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BREEDING OF WINTER BARLEY (*HORDEUM VULGARE* L.) UNDER SOUTHERN KAZAKHSTAN CONDITIONS

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SUMMARY

The barley (*Hordeum vulgare* L.) grain demand gradually increases, which could be due to many reasons, and particularly that of rapid growth of livestock farming in Kazakhstan. In South Kazakhstan, as well as generally in Central Asia, growing barley is mainly during autumn. In these existing environmental conditions, drought stress is the most critical cause of the barley crop decline. Therefore, a suggestion indicated that barley cultivars must be resistant to environmental fluctuations, especially to varied rainfall conditions. The task of combining numerous economically valuable and biological traits in one genotype requires processing a large germplasm, developed locally and internationally. The objective was to assess the adaptability and yield potential of 103 barley lines under rainfed conditions. Genotypes L-1/T-74, Tokak, L-8/T-59, and L-12/T-60 incurred placement in the early-ripening group as compared to the mid-ripening cultivar Bereke 54. Fifteen genotypes showed high productivity (up to 430 g/m²) and 1000-grain weight exceeding 60 g. Six barley genotypes appeared to be resistant (R) to helminthosporiosis. The barley genotypes (L-12/T-75, L-34/T-75, L-35/T-75, L-33/T-75, H-3-1, and H-12-3) showed the highest 1000-grain weight. In grain yield, the barley genotypes L-1/T-74, L-2/T-74, and L-6/T-74 exceeded the standard cultivar by 23.0 to 56.0 g/m².

Keywords: Winter barley (*H. vulgare* L.), germplasm, advanced lines, high-yielding genotypes, resistant to adverse climatic factors, yield and quality traits

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Key findings: The barley (*H. vulgare* L.) germplasm study identified donors with the highest potential for breeding valuable traits at the southern steppes of Kazakhstan. The study identified 15 highly productive, winter-hardy, disease-resistant, and environmentally resilient winter barley genotypes, which can be favorable in hybridization and full breeding programs to increase productivity.

INTRODUCTION

Barley (*Hordeum vulgare* L.) is the most important crop in both domestic and world agriculture. Along with the wheat crop, it played an influential role in the birth of civilization in the ancient world, being globally cultivated in all agricultural areas. In the recent past, the annual barley production has fluctuated between 140 and 151 million tons of grains (FAOSTAT, 2024).

About 75% of the world's barley production served for fodder purposes, with 20% utilized to produce malt for the brewing industry and only 5% for food production (Blake *et al.*, 2011). The barley's greater production and consumption may have several reasons, such as the ability to meet various requirements of livestock and processing industries, its greater adaptability to different natural and climatic factors, and the relatively low cost of cultivation. Hence, the cost of barley grain production is low. Barley grain contains massive protein and starch, which can be beneficial as an excellent food. The barley protein contains numerous indispensable amino acids and is particularly deficient in lysine and tryptophan (Sariev and Abugalieva, 2012; Tokhetova and Umirzakov, 2020).

In the Republic of Kazakhstan, barley cultivation is prevalent under irrigated conditions and dry and non-irrigated agriculture. Barley attached greater importance to its utilization as food, feed, and for technical purposes. Barley is a crop of versatile use in terms of sowing area and grain production in Kazakhstan, ranking second after wheat with a cultivated area of more than 2.1 million ha at an annual gross fee of 6,225,4 - 6848,0 US dollars (USD). In Kazakhstan, the registered barley cultivars are over 60, including 45 cultivars developed through local breeding (State list of breeding achievements

recommended for use in the Republic of Kazakhstan—Almaty, 2024). Given the considerable development in the processing industry and animal husbandry, evidence occurs of a belief that in the long term, the barley's potential role will steadily improve, especially against the background of constantly increasing environmental and energy problems (Amezrou *et al.*, 2018).

With changing climatic conditions and rising uncertainties at different stages of economic development, a dire need persists to develop and introduce new barley cultivars with various economically valuable traits and adapted to existing environmental conditions. At the maximum extent of the requirements of agriculture, it should be a main goal of current breeding research work (Yerzhebayeva *et al.*, 2025). Paying special attention has occurred in previous years to the development of high-yielding, both spring and autumn crop-resistant bivarietal grain cultivars with large and well-made grains suitable for the grain processing industry. Selection of two-row cultivars of sour barley, capable of consistently providing the highest grain yield over the years, was also suitable for brewing (Filippov and Dontsova, 2015).

Barley growing is mainly best during the autumn planting time in Southern Kazakhstan and generally in Central Asia. Its further promotion in the North is largely relevant to progress in breeding for frost resistance. It is necessary to justify and develop a concept of synthesis of qualitatively new genotypes of barley, which can significantly expand the cultivation area of this crop in Kazakhstan (Ortaev, 2001; Tokhetova and Umirzakov, 2020).

Among major cereal crops, winter crops occupy a special place. The winter crop advantage over spring crops is that in fall, they develop a powerful root system and bush well,

grow well in early spring, and ripen 10 to 15 days earlier than spring crops. The winter ones utilize well the autumn moisture, suffering less from drought and dry weather conditions. Winter barley is less frost-resistant than wheat and is sensitive to spring frosts. The studies established that the meteorological conditions during the growing season of barley have a significant influence on its yield (El-Hashash and El-Absy, 2019). A close relationship was evident between grain yield and yield-related traits of barley (Raggi *et al.*, 2017; Elakhdar *et al.*, 2022).

In developed countries, crop yields have increased by more than 40% over the last quarter of a century, and 50% for cereals are due to continuous development of new barley cultivars and hybrids. In the environmental conditions of the south and east of Kazakhstan, winter barley is 1.3 times more profitable than spring barley. For the cost of gross production, one hectare has the highest profitability after winter wheat, which is 1.2 times lower. The primary focus is on continuous crop change and not on crop renewal (Chudinov and Abughalieva, 2019; Baymuratov *et al.*, 2024).

In this connection, studying the world germplasm collection, identifying valuable sources of raw material, and developing intensive cultivars of barley that meet the requirements of agricultural production and the processing industry have become particularly crucial nowadays. This type of research will contribute to a sharp enhancement in crop yield, grain quality, and green mass of barley, as well as reduce the cost of production (Zhou, 2009; Yerzhebayeva *et al.*, 2025). The presented study aimed to evaluate the productivity and adaptability of barley's advanced lines and identify high-yielding genotypes resistant to insect pests and diseases and adverse climatic conditions in South Kazakhstan. Therefore, this study sought to evaluate the productivity, resistance, and adaptability of advanced barley lines and identify promising donors for breeding programs in Southern Kazakhstan.

MATERIALS AND METHODS

Breeding material and experimental site

The research work took place in 2015–2017 at LLP—Krasnovodopadsky Agricultural Experimental Station, in the Department of Barley Breeding, located in the Saryagashsky District of the Turkestan Region of the Republic of Kazakhstan. The breeding material comprised 103 landraces of barley (*H. vulgare* L.) obtained from the ICARDA (International Center for Agricultural Research in the Dry Areas), with the hybrid populations procured through local breeding. Of these, 39 genotypes comprised multi-row and 64 genotypes were of double-row barley. The climate characteristics included recording amplitude fluctuations in daily and annual temperature regimes, frequency of precipitation with their timing to the winter-spring period, and abundance of light and heat. Duration of sunshine was 2692–2889 hours per year. Clear days were more than 240, reaching 23–25 in summer and decreasing to 4–5 days in winter months.

Experimental soil and crop husbandry

The soil cover is represented by typical gray soils with a heavy loamy texture, characteristic of the semi-protected rainfed (bogara) zone. The humus content ranged from 0.8% to 1.1%, gross nitrogen (0.08%–0.1%), gross phosphorus (0.1%–0.15%), potassium (252 mg/kg), volumetric weight of the soil (1.15–1.30 g/cm³), and pH (7.1). For barley, the crop season begins in the month of September. However, the soil moisture and field crop health depend on the amount of rainfall in September and October. The cultivation of barley experiment proceeded according to the generally accepted technology in this area. The sowing of barley genotypes used the SFFC-7 seeder at the optimal time according to the adopted method VIR (1989) in subplots of 1 m², replicated three times. The barley cultivar Berek-54 served as a standard.

Phenological observations

The study used a generally accepted method of VIR 1986. The main phases of the development of barley plants entailed observations. In determining the breeding value by phenological features, the calculation of the duration of interphase periods (shoots dyeing and dyeing–wax ripening) ensued. The resistance in barley genotypes obtained detection under field conditions. The pre-harvest, when determined, counted the number of plants in the autumn (in the full-growth phase) by 1/4 m² and in the spring at the beginning of the growing season. According to the method, the seedling showed the stability of barley genotypes on the scale: 1 (very low durability, preserved after feeders—20%), 3 (low to 35%), 5 (average up to 50%), 7 (above average to 75%), and 9 (high—more than 75% remained after overwintering).

The conduct of immunological evaluation occurred under field conditions. The stability assessment of the genotypes was by comparison (% ratio): R (resistant—up to 10%), MR (moderately resistant—up to 30%), MS (moderately susceptible—up to 60%), and S (susceptible—80%–100%). The barley crop entailed harvesting sickle kernels at the beginning of full maturity. The threshing was successful with the SMP-500 thresher. Phenological and immunological assessments continued annually.

Statistical analysis

The data analysis used the analysis of variance (ANOVA), with means compared by the LSD test at $p \leq 0.05$. All the recorded data assessments were according to the generally accepted methodology of Dospheov (1985). The following standards and research methods served in conducting technological analyses: GOST 13586.1-2014—Grain methods used for determining the quantity and quality of gluten in wheat; GOST 9353-2016—Wheat for Technical conditions; GOST 13586.5-2015—Grain method for determining moisture content; GOST 10840-2017—Grain methods for determining nature; GOST 10987-76—Grain methods for determining vitreousness;

GOST 10846-91—Grain and grain products method for determining protein; GOST 10845-98—Grain and grain products method for determining starch; and ISO 5529:1992 methods for determining sedimentation of Zeleni.

RESULTS AND DISCUSSION

Phenological observations

Phenological traits are the most important characteristics of a cultivar in determining its suitability for cultivation in existing conditions and the length of the growing season in crop plants, including barley (*H. vulgare* L.). The growing season has an inextricable link to productivity, as well as various other properties, such as drought resistance, chemical composition of plants and product quality, and resistance to the most dangerous diseases and pests. According to international practice, calculating the duration of the main growing season is from January 01. On average, over two years, the period of barley's full ripening was 150–156 days. As a result, the studied barley genotypes underwent division into three groups based on their ripening period: early maturing, mid-maturing, and late maturing. For the standard cultivar Bereke 54, it ripens at an average of 153 days, thus being included in the mid-maturing group. For the early-ripening group, the ripening period averaged 150–152 days, which was 1–3 days earlier than the standard mid-ripening cultivar Bereke 54. However, the said group included 21 barley genotypes, such as L-1/T-74, Tokak, L-8/T-59, and L-12/T-60. Hence, a dire need persists to develop new barley cultivars with various economically valuable traits and adapted to existing environmental conditions (Yerzhebayeva *et al.*, 2025).

Immunological evaluation

In Southern Kazakhstan, the pathogens of the rust, powdery mildew, and helminthosporiosis diseases are widespread. *Helminthosporium* is a genus of fungi that primarily affects the grasses and other plants, causing diseases like

leaf spots, blights, and crown rots. The said fungi produce large, multi-celled, and darkly pigmented conidia (spores). Therefore, the presented study also focused on studying barley germplasm for resistance to helminthosporiosis, which appeared mostly during the heading and milk ripeness stages, thereby causing greater damage. The regionalized standard cultivar Bereke 54, although highly productive, proved moderately impacted by helminthosporiosis and powdery mildew (up to 60%).

During the study years (2015–2017), the disease manifested with varying degrees depending on the environmental conditions of the crop season and the origin of the barley genotypes, with fluctuations from 10% to 90%, revealing the genotypes with very low resistance (MS–S). The majority of barley genotypes revealed a medium level of resistance (MR). However, six barley genotypes identified emerged to be resistant (R) to helminthosporiosis. The selected genotypes were the valuable sources for helminthosporiosis. The genotypes L-12/T-75, L-34/T-75, L-35/T-75, L-33/T-75, H-3-1, and H-12-3 demonstrated stable resistance to helminthosporiosis.

Winter hardiness

Winter hardiness refers to a plant's ability to survive the adverse conditions of winter, particularly cold temperatures, frost, and duration of cold periods. Factors influencing this hardiness include the plant's acclimation to cold, the severity and timing of cold snaps, and environmental conditions like the snowfall and sunlight. By studying the winter hardiness in barley genotypes, most barley genotypes had a winter survival rate of 7–8 points and showed average resistance. However, over the study years (2015–2016), in winter the average daily air temperature was higher than the long-term average. The average daily air temperature for 2015–2016 was in December (+3.6 °C), January (+5.1 °C), and February (+7.0 °C), compared with the long-term average, i.e., December (+2.4 °C), January (+1.7 °C), and February (+2.5 °C). In 2016–2017, the average daily air temperature was in December

(+4.4 °C), January (+1.8 °C), and February (+1.5 °C). Nevertheless, the barley standard cultivar Bereke-54, South Kazakhstan 43, and N-3-1 selections from Krasnovodskaya SHS and the genotypes from ICARDA, such as L-11/T-55, L-1/T-74, and L-56/T-75, showed the highest winter resistance (9 points). Past studies revealed that barley's potential role would steadily enhance, especially increasing background of constantly increasing environmental and energy problems (Amezrou *et al.*, 2018). Frost-resistant barley genotypes can significantly expand their cultivation area in North Kazakhstan (Ortaev *et al.*, 2019; Tokhetova and Umirzakov, 2020).

Lodging resistance

The crop lodging resistance under boggy conditions caused by excessive wet and muddy settings displayed a close association to plant height, especially in wet years. The study results enunciated that the plant height in the studied barley genotypes varied on average in the germplasm from a minimum of 56 cm (L-6/T-74) to a maximum of 123 cm (L-2/T-75). The barley genotypes with a plant height of 90 cm and above manifested no resistance to lodging. The genotypes (L-1/T-74, L-2/T-75, L-6/T-74, H-3-1, H-13-1, and H-12-3) with a plant height of 65–85 cm showed the highest and considerable resistance to lodging (Table 1). The barley genotypes evaluation further allowed us to identify the valuable source material, in terms of lodging resistance, and recommend it as a source material. Lodging is a detrimental phenomenon that occurs globally throughout all barley-growing regions, with yield and quality losses depending on the growing season, crop growth stage, and the cultivar (Laidig *et al.*, 2022).

Drought and heat resistance

For barley cultivars cultivated in Southern Kazakhstan, drought and heat resistance were one of the determining and pivotal factors. Therefore, it was necessary to select the drought-resistant barley genotypes, which requires the development of innovative methods and the search for marker traits that

Table 1. Mean performance of the selected barley genotypes for yield-related traits.

Barley genotypes	The originator	Plant height (cm)	Peduncle length (cm)	Spike length (cm)	Grains ear ⁻¹	Grain weight ear ⁻¹ (g)	1000-grain weight (g)	Grain yield per m ² (g)
Berke 54, st.	*Krasnovodopadsky AES, Kazakhstan	75.0	22.0	7.5	67	1.8	41.0	374.0
Yuzhno-Kazakhstanskii 43	Krasnovodopadsky AES, Kazakhstan	87.5	26.1	11.0	30	2.1	48.0	300.4
L-1/T-74	ICARDA	73.5	26.7	8.5	66	2.7	48.1	430.5
L-2/T-74	ICARDA	77.5	27.1	7.7	77	2.8	48.2	410.7
L-6/T-74	ICARDA	65.5	26.7	7.7	70	2.6	48.9	397.6
L-9/T-74	ICARDA	77.5	24.2	7.7	69	2.0	49.6	384.8
L-12/T-74	ICARDA	75.5	23.5	8.2	72	2.3	49.1	382.2
L-21/T-75	ICARDA	80.0	25.0	9.5	71	2.5	58.2	392.9
L-42/T-75	ICARDA	73.5	22.7	11.3	32	2.0	56.5	386.6
L-56/T-75	ICARDA	66.0	28.0	11.0	33	2.4	59.1	375.5
L-23/T-75	ICARDA	78.0	22.5	10.0	33	2.9	56.3	379.3
H-11-55	Krasnovodopadsky AES, Kazakhstan	83.2	30.0	12.5	31	2.9	62.0	376.0
H-3-1	Krasnovodopadsky AES, Kazakhstan	80.0	28.5	11.0	31	2.6	52.5	374.6
H-12-3	Krasnovodopadsky AES, Kazakhstan	81.5	27.2	11.5	31	2.4	55.4	380.0
H-13-1	Krasnovodopadsky AES, Kazakhstan	78.0	25.6	11.0	33	2.2	49.6	382.2

*Krasnovodopadsky Agricultural Experimental Station LLP

would correlate with crop productivity. The length of the peduncle is one of the most important morphological characteristics of barley drought resistance. The longer the length of the peduncle in plants, the more drought-resistant and productive barley genotypes are. Based on the results, the length of the peduncle in the barley genotypes ranged from a minimum of 18 cm to a maximum of 30 cm. However, overall the 15 drought-resistant genotypes were notable for having the highest length of terminal internode (26–30 cm). Genetic improvement of drought tolerance in crop plants is one of the most cost-effective and sustainable solutions to increase crop productivity and yield stability (Bornare *et al.*, 2012).

Yield-related traits

In the presented studies, in multi-row barley genotypes, the average spike length ranged from 6.5 to 9.5 cm. The longest ears (measuring 9.0–9.5 cm) resulted in the

genotypes L-6/T-74, L-9/T-74, L-56/T-75, and L-42/T-75. Among two-row barley genotypes, the highest spike length (12.5 cm) was visible in the genotype L-11/T-55. The highest spike length values were also evident in the barley genotypes L-42/T-75, L-37/T-75, H-12-3, and H-12-1.

The number of grains per spike is an essential trait when selecting a genotype for productivity and is a prerequisite for a higher grain yield. However, the grains per spike incur influences both from the genetic makeup of the genotypes and the existing environmental conditions. The results revealed that in the germplasm of multi-row barley, the number of grains per spike varied on average between 53 and 77 grains. The barley genotypes L-12/T-74, L-2/T-74, and L-6/T-74 were leading with the highest number of grains per spike (ranging from 66 to 77). In two-row barley genotypes, the average number of grains per spike was 23–33. The maximum number of grains per spike (30–33) was evident in the barley genotypes, viz., L-2/T-75, L-45/T-75, L-

56/T-75, L-23/T-75, N-3-1, N-13-1, and N-12-3. A close relationship existed between grain yield and yield-related traits of barley (Raggi *et al.*, 2017; Elakhdar *et al.*, 2022).

Results of the presented research have identified the barley genotypes with the highest grain weight per spike, i.e., L-1/T-74 (2.7 g), L-6/T-74 (2.65 g), L-23/T-75 (2.89 g), H-3-1 (2.67 g), and H-12-3 (2.04 g) (Table 1). In barley grains, the 1000-grain weight classification had the following indicators: very low (less than 36.0 g), low (36.1–40.0 g), average (40.1–45.0 g), high (45.1–50.0 g), and very high (more than 50.0 g). The formation of a cultivar with the highest 1000-grain weight is the final indicator of obtaining high and stable yields. In these experiments, we observed some variation in studied barley genotypes for 1000-grain weight, ranging from 33.0 to 62.0 g. However, the largest grains resulted in two-row barley cultivars, while the smallest were 41.0 g. Overall, the barley genotypes (L-12/T-75, L-34/T-75, L-35/T-75, L-33/T-75, H-3-1, and H-12-3) showed the highest 1000-grain weight. Baymuratov *et al.* (2024) reported that 1000-grain weight had characteristics of a high degree of biological stability and heritability, which authenticate that the said trait can be more effective for fruitful early selection through breeding.

In barley, the grain yield and quality mostly gained influences from the integration of nutrients and environmental conditions. The better the growing conditions, such as water, nutrition, light, and other factors, the higher the grain yield. In Southern Kazakhstan, in obtaining a higher yield, the main determining factor is the water supply to crop plants. The genotypes underwent evaluation for grain yield being a major characteristic, determining the grain weight per m² to establish the breeding value of barley genotypes. This characteristic was a summary indicator of the spike in the two-row and multi-row barley cultivars. Previous studies established that meteorological conditions during the growing season of barley have a significant influence on its yield and quality traits (El-Hashash and El-Absy, 2019).

In the study years with different weather conditions, significant differences were remarkable among the barley genotypes for various traits. An increase in one of the elements of productivity often leads to a decrease in other traits; however, the grain yield varied nonsignificantly. In these studies, the barley genotypes varied significantly for grain yield depending on the crop season. The average yield of the barley standard cultivar Bereke 54 over two years was 374.0 g per m². Grain yields ranged from 300 to 430 g/m², with 12 lines exceeding the Bereke 54 standard. Twelve barley genotypes were successful in their identification as the most productive compared with the standard cultivar. The promising lines L-1/T-74 (430.0 g/m²) exceeded the standard by 56.0 g/m², L-2/T-74 (410.7 g/m²) exceeded the standard by 36.7 g/m², and L-6/T-74 (397.0 g/m²) exceeded the standard by 23.0 g/m². The selection of two-row cultivars was capable of consistently providing the highest grain yield over the years, which was also suitable for brewing (Filippov and Dontsova, 2015).

The analysis of the main biochemical and technological indicators of grains obtained from different winter barley breeding lines, including the standard and promising hybrid lines, appears in Table 2. Based on a set of characteristics (high naturalness, protein, and starch content), the lines L-6/T-74, L-9/T-74, L-2/T-74, and L-42/T-75 stood out as promising. For areas related to improving protein quality, the barley genotypes L-56/T-75 and L-42/T-75 were of particular interest. For brewing purposes, it was advisable to select barley lines with the highest starch content and a favorable quality index, such as H-13-1, H-3-1, L-23/T-75, H-11-55, and L-1/T-74. Thus, the studied barley genotypes were distinctive with a wide variability of traits, which creates favorable conditions for subsequent selection, depending on the target direction, such as brewing, feed, and food. In the current breeding programs, the prime focus is on continuous crop change and not on crop renewal (Chudinov and Abughalieva, 2019; Baymuratov *et al.*, 2024). This type of

Table 2. Mean performance of the selected barley genotypes for technological properties.

Barley genotypes	Nature (g/L)	Protein (%)	Humidity (%)	Starch (%)	Extractability γ (%)	Quality index (%)
Bereke 54, st.	599	13.5	8.5	60.4	78.2	28.5
Yuzhno-Kazakhstanskii 43	566	13.3	8.4	60.4	78.4	31.0
L-1/T-74	605	11.8	8.3	60.6	78.5	31.8
L-2/T-74	623	12.7	8.4	61.1	78.2	31.0
L-6/T-74	646	13.3	8.2	60.1	78.3	31.3
L-9/T-74	641	12.8	8.3	60.7	78.6	31.0
L-12/T-74	574	13.2	8.5	60.6	78.3	31.1
L-21/T-75	601	13.1	8.3	60.7	78.2	30.0
L-42/T-75	596	14.2	8.2	59.6	78.2	30.9
L-56/T-75	589	13.8	8.4	60.0	78.5	31.0
L-23/T-75	612	13.1	8.3	61.0	78.3	30.7
H-11-55	525	12.8	8.4	60.0	78.4	31.9
H-3-1	606	12.7	8.3	60.7	78.6	30.5
H-12-3	590	12.7	8.4	61.2	78.3	31.0
H-13-1	586	12.6	8.4	62.0	78.5	30.5

research will contribute a considerable improvement in grain yield and quality and green mass of barley with a reduced cost of production (Zhou, 2009; Yerzhebayeva *et al.*, 2025). The findings demonstrate significant genotypic variability among ICARDA and local winter barley lines under dryland conditions. The identified drought-tolerant and winter-hardy genotypes confirm earlier reports of adaptive variability in barley (Elakhdar *et al.*, 2022; Yerzhebayeva *et al.*, 2025). Similar to studies by Filippov and Dontsova (2015), two-row genotypes showed stable productivity and high 1000-grain weight. The results highlight the importance of selecting genotypes combining yield stability and disease resistance for the arid steppe zone of Kazakhstan.

CONCLUSIONS

Research based on barley germplasm under the conditions of the southern steppes of Kazakhstan made it possible to identify donors with the highest breeding potential and sources of valuable traits for this region. As a result, 15 winter barley genotypes characterized by high productivity, winter hardiness, disease resistance, and environmental resilience were successful in their selection. The identified genotypes will benefit future hybridization

schemes to enhance drought and cold tolerance in regional breeding programs.

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