Wonder	1973	Bred variety from 1920s	W1340	1922. Carter's Tested Seeds Ltd Cited in Peachey (1951)
Iron Red	1973	Bred variety from 1930s	W1162	1938. Edward Webb and Sons Ltd Cited in Peachey (1951)
Oxford Prize	1973	Bred variety from 19th century	W1035	Lawson (1852) recorded being grown in Scotland in 1839.
Steadfast	1952	Bred variety from 1940s	W0513	Fradgley <i>et al.</i> (2019) record year of release as 1941. Cited in Peachey (1951)
Sherriffs Epi Carre	1973		W0989	Cited in de Vilmorin (1880)
White Marvel	1973	Bred variety from early 20th century	W1086	Old variety. Tested at NIAB in 1926
Prince Albert	1973	Oxford Red Selection	W0999	Cited in de Vilmorin (1880)
Rouge d'Ecosse (Blood Red)	1973	Bred variety from 19th century	W0988	Old Scottish variety. Cited in de Vilmorin (1880)
Hybrid 46	1956	Bred variety from 1940s	W0408	1946 introduced by C.W. Marsters Ltd Cited in Peachey (1951)
Yeoman 2	1973	Bred variety from 1920s	W0975	Cited in Percival (1934)
Redman	1952	Bred variety from early 20th century	W0509	1934–1959 Gartons. Cited in Peachey (1951)
Chidham 1	1973	Historic English LR	W1002	Found in Chidham, Sussex, 1790. Cited in Copland (1865).

Table 3. On-farm conservation of landrace wheat varieties that are maintained for thatching and milling in England. Some farmers maintain more than one variety

Variety	Years maintained on-farm	Approx. annual scale (ha)	Use
Maris Widgeon	1–54	111.71	Thatch, milling
April Bearded	3–20	62.15	Thatch, milling
N59	6–50	102.43	Thatch, milling
Squareheads Master 13/4	3–30	17.00	Thatch, milling
Squareheads Master	2–30	14.87	Thatch, milling
Öland	1–10	19.03	Milling
Miller's Choice	4–10	54.25	Milling
Orange Devon Blue Rough Chaff	1–15	10.93	Milling
Red Lammas	6–8	26.32	Milling
Aquila	30	57.89	Thatch
Yeoman	11	6.07	Thatch, milling
Balcaskie	5–8	20.74	Milling
Atle	30	8.10	Thatch, milling
Maris Huntsman	NA	114.57	Thatch
Hen Gymro	1	< 1.00	Milling
Torth y Tir	3	10.12	Milling
Trencher	12	40.49	Milling
Einkorn	6	2.02	Milling
Spelt	6	2.02	Milling
Lys Brun	10	6.07	Milling
New Harvester	45	3.64	Thatch, milling
Hunter's	5	20.24	Milling
Percival's Blue Cone	1	4.05	Milling
Kent Old Hoary	4	7.49	Milling
Old Kent Red (local variety of Red Lammas)	4	7.49	Milling
Elite Lepeuple	4	4.05	Milling
Cornovii	NA	3.24	Milling

local environment, are more resilient to adverse weather conditions and are well suited to low-input systems. In addition, farmers felt a personal connection to growing LR varieties from their locality. Many farmers have grown these varieties for generations and therefore recognize the heritage value of maintaining the crop. Although LRs often yield lower than modern cultivars, supplying niche markets means they can achieve a higher market price than modern cultivars. Farmers like that they have the freedom to set their own price that accurately reflects the cost of producing the crop, and a pricing structure is agreed with the purchaser in advance of sowing. For farmers that grow wheat for milling, they reported that LR varieties have a better taste and higher nutritional content than modern cultivars, which is popular amongst artisan bakers.

Figure 2 summarizes the main challenges of growing LR reported during farmer interviews, some of which are more specific to thatching than milling and vice versa. From the total number of responses ($n = 72$), unfavourable weather conditions ($n = 18$; 25%), labour shortages ($n = 14$; 19%) and lack of modern machinery ($n = 13$; 18%) were the three main challenges. Old machinery was reported to be a significant challenge for thatch

straw growers who are reliant on traditional harvesting methods and equipment. Growers mentioned that it is expensive to maintain old machinery, and there is limited opportunity to buy new parts. As a result, growers often have to complete their own repairs. Similarly, labour shortages are a particular problem for growers that supply the thatching industry. Growers stated that it takes between six and eight people to harvest and thresh long-straw wheat, however, staff are only required for a few weeks per year during harvest. Growers also reported that harvesting long-straw wheat is physically demanding and unappealing to the younger generation, making it difficult to find labour. Additional challenges include market demand ($n = 7$; 10%), lower yield compared to modern varieties ($n = 6$; 8%), seed availability and storage ($n = 6$; 8%), lodging ($n = 5$; 7%) and weeds and disease ($n = 3$; 4%). Market demand and yield are particularly challenging for growers that supply the milling industry. The amount of LR wheat that farmers can grow is limited by demand from millers and the artisan baking sector. One farmer expressed that it is unfeasible to grow more LR wheat than what can be sold to suppliers, since the price difference between growing LR for human consumption compared to selling

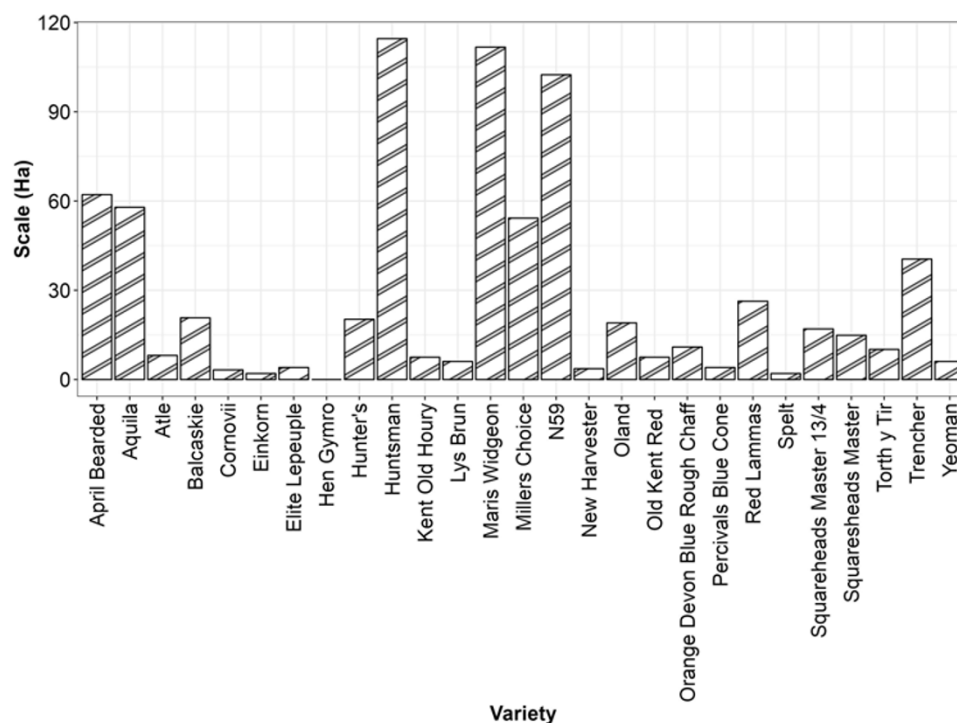


Figure 1. Wheat landraces and heritage varieties maintained on-farm in England, showing the scale at which these varieties are grown.

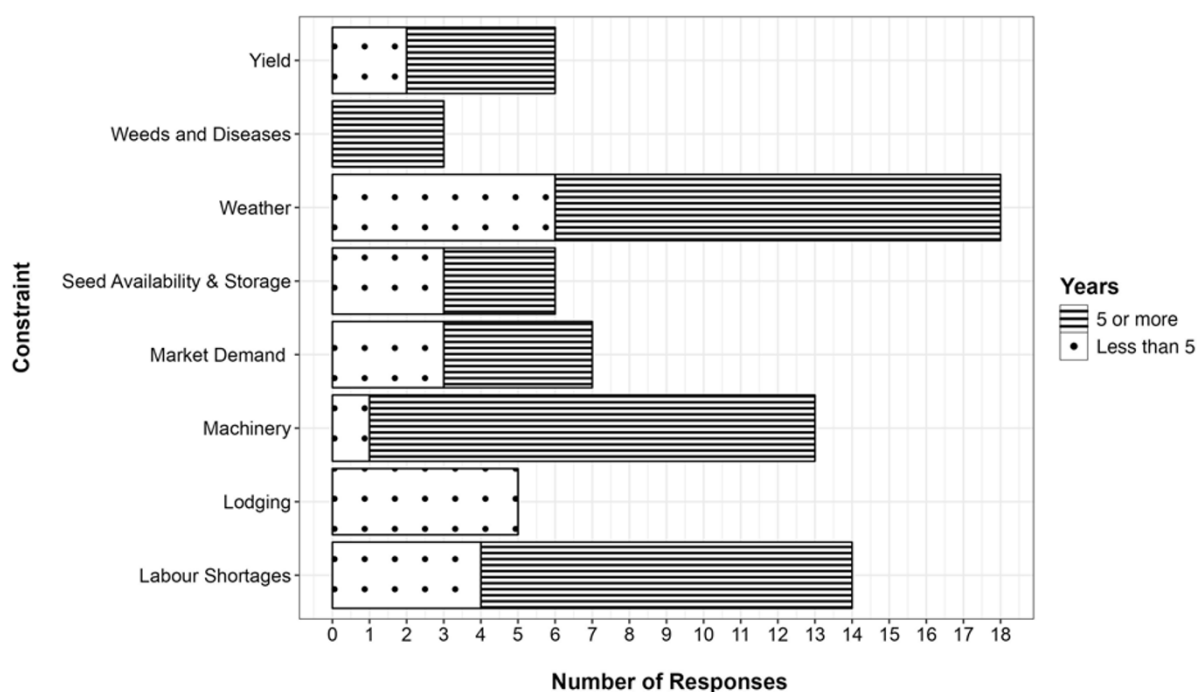


Figure 2. The main challenges of cultivating landrace and heritage wheat that were reported during farmer interviews, showing the number of individual responses for each challenge depending on the number of years farmers had been growing these varieties.

it for animal feed is substantial due to LR varieties yielding less than modern varieties. Aside from those farmers growing Maris Widgeon, where seed was sometimes purchased, farmers home-saved seed for the next growing season. Any further advantages and challenges that were reported during interviews are summarized in Table 4.

To investigate the challenges of growing LR further, the length of time growers had been cultivating these varieties was considered (Fig. 2). Although the primary focus of this research was on growers that had been cultivating LR for 5 or more years, there were 15 growers interviewed that had been growing for less than 5 years. Many of the constraints to cultivation were comparable between

Table 4. Farmer's opinions on the advantages and challenges of growing LR wheat varieties for the thatch and milling industries

Use	Advantages of growing landrace (LR) wheat	Challenges of growing landrace (LR) wheat
Thatch	Grows well in the local environment and produces good quality straw that is the correct length for thatching.	Seed availability
	Farmers enjoy growing LR varieties and consider the heritage value of maintaining the crop. Personal interest in LR varieties.	Bad weather
	LR varieties are more resilient and perform better when the weather is poor compared to modern cultivars.	Old machinery that is expensive to maintain. Limited opportunity to buy new parts. Many growers have to complete their own repairs.
	Easy to grow/low maintenance.	Lack of skilled labour for repairs and harvesting thatching straw. Difficult to find short-term labour for harvest.
	Fixed price agreements with buyers.	- Ageing grower population with few young people trained. - Loss of small farms - Storage of seed, machinery and straw (especially with rats/mice, etc.)
Milling	LR varieties are well suited to low-input, organic systems.	Seed availability
	Higher market price for LR varieties compared to modern cultivars.	Market opportunities are limited.
	Growers like that they can set their own price for grain that reflects the cost of producing LR crop.	Lower yield compared to modern cultivars.
	LR varieties have a better nutrient content and are received as having enhanced taste compared to modern cultivars.	Lodging in fertile soil
	LR varieties are more disease resistant under low-input, organic systems.	Fluctuations in market demand due to competition from other growers.
	Personal connection to growing LR varieties as farmers have grown them for generations.	Single LR varieties are not as dynamic as populations.
	Good ground cover from the taller LR varieties, which helps to suppress weeds.	Quality assurance between seed exchanges (e.g., increasing concern of the fungus bunt).
	LR varieties are taller than modern varieties, so they will grow above a clover lay without being smothered.	Consumer perception and purchasing habits: it is difficult for consumers to purchase and change from products made with modern cultivars that are usually cheaper and more readily available.

growers irrespective of the length of time of cultivation and maintenance on-farm, with the exception of two key differences between the groups. Lodging was found to be a major constraint to production for growers that had been cultivating LR for less than 5 years, whereas weeds and diseases were a significant challenge for growers that had grown LR for 5 or more years.

Discussion

Market demand: Implications for LR conservation

This research found that both the number of LR varieties maintained on-farm and the scale on which they are grown have increased since Scholten *et al.* (2009) completed their LR inventory of the UK. In 2009, seven LR varieties were cultivated, with an average cultivation scale of two hectares (Scholten *et al.* 2009); there are now 27 recorded varieties grown over a total of 737 hectares. Notably, more LR are now grown for milling purposes to supply the artisan baking sector. The market for alternative grains in the UK is niche but growing as consumers take more interest in locally produced and nutritious food (SAC Consulting and Scotland's Rural College 2021). In particular, more artisan bakers are using

ancient and heritage grains for their broader range of characteristics and flavour (SAC Consulting and Scotland's Rural College 2021). This is very much the case for Spelt and Einkorn, which are reintroductions as UK crops and lack the long, continuous histories of bread and rivet wheats and the associated common knowledge within the farming sector. The use of LR in alternative markets is important for raising awareness of these older varieties and ultimately can help improve their conservation on-farm. There are, however, concerns around the continuity and longevity of these alternative markets, as market demand remains a challenge for growing LR wheat, as reported by farmers during this research.

Historically, thatching has proven to be a small yet stable market for LR material, though thatch growers are increasingly faced with poor weather, labour shortages and old machinery that threaten the production and longevity of thatch. Adverse weather conditions during the 2020 harvest led to a 12-month material shortage (Chesher 2023), and longer-lasting, more severe shortages are expected as climate scenarios predict more frequent extreme weather (Semenov 2007). Historic England reports that some growers are already reducing cultivation area, becoming more selective in the varieties that they grow and experimenting with different methods of harvest to reduce weather impacts on thatching straw (Chesher 2023). There are also concerns for

the ageing and diminishing number of thatching wheat growers. Thatching straw production is dependent on the transfer of knowledge and skills through generations, with farmers stating that there are now fewer young people coming into the sector. Harvesting thatching straw is an often unpredictable process, which is also physically demanding, making it a less appealing occupation to the younger generation, as reported during this research.

Seed availability: Implications for on-farm and *ex situ* maintenance

Most LRs in the UK are obsolete varieties and are not available to buy commercially. Maris Widgeon is one of only two LR wheat varieties registered on the UK National List. Propagation material for Maris Widgeon can be purchased from seed companies, but for all other varieties, seed has to be home-saved after each harvest, as it would have been in traditional farming systems. This limits opportunities for new growers to get involved and start cultivating LR since seed cannot be obtained.

Seed exchange between small-scale farms through 'informal seed systems' – farmers' access to seed through their own production, farmer-to-farmer exchange and local markets – has long been key to the circulation of LR and a crucial component of on-farm management of crop diversity (Louwaars and Manicad 2022; Nabuuma *et al.* 2022; Westengen *et al.* 2023). Intensification of agriculture introduced a more formal system, in which national policies and legal frameworks govern the development, distribution and sale of certified seeds (Ncube *et al.* 2023; Westengen *et al.* 2023). Recognizing the importance of LR diversity, the European Committee published the Directives 2008/62/EC and 2009/145/EC that permit the registration of conservation varieties, including LR and obsolete varieties (Thanopoulos *et al.* 2024), yet far fewer conservation varieties are registered than the known number of LR in Europe (Khan *et al.* 2020). Farmers remain reluctant to register LR as conservation varieties due to registration costs, even though they are lower for this category of crop, failure of material to meet legislative demands and limited commercial interest (Khan *et al.* 2020; Sandström *et al.* 2024). Some countries, such as Italy (Bertacchini 2009), have more relaxed seed legislation to support the conservation of heterogeneous material. The introduction of more inclusive seed marketing laws and policies that actively encourage LR trade (Batur *et al.* 2021) and support informal seed systems could build a stakeholder network for on-farm conservation while recognizing farmers as stewards of plant genetic diversity and local heritage. UK Grain Lab, a Community Interest Company that acts as an incubator for grain networks across the UK and Ireland, exemplifies this: it facilitates knowledge exchange between growers, millers, bakers and researchers, and its members hold and grow several 'amateur' collections.

While informal seed exchange between farmers can supply new growers, the seed can be of varying quality; seed cleaning on-farm can be challenging and often leads to cross-variety contamination. Small samples of seed can be withdrawn from Genetic Resource Centres, though bulking up can take several growing seasons, and availability depends on sufficient sample stock. This research found that there are LR wheat accessions maintained in UK germplasm collections that new growers could use, but there is no easy way to identify all UK LR material held *ex situ*, partly because Genetic Resource Centres apply inconsistent data management standards (Kell *et al.* 2009; Hay and Whitehouse 2017). International information systems for PGR, such as Genesys, have made a considerable difference to how resources are managed and shared globally

(Weise *et al.* 2020). However, standardizing UK data management, alongside the proposed production of a national inventory and indicator by Clarke *et al.* (2026), would likely improve the *ex situ* conservation of UK LR varieties.

This research found that there are wheat varieties maintained on-farm that have not been submitted to UK Genetic Resource Centres, or they have not been sampled within the last 50 years. Diez *et al.* (2018) suggest that effective *ex situ* conservation would involve the storage of all genes and gene combinations for each variety that evolve over time. This would ensure that PGR maintained in Genetic Resource Centres are representative of the genetic diversity currently maintained on-farm, but growers would need to regularly provide samples for maintenance in Genetic Resource Centres, say every 10 years (Maxted *et al.* 2020). The SLPS, established in 2006, aims to conserve seed of Scottish LR *ex situ* while providing growers with the opportunity to deposit their own seed for safe keeping (Green *et al.* 2009). Growers are encouraged to provide a sample of seed periodically to a) conserve maximum genetic diversity and b) monitor how populations change over time. In the event of a bad harvest, growers can request the restoration of their seed that is locally adapted in order to continue growing the crop in subsequent years (Green *et al.* 2009). A similar protection scheme in England and Wales would help to safeguard important PGREF for future generations and ensure that farmers have access to their own properly maintained, viable seeds.

Importance of LR for supporting ecosystem function

The ecological benefits and ecosystem services provided by LR are a major motivator for cultivation, especially among organic and low-input growers. Throughout this project, growers reported that LR showed greater disease resistance under organic and low-input conditions, improved weed suppression, and was more resilient to adverse weather conditions than modern cultivars. LRs' large rooting systems improve soil structure and resource uptake to support cultivation in marginal environments (Bektas *et al.* 2016; Ortman *et al.* 2023). Having the ability to grow successfully without agrochemical inputs has social, economic and environmental benefits, and growers valued their low maintenance and ease of management. Weed control challenges many organic farmers, but several growers found LR suppressed weeds more effectively than modern cultivars, owing to their long straw and good ground cover under low-input systems. This is consistent with Ortman *et al.* (2023), who found that farmers' acceptance of some weeds as part of a diverse on-farm ecosystem was regarded as more important than weed-free fields.

Many farmers are exploring the use of 'living mulches' for agronomic and environmental benefits such as improved soil health and quality (Sjursen *et al.* 2011; Koudahe *et al.* 2022), reduced soil erosion and leaching (Abdalla *et al.* 2019), nitrogen fixation (Dabney *et al.* 2010), pest and weed control (Carmona *et al.* 2021) and forage production. There is a potential risk of reduced grain yield due to competition for resources between the main crop and cover crop, but this was not reported by growers during this research; long straw LR varieties could be under-sown with clover without negative impacts on yield. Känkänen and Eriksson (2007) found that clover is a good choice of cover crop as clovers do not compete strongly with the main crop, allowing higher seeding rates to maximize agronomic benefits. Tall, long-straw LR varieties can also be susceptible to lodging, where plant stems fall and are permanently displaced by heavy rain or wind (Pinthus 1974). Rivet wheats are very tall (130 cm) and prone to lodging, making them

challenging varieties to grow (Costanzo *et al.* 2019). Traditionally associated with both the milling and thatching industries, rivet wheats were widespread in the UK until the first half of the 20th century, but their decline since then has meant that they are now rarely cultivated (Costanzo *et al.* 2019). This study found that while rivet wheats are maintained in Genetic Resource Centres, only one variety (Percival's Blue Cone) is currently maintained on-farm in the UK for milling.

The potential of LR has not yet been fully recognized in modern plant breeding. A study by Cheng *et al.* (2024) investigated the untapped diversity in the A.E. Watkins LR collection of bread wheat. The Watkins collection is comprised of 827 accessions collected from 32 countries in the 1920s and 1930s. It was found that five of the seven Watkins ancestral groups are phylogenetically isolated from modern wheat varieties, representing a highly valuable and underutilized resource for wheat breeding. Within these ancestral groups, there are haplotypes unique to Watkins accessions that have known benefits for yield potential, adaptation, human nutrition and disease resistance (Cheng *et al.* 2024). The recent interest and exploration of LR materials in the Watkins Collection in the UK has only been possible through successive funding rounds of BBSRC and the Defra-funded public/private partnership Wheat Genetic Improvement Network. These have led to the development of a pipeline of valuable new pre-breeding resources that exploit unique genetic variation in LR material. These, together with the ongoing development of locally adapted populations of CCPs such as YQ, are set to expand the genetic diversity, crop performance and resilience in commercial cultivars in the future. Reporting on and capturing the extant wheat LR currently grown in the UK and their markets before these developments come through to commercially grown crops provides an important baseline dataset against which future surveys can be compared, while also highlighting the importance of collecting and conserving LR diversity for the future.

Conservation recommendations

Veteläinen *et al.* (2009b) proposed 10 target actions with the primary aim to achieve effective and sustainable conservation and use of European LR diversity. Although progress has been made, many of these recommendations still apply:

- **Develop an effective way to systematically conserve LR diversity *in situ* and *ex situ*** – complementary conservation of LR is recommended to maximize conservation efforts. Encourage the submission of new samples to update gene bank collections, supported by guidance as proposed by Clarke *et al.* (2025). Improve and standardize data management for *ex situ* conservation, including the production of a national inventory and indicator as proposed by Clarke *et al.* (2026). Encourage the use of LR on-farm to maintain local diversity, for example, through community seed banks.
- **Create national priority LR lists and identify priority sites for on-farm conservation** – encourage on-farm conservation efforts through the establishment of active on-farm conservation programmes, as proposed by Veteläinen *et al.* (2009b). Establish new or alternative market opportunities to expand and support existing on-farm LR cultivation.
- **Ensure public awareness, effective security and legislative protection for LR diversity** – improve awareness of LR and implement policies to encourage and maintain on-farm conservation, such as improving grower access to propagation material.

- **Promote sustainable utilization of LR** – recognize the full potential of LR in breeding programmes, promote the sustainable use of LR, and safeguard LR diversity for future generations.

Concluding thoughts

The importance of PGR is widely recognized across the globe, and the sustainable conservation of LR varieties will be essential for future food security. Results of this research show that there are now more LR wheat varieties grown on-farm in the UK compared to 2009, and the scale at which these varieties are grown has also increased. This can, in part, be attributed to the use of LR in niche markets, including thatching and artisan baking. There is more LR material available that could be grown on-farm or utilized *ex situ*. A significant amount of LR diversity is already maintained in UK Genetic Resource Centres, but better data management and the submission of more recent seed samples would significantly improve *ex situ* conservation of LR. During this study, several growers expressed their concern about on-farm conservation of LR, especially with regard to unfavourable weather conditions, limited market demand and seed availability. Improving access to propagation material of LR, for example, through exchange of *ex situ* and *in situ* material, should be a priority to enhance diversity and ensure the continued conservation of LR diversity in the future.

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Ethical standards. This study adhered to all ethical standards and guidelines. The participants were contacted by email, and the email provided full information about the study and data protection. Participants were informed that all interviews would be treated as anonymous, any personal data processed in relation to the study would be done in accordance with the General Data Protection Regulation (GDPR), and that they were free to withdraw from the study at any time or choose not to answer certain questions. Data were stored securely (on a drive, only accessible to people working directly on the project) and used only for the purposes of academic study.

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