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What makes a change? Understanding the renewal process of barley cultivars on Finnish farms

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ABSTRACT

The potential to adapt to climate change varies depending on the crop and is considered low especially for barley (*Hordeum vulgare* L.) in Europe. Barley is the most widely cultivated crop in Finland, grown in a wide range of climatic and edaphic conditions. Access to a large and diverse assortment of locally well adapted, climate-resilient barley cultivars is the premise for successful cultivation. Barley has plenty of cultivar choices in Finland. However, cultivar switch is "a hidden process," and in this study, we therefore aimed: 1) to increase understanding of farmers' cultivar renewal process; 2) to study how yield and growing time of new cultivars have changed when farmers switched cultivars; and 3) to describe how farms with willingness to change cultivars differ from those reluctant to make a change. The renewal interval of barley cultivars is long: The cultivars grown in 2018 were usually introduced to the Official Variety Trials as early as 2008–2012. The median age difference between replaced and new cultivars was seven years. The probability of switching cultivars was systematically higher on larger farms and farms with a large cereal area. New cultivars were allocated primarily to high-yielding field parcels owned by a farmer. Farmers aspired for an increased yield potential, but this did not necessarily entail a shift to later maturity. We found strong spatial dependency in cultivar renewal if the distance between the neighboring farms was < 5 km. The direction of the change was not only toward new breeds as long as the cultivar was high yielding. When returning to an older cultivar, it was likely that the new breed did not meet the farmer's expectations, or that the growing season was exceptionally challenging.

1. Introduction

Since domestication, barley (*Hordeum vulgare* L.) has become a widely distributed crop, which evidences its capacity to adapt to diverse conditions and serve various uses (Dawson et al., 2015). Genetic gains in barley yield and other important traits have been notable (Öfversten et al., 2004; Peltonen-Sainio and Jauhiainen, 2010; Laidig et al., 2016; Rajala et al., 2016; Cossani et al., 2022). However, climate change may negatively impact barley production throughout Europe (Moore and Lobell, 2014). Weather constraints and extreme events may further reinforce the recent trends of stagnated yields and increased yield gaps, despite genetic gains (Palosuo et al., 2015; Peltonen-Sainio et al., 2015; Schils et al., 2018). In general, a wide range of adaptation options is available in Europe (Olesen et al., 2011). The adverse effects of climate change can be mitigated with climate-resilient cultivars (Ingvordsen et al., 2015a, 2015b; He et al., 2022). Switching to such cultivars is especially crucial in regions where other options are neither feasible nor cost-effective (Trnka et al., 2011).

The genetic diversity of crops has decreased over the ages (Khoury et al., 2022). Improving resilience to weather constraints calls for a retreat from the appreciation of extensive uniform plant stands toward diversity. This concerns genomic resources used in breeding programs (Bustos-Korts et al., 2019, Kumar et al., 2020), cultivar choices available for farmers (Ingvordsen et al., 2015a), as well as the use of cultivar mixtures (Creissen et al., 2016), intercrops (Brooker et al., 2015), and diverse crop choices and rotations at farm and landscape scales (Peltonen-Sainio and Jauhiainen, 2019, 2020). Rapid and effective breeding cycles are needed to deliver climate change adaptation in real time (Atlin et al., 2017). By using diverse genomic resources (Hill and Li, 2022; Li et al., 2022) and knowledge-driven precision crop designs (Liu et al., 2021) coupled with machine learning and artificial intelligence (Thudi et al., 2021), the breeding of climate-resilient cultivars can be accelerated to meet emerging future needs.

The potential to adapt varies depending on crop, and in Europe, it

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was found to be low for barley when considering changing climate (Moore and Lobell, 2014). In some regions, it may therefore be possible to replace barley with less vulnerable crops (Frutos Cachorro et al., 2018). Barley has long been the most widely cultivated crop in Finland, covering 21% of cultivated land area today (35% if grasslands are excluded) (Luke Statistics, 2022). It is often cultivated monotonously considering both rotations and land use (Peltonen-Sainio et al., 2017), which increases the risk of crop loss and failure (Hiremath et al., 2021). Barley can be grown as an early maturing crop virtually anywhere in Finland, and it will therefore probably maintain an important role in the future — even though its growing area has declined as climate warming has enabled the expansion of other crops (Peltonen-Sainio and Jauhiainen, 2020). Hence, barley is grown in a wide range of climatic and edaphic conditions in Finland, which exposes it to variable challenges (Peltonen-Sainio et al., 2016). In the future, projected elevation in temperature and higher variation in precipitation (Ruosteenoja et al., 2016) call for cultivars that are well-adapted to changed conditions. Access to a large and diverse assortment of locally well adapted, climate-resilient, and resistant barley cultivars is the premise for successful cultivation. Well-adapted cultivars also improve the likelihood of the profitable use of other adaptive measures (Zhao et al., 2022), where adaptation options other than merely switching cultivar or crop are feasible (Trnka et al., 2011).

Farmers play a core role in adaptation, and they need to adopt or alter a large number of practices in a timely manner in Finland (Peltonen-Sainio et al., 2020), which often means investment (Zhao et al., 2022). The impacts of climate change on agriculture thus depend on how and to what extent farmers adapt to changing conditions (Moore and Lobell, 2014). However, farmers' transformation capacity, which is shaped by values and views on threats, opportunities, and operating limits (Peltonen-Sainio et al., 2020; Sorvali et al., 2021a, 2021b), is often neglected as a source of uncertainty, e.g., in climate change impact assessments (Moore and Lobell, 2014). Switching cultivars is a fairly priced measure in the sense that it is coupled with the purchase of certified quality-guaranteed seed. However, Finnish farmers tend to use farm-saved seed for many years, and the cultivar shift interval is therefore long (Peltonen-Sainio et al., 2011; Rajala et al., 2011). However, cultivar change is critical for coping with the local conditions and adapting to climate change from farm to national scale. Furthermore, choosing a cultivar contributes, more or less, to all farm operations, their timing throughout the growing season, and eventually farm economy in various ways. However, understanding farmers' possible motives to change a cultivar has largely remained hidden knowledge. Therefore, with this study we aimed: 1) to increase understanding of farmers' cultivar renewal process in Finland; 2) to study how yield and growing time of new cultivars have changed when farmers switched cultivars; and 3) to describe how farms with willingness to change cultivars differ from those reluctant to make a change.

2. Materials and methods

2.1. Barley cultivars used by Finnish farmers

Spring barley is the most common crop in Finland covering ca. 450,000 ha, i.e., 21% of the cultivated land area (Luke Statistics, 2022). It is cultivated throughout Finland for use as feed or malting. Barley was therefore used as a model crop in this study. Data from the Finnish Food Authority (FFA) and Official Variety Trials (OVT) were gathered to estimate the probability of a farmer cultivating a new barley cultivar in the 2018 growing season compared to 2014. Field parcel -scale information on cultivars grown by farmers were available in FFA data. OVT includes all cultivars without specification of use (feeding/malting) and farmers use cultivars for both purposes. In the FFA, barley types are specified, because farmer's intended use of barley is asked close to sowing. However, the final use often differs from the planned/registered one: farmers may aim malting barley due to the premiums but may end up in low yields (i.e., lot sizes) and/or quality acceptable only as feed. Based on the data, it was, however, apparent that majority of farms had the same intended "final use" in 2014, 2018 and 2020.

Cultivar age was determined as the year it was introduced to OVT. "A new cultivar" was characterized as one that was introduced into OVT for the first time during 2013–2015. In 2013, "Eifel," "Fabiola," "Gesine," "Luhkas," "Pompe," "Rgt Planet," "Soulmate," "Vertti," and "Vilgott" were introduced to OVT, while "Arild," "Avalon," "Crescendo," "Popekka," "Repekka," "Uta," "Vipekka," "Eversti," and "Laureate" were newcomers in 2014 or 2015. "Rgt Planet" (10,351 field parcels), "Vertti" (3234), "Arild" (2033), "Luhkas" (1660), and "Eifel" (1541) had become the most popular new cultivars by the 2018 reference year, while the rest of the newcomers each had less than 1000 field parcels (with the least for "Popekka," "Gesine," and "Laureate"). The oldest recognized cultivars in 2018 were introduced to OVT 33 years ago. We examined the progress in some other important traits of barley (e.g., stem height and grain protein concentration) and found that only growing time from sowing to yellow ripeness (days) and grain yield (kg ha^{-1}) were potential to have impacts on farmers' decisions.

The growing time and grain yield of all the cultivars were estimated using OVT data from 1970 to 2021. The data contained 1059 trials, including 979 barley cultivars and breeding lines ($N = 23,521$ observations in total). A mixed model was fitted to the data, in which the cultivar was used as a fixed factor, and the trial as a random factor. The model resulted in mutually comparable estimates of growing time and grain yield for all the studied cultivars. The yield level estimate of a single cultivar was not affected depending on the presence of a cultivar is trials where the average yield was high or low. These estimates were weighted with the FFA data to compare the yield potential (Y_{pot}) of a new cultivar compared to the average for older cultivars: The difference between two weighted averages in 2018 was calculated (all new cultivars vs. others), weighted by the cultivation area of each cultivar. The same estimates were used to compare cultivars grown in 2014 (all cultivars) and 2018 (separately those fields where farmer switched back to an older cultivar or renewed a cultivar). Thereby, yield potential is practically a weighted average, where the weight is the cultivated area of each cultivar in 2014, 2018 or 2020. This was essential because there were differences in the yield levels of new cultivars, and in addition, some new cultivars have been cultivated more in the south, while others in the east. The cultivation area of old cultivars also varied depending on region and other variables. With weighting, it was possible to compare the potential old with the potential new cultivars in the case of many kinds of farms.

2.2. Estimation of probabilities that farmer renews a barley cultivar

Before the statistical analyses, field parcels and farms that possessed a parcel included in this study were grouped as follows: 1) geographical region (merging 16 Centers for Economic Development, Transport and the Environment, ELY Centers to form 4 main regions: South-, West-, East/North-Finland and the inland region); 2) farm size (<50, 50–99, 100–199, and ≥200 ha); 3) farming system (organic and conventional); 4) farm type (cereal, special crop, horticulture, cattle, pig, poultry, horse/sheep, and other farms); 5) share of cereal area on a farm (<25%, 25–75%, and ≥75%); 6) ownership of the field parcel (owned and leased); 7) parcel's productivity gap (no gap when compared to the best 10% of parcels, 1–20%, 21–40%, and >40%); 8) parcel's dominant soil type according to Lilja et al. (2006) (coarse mineral soils like *Haplic Podzol 1* and *2*, clay soils like *Vertic Cambisol*, other clay soils, including *Eutric Cambisol, Gleyic Cambisol*, and *Gleysols*, and organic soils, including *Fibric/Terric Histosol 1* and *2* and *Dystric Gleysol*); and 9) field slope (<1.30, 1.30–2.89, 2.90–6.99, and ≥7.00).

143,120 field parcels (corresponding to 399,750 ha) were found to have a cultivar name available in both the FFA and OVT data. The probability of a farmer selecting a new barley cultivar in 2018 was modeled by Logistic Regression (1 =new cultivar; 0 =old cultivar). At first, a univariate model was fitted. The dependent variables were: 1) geographical region; 2) farm size; 3) farming system; 4) farm type; 5) share of cereal area on a farm; 6) ownership of the field parcel; 7) parcel's productivity gap; 8) parcel's dominant soil type; and 9) field slope. The total number of field parcels in the analysis was 133,945 (366,783 ha) because the data on soil type and field slope had missing values. In addition, the productivity gap was defined for 95,742 fields (258,921 ha). Thereafter, a multivariate logistic regression model was fitted, including all nine dependent variables at the same time. The results of this were called adjusted results. The model was fitted using SAS/LOGISTIC-software.

The results of the logistic regression were presented using Odds Ratios (OR) and their 95% confidence intervals (CI). In general, the OR is one set of odds divided by another (e.g., odds for South compared to odds for East/North-Finland). An odds ratio of 1.00 indicates that the event under study is equally likely in both groups. An odds ratio greater than 1.00 indicates that the event is more likely in the first group, whilst an odds ratio of less than 1.00 indicates that the event is less likely in the first group. A 95% CI for the odds ratio shows how high and how low the actual population odds ratio may be. The CI is related to the P-value: The odds ratio is not statistically significant if the CI includes 1.00.

Spatial correlation is a measure to examine the relationship between "close" spatial units. If a farm selects a new cultivar, how often do nearby farms make the same decision? This correlation was measured using the variogram (Webster and Oliver, 2007). The analyzed variable was the proportions of a farmer's field having a new cultivar, typically 0 or 1, but the proportion was between these if the farm cultivated both old and new cultivars. An empirical semivariogram was calculated using SAS/VARIOGRAM software with lags < 0.5 km ($N = 4597$ pairs of farms; the same farm could be included in several pairs), 0.5–1.5 km ($N > 28{,}000$ pairs of farms), 1.5–2.5 km, ($N > 45{,}000$ pairs of farms) … up to 49.5–50.0 km ($N > 460{,}000$ pairs of farms). A relative empirical variogram was then calculated by defining the sill variance as 100%. The sill variance is commonly considered the variogram value where the variogram function flattens off at an increasing distance. This is also the variance of uncorrelated observations (100% uncorrelated). If the observations are not correlated, it indicates that each farm makes an own independent decision and hence, farms that choose the new cultivar appear randomly on the map. The spatial correlation was calculated using farm data, not parcel-scale data (i.e., the mean of the mid-points of all field parcels on a farm was calculated, and this point was used in the spatial analysis).

In 2018, a new cultivar was found for 17,245 fields. Of these, 6897 also had barley in 2014. The difference between cultivar age, yield, and growing time was calculated by comparing the earlier cultivar to its replacement, i.e., according to the data available on 6897 fields. The results were presented as averages and frequency distributions (also as a cumulative distribution function). The distributions were presented for each region, farm size, and farm type. The spatial correlation between different decisions between 2014 and 2018 was measured using a variogram like the farmer's decision to select a new cultivar in 2018. Changes from 2018 to 2020 ($N = 7074$ in 2020) were analyzed in the same way as those between 2014 and 2018.

The probability of a farmer renewing a barley cultivar was estimated, depending on an increase in the Y_{pot} provided by a new cultivar. However, this increase may depend on farm characteristics. For example, farmers in East/North-Finland may choose cultivars with a shorter growing season than farmers in South-Finland. Furthermore, cultivars that may meet the needs of pig farms may differ from malting industry specifications. The Y_{pot} for different kinds of farms was calculated as a weighted mean of cultivars' yields according to OVT data so that the cultivation area was used as weights: Weights were calculated separately for farms with new and old cultivars in 2018. The Y_{pot} increase of a new cultivar is the difference between the means of similar farms with an old or new cultivar. The increase in the Y_{pot} of a new cultivar was calculated by considering all farm characteristics (e.g., region, farm size, farm type). Logistic Regression was used to model the probability of a farmer selecting a new cultivar as a function of the increase in Y_{pot} of a new cultivar on a farm having comparable characteristics to their own farm. The basic idea of this analysis was to observe how important the Y_{pot} is for cultivar selection: e.g., if the cultivar used in similar farms is poor in terms of yield compared to the new cultivars, does the farmer switch more often to the new one, and if the new cultivar does not produce much higher yield than the typical older cultivars, do farmers stick to older ones. Before analysis, in the case of average Y_{pot}, the increase in Y_{pot} of a new cultivar was defined as 1.00. Thereby, a value of e.g., 1.10 means that the average Y_{pot} of a new cultivar was 10% higher than average.

3. Results

3.1. Age range of barley cultivars grown in Finland

Barley cultivars and their age (based on the year of cultivar introduction to OVT) grown by farmers differed, depending on region (Fig. 1). The most common age group of cultivars used in the 2018 growing season was 2008–2012. However, the regional differences were significant: As many as 79% of field parcels had cultivars introduced during 2008–2012 in East/North-Finland. The equivalent figures for South-Finland were only 46%, for inland regions, 53%, and for West-Finland, 67%. Cultivars introduced during 1998–2002 were the least favored age group by farmers. Only 4% of cultivars dating to before 1998 were grown in East/North-Finland in 2018, while 8–11% were grown elsewhere. Cultivars introduced during 2003–2007 were also less used in East/North-Finland (10%) than elsewhere, especially in South-Finland (28%) and inland regions (23%). On the other hand, the newest cultivars (2013–2015) were less favored in East/North-Finland and most favored in South-Finland (16%) and inland regions (11%) (Fig. 1).

3.2. Farm and field parcel characteristics matter to cultivar switch

Many farm and field parcel characteristics differ depending on region and hence, adjusted odds ratios (that acknowledge interdependencies) were used to analyze differences in probabilities for a cultivar switch from 2014 to 2018 (Table 1). The renewal of barley cultivars was more probable in South-Finland, followed by inland regions, compared to East/North-Finland. Peatlands are most common in the East/North region and field parcels with other soil types (especially clay soils) were therefore more commonly used for newer cultivars. The likelihood of switching to newer cultivars was systematically higher in larger than smaller farms, as was the case if the cereal area was $\geq 25\%$, the field parcel was owned by a farmer, and the yield gap of a parcel was low, i.e., it had a high production capacity. Differences were also found between farm types in probabilities to renew cultivars in descending order of farms with a primary focus on special crops → horticulture → pig → poultry or cereals → cattle (Table 1). Whether the field parcel was under organic or conventional cultivation did not affect the probability of switching to newer cultivars (data not shown).

When farmers renewed a cultivar after the 2014 growing season, they usually replaced the older cultivar with one being seven years younger (Fig. 2A). The mean difference was 8.8 years. Some very old cultivars ($\geq$16 years) had held on until they were switched for newer ones. However, more than 70% of the replaced cultivars were < 9 years older than the substituting cultivar (Fig. 2A). The cultivar renewal pace tended to be higher elsewhere than in inland regions (Fig. 3A), as well as on poultry, pig, and cattle farms compared to crop production farms (Fig. 3B). When considering regional differences for cereals farms alone, those located in West- and Sound-Finland had a higher renewal pace (by ca. two years) than in inland regions and East/North-Finland (Fig. 3C). Cereal and pig farms in West-Finland tended to start cultivar renewal slightly earlier than elsewhere (Fig. 3C-D).

Barley cultivars were changed in both ways, i.e., farmers not only

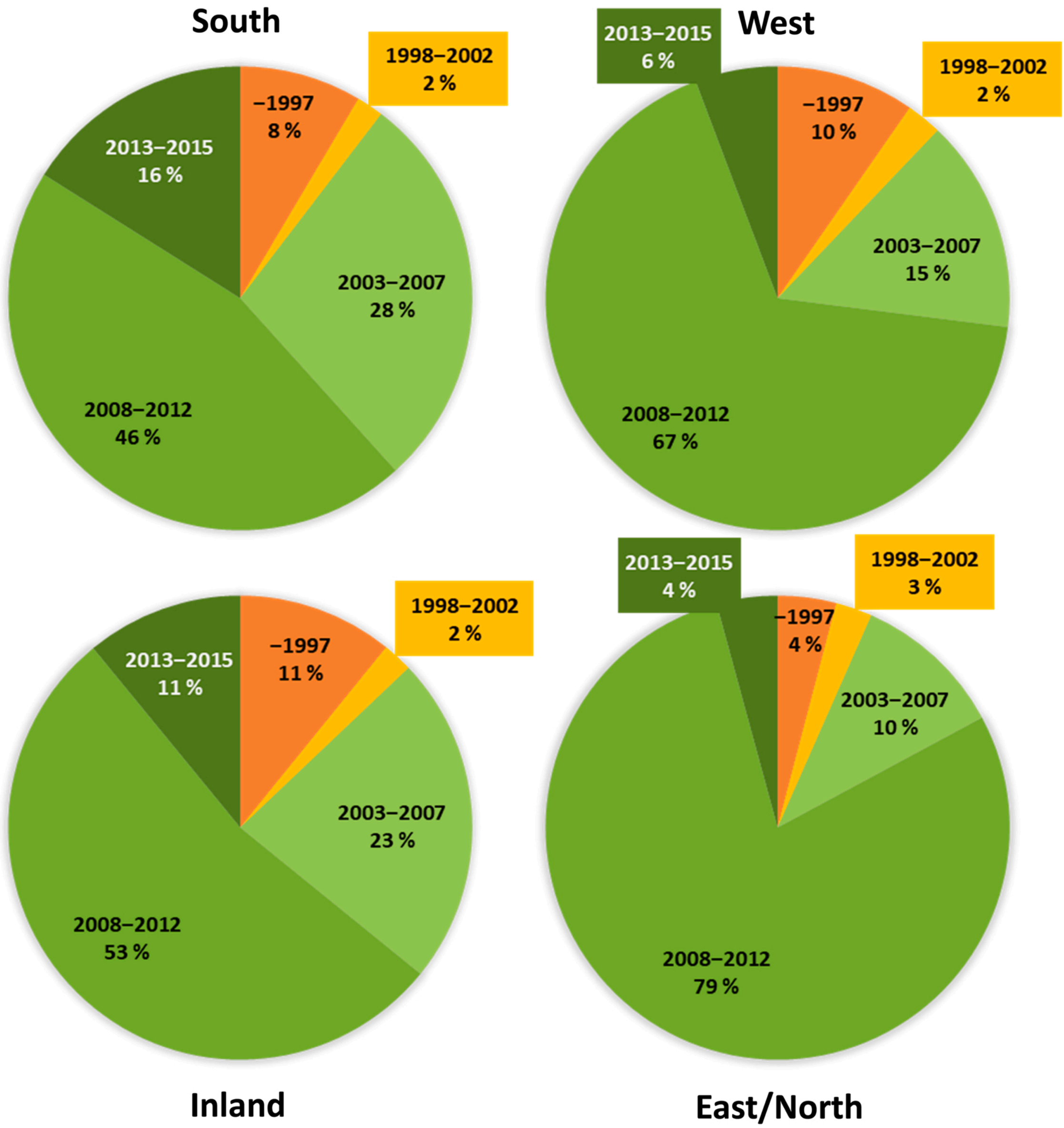

Fig. 1. Shares of age groups of barley cultivars grown in 2018 depending on region. Cultivar age was defined to be the year when it was introduced to the Official Variety Trials. The share of each age group in a region was defined as the percentage of field area allocated to cultivars that belonged to the age group (N = 143,120 fields, 399,750 ha).

renewed cultivars, they also switched back to older ones (Table 2). This was apparent when the data from 2014 and 2018 were supplemented with the additional year of 2020. Most of the farmers (71%) who adopted a newer cultivar in 2018 also continued its cultivation after two years, while 11% purchased a new cultivar again, and 18% switched back to an old cultivar. Farmers in Southern Finland and inland regions continued the cultivation of the same renewed cultivar more frequently than farmers in West- and East/North-Finland, where farmers more often switched back to old cultivars. In East/North-Finland, ca. 17% of farmers who switched to a new cultivar by 2018 tended to switch again to an even newer one, while the share was about 9–12% elsewhere. Farmers who had very large farms (≥200 ha) were more inclined to switch the cultivar again to an either newer or older cultivar. Farmers who had crop production farms continued with the same cultivar that was renewed in 2018 more frequently than those with animal farms. However, more than 20% of farmers with animal farms returned to older cultivars (Table 2).

3.3. Role of grain yield, growing time, and encouraging neighbors

The mean difference in grain yield between old and new barley cultivars was 400 kg ha^{-1}, but the yield difference ranged greatly, depending on farm and field parcel characteristics. In South-Finland the difference was highest, ca. 600 kg ha^{-1} compared to 400 kg ha^{-1} in inland regions and 280 kg ha^{-1} in West-Finland, while in East/North-Finland the difference was almost non-existent (26 kg ha^{-1}) (Fig. 4A). The yield of the modern cultivars tended to increase the larger the farm, and the yield difference tended to be highest (440 kg ha^{-1}) on the very large farms (≥200 ha) and lowest (ca. 380 kg ha^{-1}) on farms of < 100 ha (Fig. 4B). The higher the share of the cereal area on a farm, the lower was the relative yield of older cultivars compared to the mean (Fig. 4C). While a slight increase was again found for newer cultivars in the case of higher cereal areas: The difference was highest (450 kg ha^{-1}) in the case of > 75% of cereal areas on a farm and lowest (330 kg ha^{-1}) in the case of a < 25% cereal area. The yield benefit of using newer barley cultivars was highest on special crop farms (570 kg ha^{-1}), followed by other farm types in descending order of farms with a primary

Table 1
Adjusted odds ratios (OR) with 95% confidence intervals (CI) showing how the probability of a farmer renewing a barley cultivar depends on farm and field parcel characteristics. When the odds ratio is < 1.00, a new cultivar is adopted significantly less frequently, and when it is > 1.00, significantly more frequently than the reference (heading in italics), provided that the CI does not include the value 1.00.

Characteristic	OR	95% CI	
Region (P < 0.001) compared to East/North-Finland			
South-Finland	2.56	2.31	2.82
West-Finland	1.03	0.94	1.14
Inland region	1.92	1.74	2.11
Farm size (P < 0.001) compared to 50 ha			
50–99 ha	1.37	1.30	1.45
100–199 ha	2.04	1.93	2.16
≥ 200 ha	3.07	2.87	3.29
Farm type (P < 0.001) compared to cattle farm			
Cereal	1.56	1.47	1.65
Special crop	2.42	2.25	2.61
Horticulture	2.02	1.7	2.39
Pig	1.65	1.53	1.78
Poultry	1.58	1.4	1.77
Horse/sheep	1.05	0.74	1.49
Others	0.58	0.34	1.00
Cereal area on a farm (P < 0.001) compared to < 25%			
25–75%	1.66	1.48	1.87
> 75%	1.69	1.50	1.92
Ownership of a parcel (P < 0.001) compared to owned			
Leased	0.87	0.84	0.91
Productivity gap (P < 0.001) compared to > 0.40			
The best 10% of fields	1.60	1.41	1.82
0.01–0.20	1.24	1.17	1.32
0.21–0.40	1.11	1.05	1.18
Soil type (P < 0.001) compared to organic soils			
Coarse mineral soils	1.09	1.02	1.17
Clay soils (*Vertic Cambisol*)	1.55	1.44	1.67
Other clay soils	1.22	1.12	1.33

focus on poultry (500 kg ha^{-1}) → horticulture (460 kg ha^{-1}) → cereal (440 kg ha^{-1}) → pig (410 kg ha^{-1}) → horse/sheep (340 kg ha^{-1}) → other farm types (290 kg ha^{-1}) → cattle (260 kg ha^{-1}) (Fig. 4D). The yield difference was highest when new barley cultivars were allocated to field parcels with clay, especially *Vertic Cambisol*, as the dominant soil type (590 kg ha^{-1}) (Fig. 4E).

The cultivar's suitability varies depending on the characteristics of the farm: e.g., region, farming system, and farm type. When estimating the probability of a farmer renewing a barley cultivar that will be suitable for their farm by stressing an assumed increase in the Y_{pot} of a new breed compared to the average for all new cultivars, it was found that the increase in Y_{pot} was an extremely important argument for a farmer to select a new cultivar (Fig. 5). For example, if a new cultivar had a Y_{pot} of only 70%, the likelihood of the farmer switching to it was about 1%, while if the Y_{pot} was equal to the average for all barley cultivars, the likelihood was 9%. On the other hand, a Y_{pot} of 125% encouraged 30% of farmers to select such a cultivar (Fig. 5).

The difference in growing time from sowing to maturity between old (grown in 2014) and renewed cultivars (2018) varied greatly: Some newer cultivars matured more than ten days earlier than the previously used cultivar, while at the other end were cultivars that required ten more days to mature (Fig. 2B). However, farmers switched most frequently to later maturing barley cultivars: The median was + 2 days, and the mean + 1.7 days. The direction of the change in the growing time differed depending on the region, but to some extent also on farm type. Especially in East/North-Finland, but also in West-Finland, a shorter growing time was favored for renewed cultivars than for cultivars chosen in South-Finland and inland regions (Fig. 6A, C, D). In East/North-Finland, farmers did not switch to cultivars that had a growing time of ≥ 6 days longer, while such cultivars were chosen in 17% of changes in South-Finland, 14% in West-Finland, and 11% in inland regions. Early maturing barley cultivars were favored in cultivar renewal on cattle farms (Fig. 6B). On horticultural farms, later maturing new cultivars (growing time ≥6 days longer) were avoided.

A farmer who switched back to older cultivars after renewal in 2018 tended to choose a cultivar that had a growing time of 1.6 days longer and a higher yield of 240 kg ha^{-1} (Table 2). Farmers who favored very late maturing (4.2 days) and high yielding (554 kg ha^{-1}) older cultivars had farms in South-Finland. In contrast, farmers in East/North-Finland switched to cultivars with a lower Y_{pot}. Differences in days to maturity and grain yield varied depending on farm type: Differences between the older cultivar (switched to by 2020) that followed the renewed cultivar (in 2018) were found to be higher on special crop farms than on poultry, cereal, pig, and cattle farms (in descending order). Some differences were also found, depending on farm size (Table 2).

Neighboring farmers influenced decisions to change a cultivar on a farm. There was a very systematic spatial dependency: The closer the farmer was who switched a cultivar, the higher the probability was that another neighboring farmer also changed a cultivar until the distance between the farms grew close to 30 kilometers (Fig. 7). However, decisions made on neighboring farms had no systematic influence on whether another farmer switched to a newer or older cultivar. Spatial dependency was also found for cultivar characteristics. The age, Y_{pot}, and growing time of renewed cultivars on the nearby farms tended to be more alike (Fig. 8) for age and yield until the distance between farms had increased to 15–16 kilometers, and for growing time to 25 kilometers.

4. Discussion

Barley is the most common crop in Finland that is grown in variable conditions, and it has the largest number of cultivars in the National List of Plant Varieties of Finland (The Finnish Food Authority, 2022). This official list includes cultivars bred in Finland, other Nordic countries, and elsewhere in Europe. Finnish farmers almost entirely use cultivars that have been tested in Finnish conditions with multilocational experiments (i.e., in OVT). It is important that cultivar trials capture spatiotemporal environmental variation to characterize the climatic responses of new breeds compared to existing ones (van Etten et al., 2019). Such information can reliably support a farmer's decision making on cultivar choice, reduce the risk of mismatches, and enable a farmer to avoid using a poorly adapted barley cultivar, which is especially important in the greatly varying and challenging weather conditions of high-latitude regions in Europe (Peltonen-Sainio et al., 2011, 2016; Hakala et al., 2012, 2020). Despite comprehensive access to new barley cultivars, those used by farmers range from very old generations to recent breeds (Fig. 1). The most common age group of cultivars grown in 2018 was those introduced to OVT in 2008–2012, and their share was highest in East/North-Finland. The cultivar shift interval was found to be long, as the median age difference was seven years between the used and the replacement cultivar (Fig. 2). This is attributable to the large-scale use of farm-saved seed in Finland, i.e., a wide range of seed generations produced after a purchase of the certified seed (a range of 1–15 years with a median of 4–5 years) (Peltonen-Sainio et al., 2011). We found a systematic spatial dependency in cultivar change especially if the distance between farms was less than five kilometers (Figs. 7 and 8). Hence, within an immediate neighborhood, farmers tended to favor cultivars of the same age, Y_{pot}, and growing time, but this was lost when the distance reached 30 kilometers. A wide transition of experience gained by the change agent farmers takes some time (Ingram, 2008; Cerf et al., 2011), which may partly contribute to the recorded long shift interval.

It became very clear that farmers above all acknowledged the cultivar's yielding capacity when choosing a cultivar (Fig. 5). If a cultivar had 25% higher Y_{pot} compared to the average of all cultivars, the probability of switching to such a high-yielding cultivar was 30%. On the other hand, in the case of an average yield, the likelihood of choosing a cultivar was only 10%, while in the case of 25% lower Y_{pot}, it was less

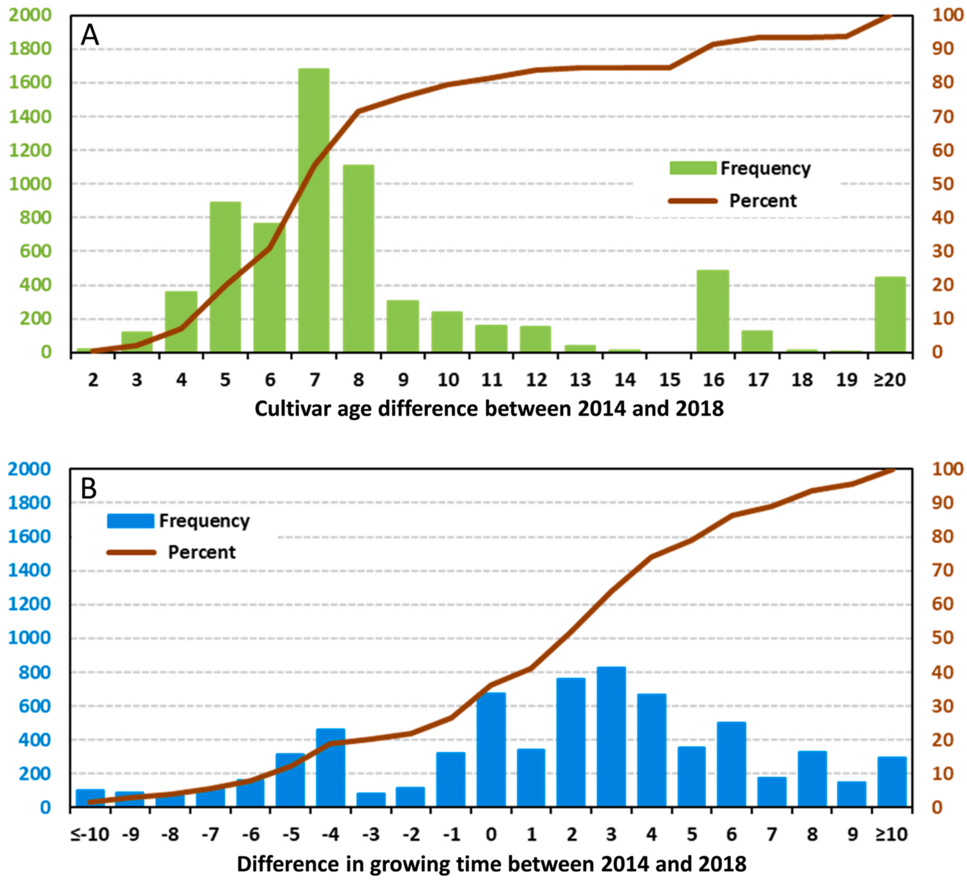

Fig. 2. Frequencies of differences in age (upper A panel) and growing time (lower B panel) of barley cultivars changed by farmers in 2018 compared to the preceding cultivars used on a farm in 2014. The cumulative percentage of age and growing time is shown by the brown line.

than 3%. The mean yield difference between old and new barley cultivars was 400 kg ha^{-1}, but it ranged greatly, depending on farm characteristics (Fig. 4). We identified that the difference expanded between old and new cultivars especially in Southern Finland, which has plenty of crop production farms with a high cereal area share (>75%), where farms are often very large (≥200 ha), and clay soils dominate. As the renewal of a cultivar coincides with the purchase of a quality guaranteed certified seed, the farmer may obtain an additional benefit of an increase in yield of some 10–13% (corresponding to 550–800 kg ha^{-1}) compared to the continuous use of farm-saved seed (Rajala et al., 2011). The farmer may also avoid hidden risks in the capacity to germinate and establish an even plant stand, as well as the potential damage caused by the use of seed of unknown quality (e.g., caused by seed-borne pathogens) (Peltonen-Sainio et al., 2011; Peltonen-Sainio and Rajala, 2014). To support the realization of the superior Y_{pot}, the switched cultivar was frequently allocated to field parcels with low productivity gaps (Table 1). Success was further emphasized by allocating a switched cultivar more often to a field parcel owned by a farmer than on leased land. Farmers are more aware of the history, suitability, productivity, limitations, and management needs of their own fields (Peltonen-Sainio et al., 2018) — not least because leasing contracts are often short in Finland (Pouta et al., 2012).

The Finnish farmers tended to use farm-saved seed for years (Peltonen-Sainio et al., 2011). In this study, most farmers (71%) who switched cultivar in 2018 compared to 2014 also continued with it two years later (2020). However, this was less frequent on animal farms and very large farms (≥200 ha) (Table 2). In the case of animal farms, this was probably attributable to the high share of on-farm use of produced barley as animal feed and thereby the need to purchase certified seed (Peltonen-Sainio and Rajala, 2014), while in the case of large field areas on a farm, economic losses accumulate with poor-quality farm-saved seed and a lower yielding cultivar. This finding was supported by a higher cultivar renewal pace found for poultry, pig, and cattle farms (Fig. 3), where production of on-farm feed is also more cost-efficient compared to commercial feeds. Although farmers primarily chose a cultivar according to the expected increase in yield (Fig. 5), barley cultivars were not only switched for newer breeds but for older ones as well (Table 2).

Interestingly, a higher share of farmers who switched cultivar again (2018 → 2020) switched to older cultivars (18%) than to a new breed again (11%). The apparent dissatisfaction with a purchased new cultivar was more frequent on animal farms and in West- and East/North-Finland, and least frequent on specialized crop production farms. Nonetheless, even when the cultivar was changed again, farmers favored high yielding older cultivars. Dissatisfaction with an earlier (2018) renewed cultivar may be attributable to unrealized expectations of the Y_{pot} of a new cultivar in the prevailing farm conditions. One cannot fully exclude the possibility of seed sale or exchange of farm-saved seed between neighboring farms, even though this is illegal. The exchange of farm-saved seed as a means of switching a cultivar may lead to dissatisfaction because only commercial certified seed has a quality guarantee. Dissatisfaction may also be fueled by weather constraints during the test period of a new cultivar purchased in 2018. This was demonstrated in another study, according to which farmers readily responded to past experiences and weather conditions by switching barley cultivars towards those showing better climate-resilience (Peltonen-Sainio et al., 2013). During the study period, pre- and post-heading mean temperatures had elevated or reduced depending on the year (compared to the long-term mean), but without regional differences in the direction of the change (Table S1). Elevated temperatures occurred more frequently in the pre- than post-heading period. Accumulated precipitation during

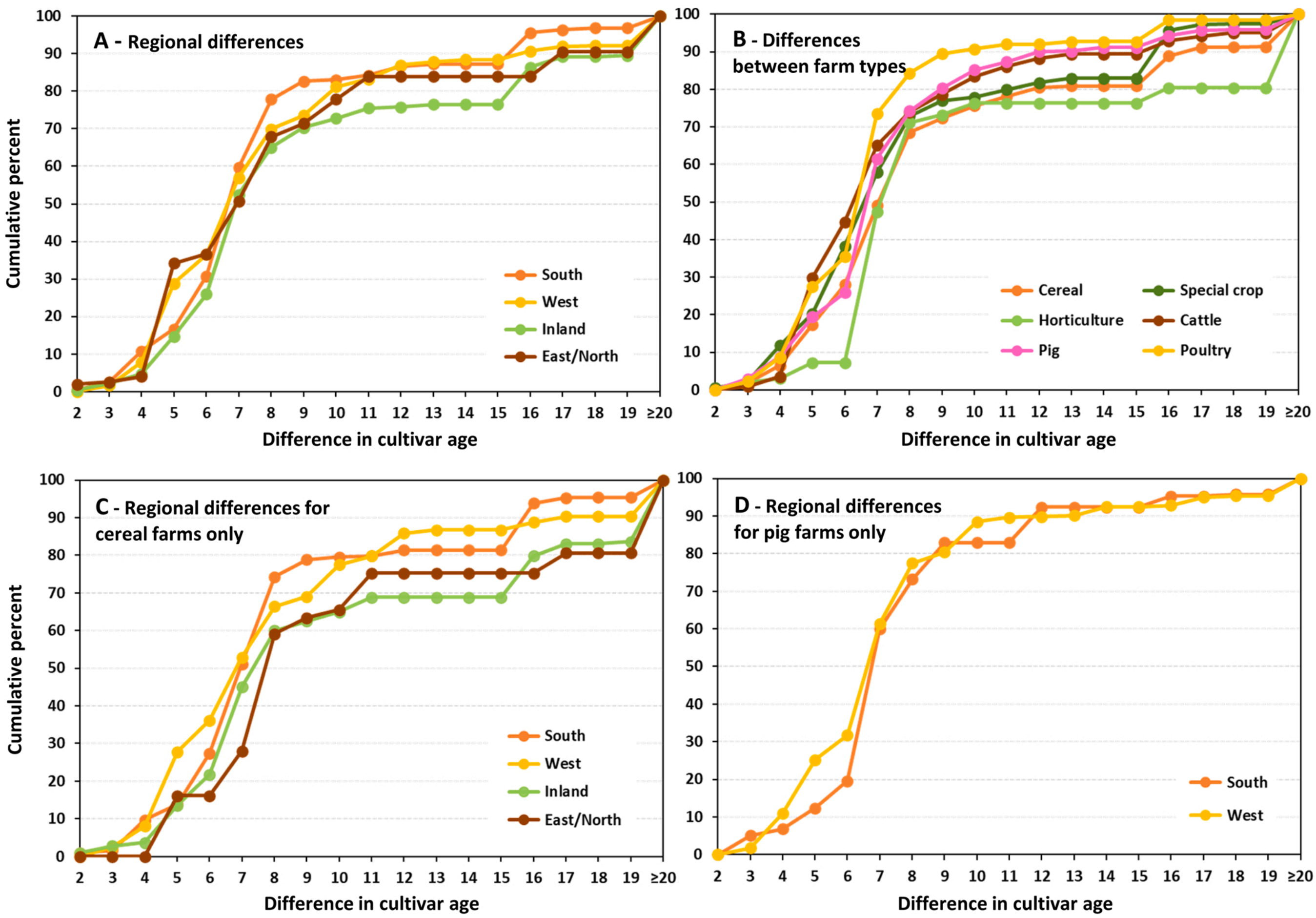

Fig. 3. The cumulative percentage of differences in cultivar age between 2014 (old cultivar) and 2018 (renewed cultivar) depending on region (panel A) and farm type (panel B), as well as the regional differences for cereal (panel C) and pig farms alone (panel D). Pig farms are mainly located in Southern and Western Finland.

Table 2
Share of farms where the farmer switched from an older cultivar (grown in 2014) to a newer cultivar (grown in 2018), but in 2020, either returned to an older cultivar, switched again to a newer cultivar, or continued to cultivate the same cultivar as in 2018, and how this varied depending on region, farm size, and farm type. The mean difference in the growing time and yield of older cultivars compared to those of newer ones (median in parenthesis) is shown if a farmer switched back to an older cultivar.

Characteristic	Share of farms (%)			Difference			
	Continued with the same cultivar	Switched again to a newer cultivar	Switched back to an older cultivar	Growing time (d)		Yield (kg ha^{-1})	
All farms	71.0	11.0	18.0	1.6	(3)	240	(110)
Region							
South-Finland	78.7	9.6	12.5	4.2	(5)	554	(455)
West-Finland	56.9	11.6	30.4	0.8	(2)	179	(31)
Inland regions	75.2	8.7	14.6	0.7	(2)	89	(−79)
East/North-Finland	63.4	16.7	28.4	0.8	(3)	-90	(−209)
Farm size							
< 50 ha	71.3	8.8	19.1	1.5	(2)	214	(79)
50–99 ha	70.0	12.7	18.4	1.1	(1)	192	(71)
100–199 ha	76.0	10.2	15.3	2.3	(3)	332	(183)
≥ 200 ha	62.3	8.2	21.0	1.1	(3)	174	(−21)
Farm type							
Cereal	73.5	13.9	17.3	2.0	(3)	264	(116)
Special crop	76.6	9.2	9.5	4.1	(4)	850	(816)
Cattle	64.9	14.0	22.9	-0.5	(−1)	3	(14)
Pig	63.6	9.7	22.4	1.6	(3)	68	(6)
Poultry	67.0	12.2	23.3	2.1	(3)	309	(370)

these periods varied depending on region but was in most cases lower than the long-term mean. Thereby, the finding that farmers often switched to later maturing and higher yielding cultivars in both study periods (2014 → 2018 and 2018 → 2020) is probably attributable to warmer summers and a lack of harvest-hampering high precipitation events (Peltonen-Sainio et al., 2013).

Using climate-resilient cultivars (Ingvordsen et al., 2015a, 2015b; He et al., 2022) is an important measure for mitigating the adverse effects of

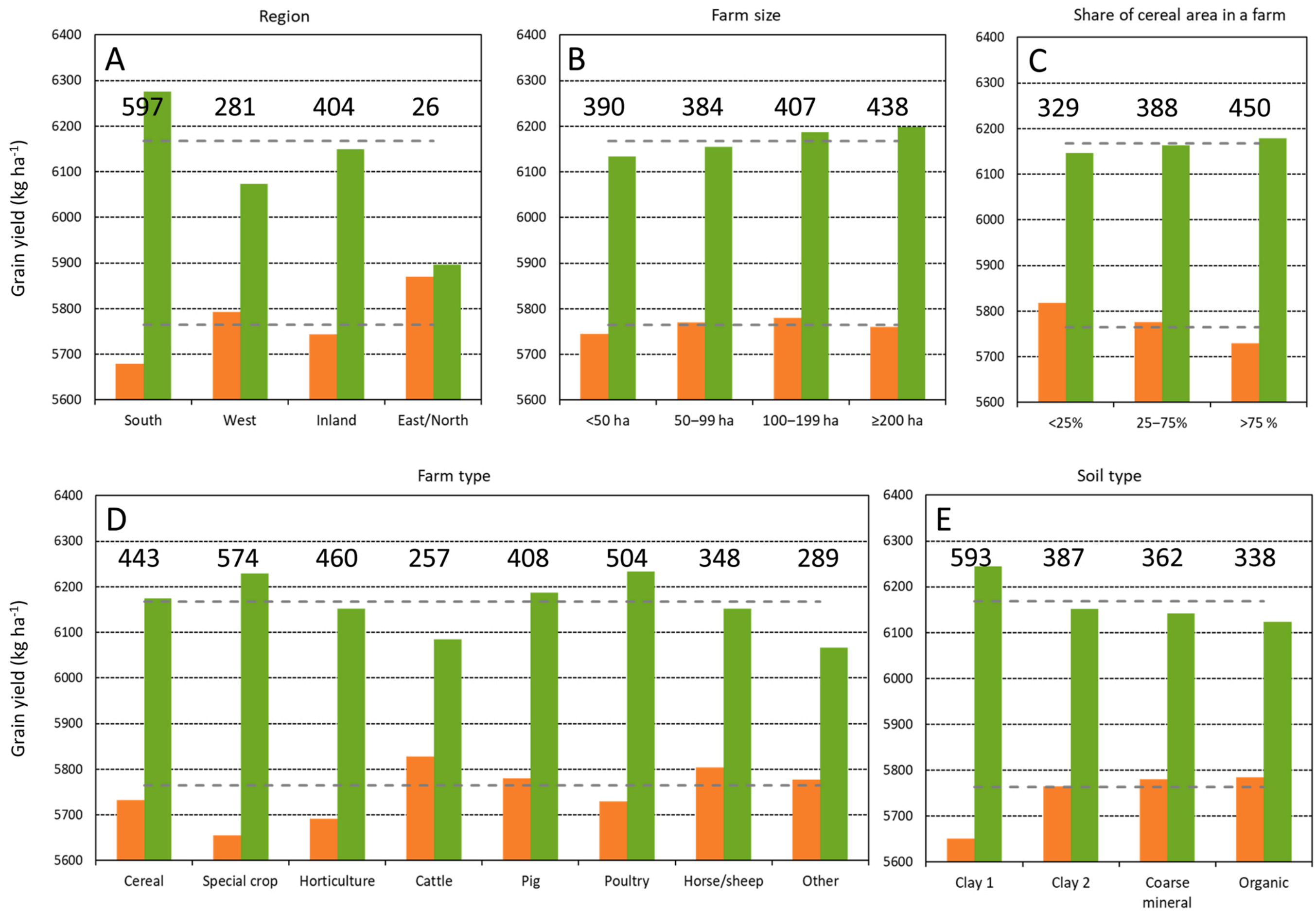

Fig. 4. The mean difference in the grain yield of barley cultivars grown in 2014 (light brown bar) and after renewal in 2018 (green bar), depending on region (panel A), farm size (B), share of cereal area on a farm (C), farm type (D), and soil type of the field parcel (E). The gray dashed line is the mean of old (5764 kg ha^{-1}) and renewed cultivars (6168 kg ha^{-1}). The yield difference between old and renewed cultivars are shown between the lines.

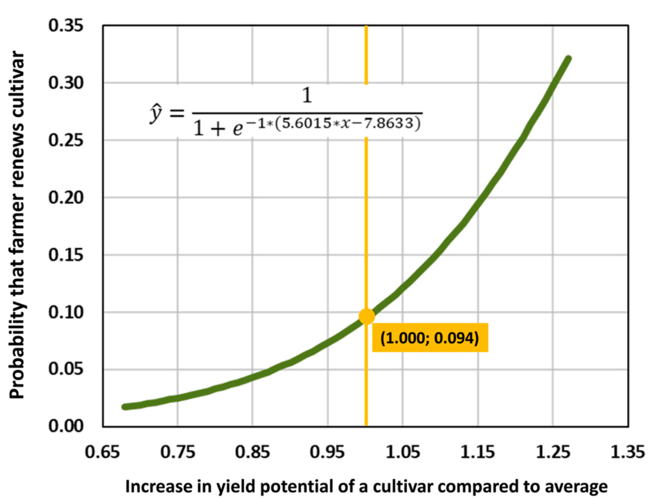

Fig. 5. The probability of a farmer renewing a barley cultivar ($P < 0.001$), depending on the potential yield increase (%) of a new cultivar. On the x-axis, the increase in potential yield of 1.00 means the farmer selects a new barley cultivar with the same grain yield compared to the average for all new cultivars.

weather variability and climate change (Hakala et al., 2012, 2020; Trnka et al., 2016). The growing time from sowing to maturity is critical at high latitudes to reducing the risk of crop failure (Peltonen-Sainio et al., 2013; Göransson et al., 2020). In this study, the growing time ranged widely (Fig. 2), from ≤ 10 to ≥ 10 days, when renewed cultivars were compared to those they replaced (2014 → 2018). Farmers most often switched to cultivars that required two more days to mature, but this differed depending on region and farm type (Fig. 6): In the Eastern/Northern and the Western coastal regions, farmers favored earlier maturing cultivars. In the short growing season typical of East/North-Finland and thereby, high risk for crop failures in the case of delayed harvest (Peltonen-Sainio and Jauhiainen, 2014; Peltonen-Sainio et al., 2016), farmers never switched to a cultivar that had a longer growing time of ≥ 6 days, which was contrary to farmers elsewhere. Interestingly, horticulture producers were also found to avoid very late maturing barley cultivars, which are mostly used elsewhere than in northern regions. Such risk avoiding behavior is probably attributable to the prioritization of agronomic measures on horticultural cash crops ahead of barley, as barley may be used only as a break-crop in rotations. Farmers who switched cultivar again (2018 → 2020) and switched back to older cultivars (18%) favored later maturity (although the difference was modest). The most striking difference, i.e., maturity occurring 4 days later, was found in Southern Finland, with the longest growing season.

As a secondary product of all the analyses that primarily aimed to understand the narrative of facts related to farmers' cultivar renewal process, we could identify a group of change agent farmers, who probably played an important role in encouraging neighboring farmers to make a cultivar change (Fig. 7). They were characterized by having very large farms (≥200 ha), special crop production [cultivating peas (*Pisum sativum* L.), faba beans (*Vicia faba* L.), rapeseed (*Brassica napa* L. and

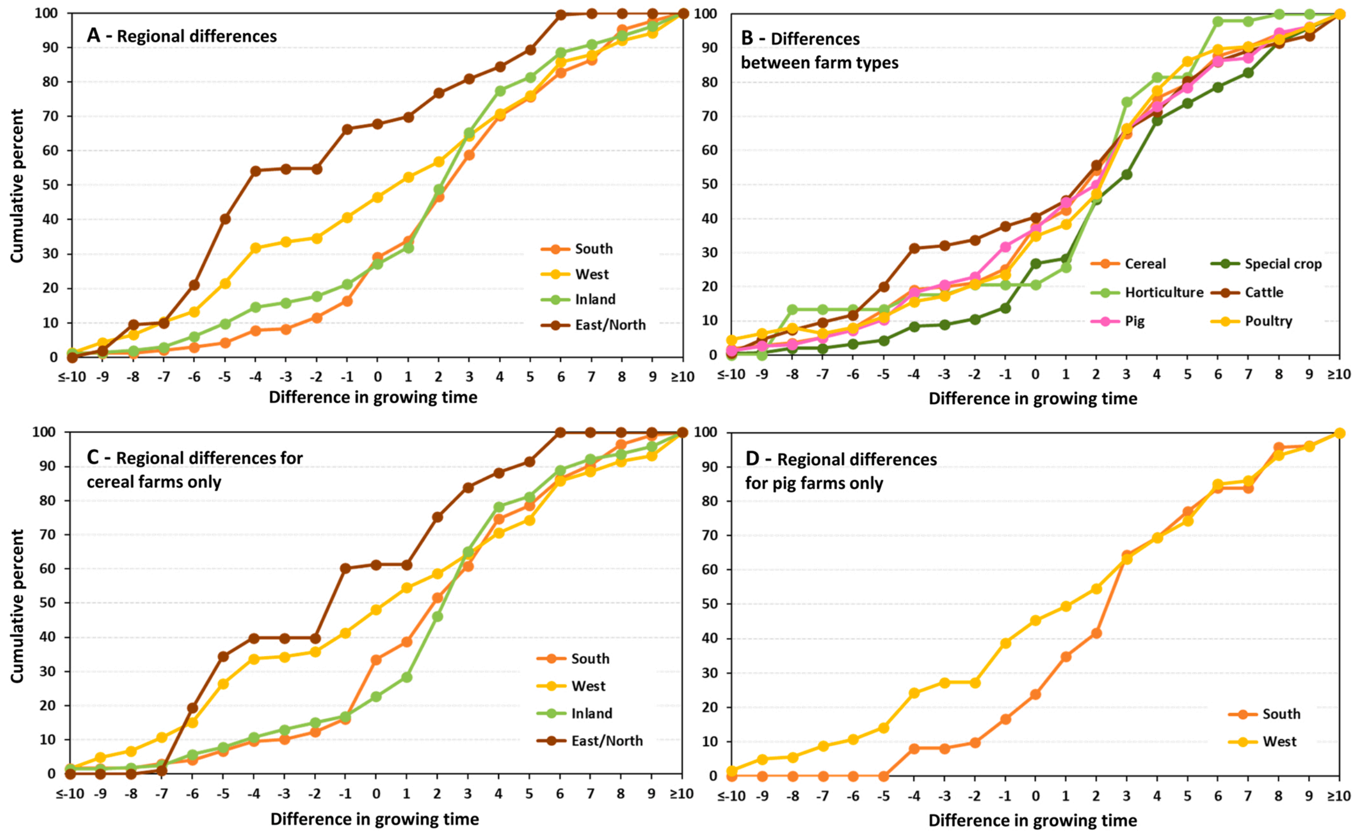

Fig. 6. The cumulative percentage of differences in the growing time of barley cultivars between 2014 (old cultivar) and 2018 (renewed cultivar), depending on region (panel A) and farm type (panel B), as well as the regional differences for cereal (panel C) and pig farms alone (panel D). Pig farms are mainly located in Southern and Western Finland.

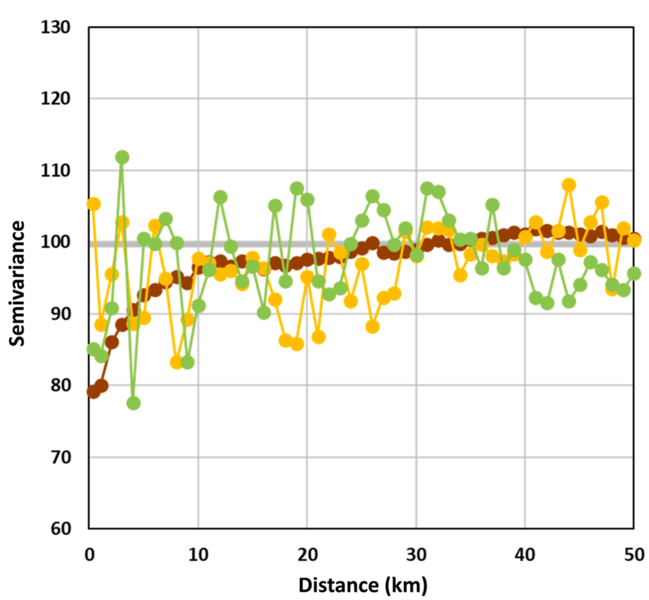

Fig. 7. A relative empirical semivariogram indicating the spatial dependency of farmers' decisions about whether to change a barley cultivar (brown), switch to a newer cultivar (green), or return to an older cultivar (yellow). The gray bold horizontal line is the reference to indicate full (100%) spatial independency.

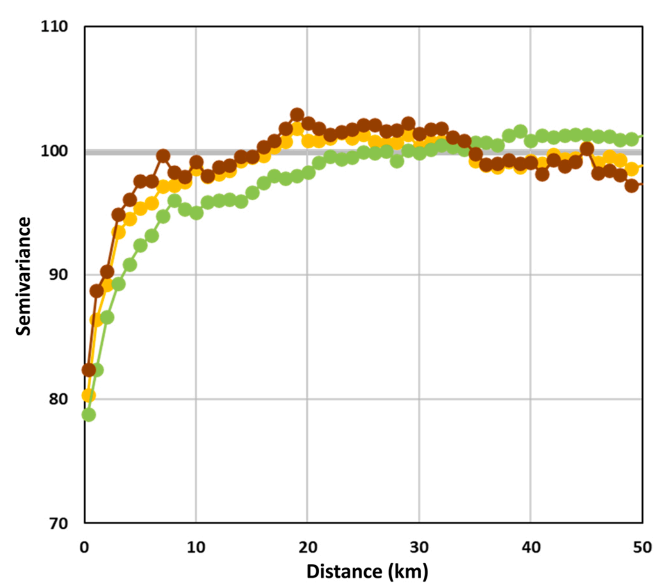

Fig. 8. A relative empirical semivariogram indicating the spatial dependency of farmers' decisions to change to a barley cultivar based on age (brown), growing time from sowing to maturity (green), and the grain yield of a cultivar (yellow). The gray bold horizontal line is the reference to indicate full (100%) spatial independency.

B. rapa L.) and/or caraway (*Carum carvi* L.)], a large cereal area on their farms (>75%), and low yield gaps, and their farms were usually in South-Finland. However, the groups of farmers who are the most likely "objects of influence" are not necessarily those at the other extreme, i.e., those who stick to using the same cultivar for a long time, but those somewhere in between. For example, farmers with small farms (<50 ha) do not necessarily have any major plans for future farming, e.g., due to their forthcoming retirement, and land may therefore be bought by an expanding farmer who frequently renews cultivars. Furthermore, farmers with a low probability of switching cultivars often had horse/sheep farms, which are typically small in Finland, have un-uniform fields, and a high productivity gap: These farmers have already adapted to the situation of limited expansion opportunities by starting to keep horses or sheep (Peltonen-Sainio et al., 2018). It was specified that the spatial dependency was strong only if the distance between neighboring farms was less than five kilometers (Fig. 5). This finding emphasizes that the probability of encouraging neighboring farmers to switch cultivars is highest in South-Finland, while it is lowest in East/North-Finland, where the field area is low, and farms are far apart.

5. Conclusions

Barley cultivars grown in Finland were not renewed quickly. Most of the cultivars grown in 2018 were introduced to OVT in 2008–2012 — however, the share differed from 46% to 79% of field parcels, depending on the region. Farmers in East/North-Finland were the least inclined to switch cultivars. Farmers usually replaced an earlier cultivar with one seven years younger. The probability of switching to a newer cultivar was systematically higher on larger farms and farms with a large cereal area. New cultivars were allocated primarily to field parcels owned by a farmer and with a high production capacity compared to the regional mean. The answer to the question "What makes a change?" is multifold, as various potential answers were found for a cultivar change, some of which were captured in this study. An increase in Y_{pot} was an evident key characteristic aspired for by a farmer when renewing barley cultivar, but this did not necessarily mean that farmers switched to a later maturing cultivar that may have had a higher risk of challenges during harvest. Farmers can choose a cultivar based on available published information from official trials and advertising materials, but we found that knowledge and experience exchange between neighboring farmers, and possibly trust in local pioneering, influenced cultivar choice especially up to a distance of five kilometers between farms (to some extent up to 30 kilometers). Nonetheless, the direction of change was not always towards new breeds, but farmers switched back to older familiar barley cultivars, which may indicate general dissatisfaction with the new breed, possibly partly because of a challenging growing season.

CRediT authorship contribution statement

Pirjo Peltonen-Sainio: Conceptualization, Validation, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Project administration, Funding acquisition. **Lauri Jauhiainen:** Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Project administration, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.eja.2023.126826.

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