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EVALUATION OF EARLY MATURING MAIZE HYBRIDS FOR YIELD-RELATED TRAITS IN AKMOLA REGION, KAZAKHSTAN

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SUMMARY

Maize (*Zea mays* L.) is one of the most widely grown cereal crops worldwide, with around 20% of its grains used for food purposes, 15%–20% for technical purposes, and 60% for feed. In the Akmola Region of Kazakhstan, maize used for silage is preferable in the milky-wax ripeness phase of the grain. The following study aimed to evaluate early-maturing and high-yielding maize hybrids' average over 2020–2021 and 2021–2022 for cultivation in the hill-plain zone of Akmola Region, Kazakhstan. Three early-ripening maize hybrids, Budan-237-MV, KizURAKS-150-SV, and Tselinny-160-SV, obtained evaluation, with the Sary-Arka-150-ASV (St.) serving as the standard, grown with the recommended agricultural technology. For the vegetation period, maize hybrids KizURAKS-150-SV and Sary-Arka-150-ASV (standard) grains reached wax ripeness in 113 days. The highest grains per cob resulted in the hybrids KizURAKS-150-SV (237 grains cob^{-1}) and Sary-Arka-150-ASV (240 grains cob^{-1}). The heaviest grain weight per cob was evident in hybrids Tselinny-160-SV (131 g) and Sary-Arka-150-ASV (128 g). The grain yield, as managed by the genotype by environment interactions, had the hybrid Tselinny-160-SV with the highest grain yield (4.4 t/ha). Therefore, the early-maturing maize hybrids KizURAKS-150-SV, Sary-Arka-150-ASV, Tselinny-160-SV, and Budan-237-MV emerged as the most suitable for cultivation in Northern Kazakhstan for forage purposes.

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Keywords: Maize (*Z. mays* L.), early-maturing hybrids, environmental factors, growth and development, cob traits, yield-related traits, grain yield

Key findings: In the comparative assessment of maize (*Z. mays* L.) hybrids for early maturity and grain yield in the hill-plain zone of the Akmola Region, the hybrid KizURAKS-150-SV occurred with 113 days and 3.3 t/ha, and the most productive hybrid with an extended vegetation period was the Tselinny-160-SV (4.4 t/ha^{-1} and 121 days).

INTRODUCTION

Maize (*Zea mays* L.) is an essential cereal crop in global agriculture, as characterized by its versatile use and high grain yield. About 20% of the produced maize grains served for food purposes, 15%–20% for technical purposes, and 60% for feeds. Among the 13 developed countries, the maize grain yield was comparatively low under dry conditions, and the average grain yield is 2.44 t ha^{-1} (FAOSTAT, 2024). Under advanced agricultural technology, some enterprises can obtain 5.0 t of grains ha^{-1} (Haarhoff and Swanepoel, 2018).

Maize grows in all the regions, from tropical heights to Scandinavian countries. Globally, maize covers an area of about 202 million hectares, and its production reaches about 1,163 million tons (FAOSTAT, 2024). Therefore, an urgent need to increase its production is necessary, especially in the context of rapid population growth and dramatic global climate change (El-Sanatawy *et al*., 2021). The use of high-yielding and adapted hybrids is one of the best approaches to enhance maize grain production.

Maize grains contain carbohydrates (66%–70%), proteins (9%–13%), fats (4.5%–9%), mineral salts, and vitamins. They are sources of flour, flakes, cereals, canned food (sweet corn), ethyl alcohol, starch, beer, glucose, dextrin, molasses, honey, syrup, oil, vitamin E, and ascorbic and glutamic acids. One kilogram of maize grains contains 1.36 feed units and 79 g of digestible protein. Thus, maize grain is an excellent feed. In Northern Kazakhstan, it is possible to grow maize hybrids with a shortened growing season, passing safely through late spring and early autumn frosts, and the grain reaches wax ripeness. Selecting the right hybrid is a crucial agronomic management practice that is primary in determining the quantity and quality of maize grains.

The threshold levels of the high temperature from germination to paniculation and at the flowering and grain filling were 39.2 °C, 37.3 °C, and 36.0 °C, respectively, depending on the maize genotypes (Kamkar *et al*., 2023). During the pollination period, pollen viability decreases due to heat stress. Similarly, damage was evident to the ear pollen tube, fertilization efficiency, and, accordingly, the grain yield decreased (Lizaso *et al*., 2018). During flowering and initial grain-filling stages, the maximum daily temperature has a more considerable effect on grain yield (R^2 = 0.689) than solar radiation (R^2 = 0.265) and precipitation (R^2 = 0.288) (Dong *et al*., 2021). Maize cobs in the milky ripeness stage of grain (20.08) are partial damages from frosts (-2 °C to -3 °C). Researchers from Wisconsin, USA, recommend using earlier sowing of maize in the first 10 days of May to avoid early autumn frosts and achieve the full ripeness of grains on the cobs (Lindsey *et al*., 2024).

Along with the grains per cob, the grain weight per cob is also a determining factor in managing the maize grain yield, which reached formation within 30 days during the flowering-grain ripening period (Kiniry and Otegui, 2024).

The maize grain yield's determinants comprised the genotypes, environments, and the genotype-environment interactions (GEI) effects. Before harvesting the cobs, it is necessary to check the grain moisture content, which also depends upon its degree of maturity. Maize slowly releases moisture content for developing dry matter content in the grains. The moisture content varies during the grain-maturity period, from milky (22.9%) to milky-waxy (27.5%) to waxy ripeness (28.1%) of the maize grains (Parvej *et al*., 2020).

The rate of moisture loss in the grains depends upon climatic conditions. At higher relative humidity and low air temperature, the moisture content decreases from 0.21% to 0.35% per day, and under favorable hydrothermal conditions, 0.52%–0.72% of moisture is lost. Grain dehydration occurs in two stages in the field, such as during ripening and after ripening in maize (Fan *et al*., 2021). When the grains reach physiological maturity, the starch and protein assimilates displace water molecules (Martinez-Feria *et al*., 2019). Grains in the milky-wax ripeness were non-adaptable to low temperatures, and therefore, frost damage appears in 15% of maize plants (Sotchenko *et al*., 2021).

Grain yield depends upon the number of plants per linear meter, cobs per plant, grains per cob, and the 1000-grain weight. Grain yield of early-maturing maize hybrids emerged significantly correlated with the number of grains per cob (r = 0.90) and the grain weight per cob (r = 0.76) (Tsimba *et al*., 2013). Sowing parameters also have a positive effect on plant development and the root system (Bernhard and Below, 2020).

The selection of an early-maturing maize hybrid can produce increased grain yield with adaptation over the years, ensuring the economical use of natural resources, such as water, solar radiation, and nutrients (Di-Salvo *et al*., 2021). The long-term experience shows that under the conditions of agro-climatic zoning of Northern Kazakhstan, the unfavorable conditions developed in a short and cool summer for the maize crop. Drought conditions that develop in the second half of the summer also negatively affect the formation of grain yield (Baisholanov *et al*., 2025). Therefore, due to the above abiotic factors, the early-maturing maize hybrids with early sowing and a short growing season contribute to obtaining a stable and high-quality grain yield (Larina *et al*., 2022).

According to FAO classification, early-maturing maize hybrids require 100–149 days for grains to ripen and the minimum sum of active temperatures (2200 °C), which corresponds to the conditions of Akmola Region, Kazakhstan (Mozhaev and Serekpaev, 2010). The presented research sought to identify and select high-yielding maize hybrids with early maturity average over 2020–2021 and 2021–2022 in the hilly-plain zone of Akmola Region, Kazakhstan. The study employed a comparative assessment of zoned maize hybrids for early maturity and yield-related traits.

MATERIALS AND METHODS

The promising maize research ran in 2020–2021 and 2021–2022 at the Research and Production Enterprise 'Elite,' Kokshetau University named after Sh. Ualikhanov, Kazakhstan. The enterprise sits in the steppe plain-hill zone, and its climate is arid, with medium heat, and the sum of active temperatures (over 10 °C) was 2200 °C. The frost-free period was 130 days, the precipitation was 280 mm, and the hydrothermal coefficient (HTC) was 0.8–0.9. The field experiment titled 'Grain productivity of early-ripening maize hybrids in the Akmola region' had a layout with the following four maize hybrids: Sary-Arka-150-ASV used as the standard (Figure 1), Budan-237-MV, KizURAKS-150-SV (Figure 2), and Tselinny-160-SV.

The experimental soil was ordinary chernozem, medium-deep, and the arable layer of 0–40 cm contained 3%–4.5% humus. Meteorological conditions during the years of research (2020–2022) were as follows: the hydrothermal coefficient according to G.T. Selyaninov (HTC) for the growing season in 2020 was 0.87, in 2021, it was 0.71, and in 2022, it was 0.21.

Along with soil characteristics, the weather conditions were the main environmental factors affecting maize plant growth (Tardieu, 2013). The experimental soil was ordinary chernozem, medium-deep and heavy loamy, with a slightly alkaline reaction, and the pH of the aqueous extract was 7.8.

Figure 1. Maize hybrid Sary-Arka-150-ASV plants at the 10–12 leaf stage.

A) B)

Figure 2. Maize hybrid KizURAKS-150-SV plants at the milky (A) and milky-wax ripeness (B) stages.

The experimental plot area was 70 m^2 (10 m in length, 7 m in width). The width of the protective path was 210 cm; the width of the interplot paths was 50 cm; and the width of the strips among the replications was 100 cm. The total area of the experiment was 5817 m^2. The experimental variants had a randomized sequence layout in three replications.

In the experiment, all the observations based on various yield-related traits followed the Methodology of the State Variety Testing of Agricultural Crops (Fedin, 1985). Zootechnical analysis of grains for dry matter proceeded according to GOST R 57543-2017 (2017). The yield-related traits' data processing employed the analysis of variance, with the means and standard errors calculated (Dospekhov, 1985). Data processing also used Microsoft Excel 2010. The accepted agricultural technology for the steppe zone of the Akmola Region was the basis used in the experiment, recommended by the Zonal Scientific and Practical Center for Agricultural Development named after A.I. Barayev (Kurishbaev *et al*., 2020; Serekpaev *et al*., 2021).

The experiment transpired in a grain-fallow crop rotation system. In the spring, soil harrowing and loosening engaged a cultivator. Sowing of encrusted seeds of maize hybrids progressed, on average, over three years to May 14, when the optimum soil temperature at the sowing depth was 10 °C. The sowing time corresponding to the conditions of the agro-climatic zone has a positive effect on the phenological development and grain yield of the hybrids (Balemi *et al*., 2020). The seeding rate per 1 ha was 35 kg. The sowing of seeds used the dotted sowing method, with a row spacing of 70 cm. Seeds of the varieties Sary-Arka-150-ASV (St.) and Tselinny-160-SV succeeded in sowing with the scheme of 12.5 cm × 70 cm, and the seed density/1 ha was 114,285 pieces. Seeds of the varieties Budan-237-MV and KizURAKS-150-SV succeeded in sowing with the scheme of 9 cm × 70 cm, and the seed density/1 ha was 158,730 pieces. No irrigation of maize occurred on the experimental plot. The maize grains harvesting ensued at the stage of full ripeness.

As no irrigation of maize took place on the experimental plot, the maize crop's harvesting continued in the waxy ripeness phase of the grain. Likewise, the harvest of maize grains emerged at the stage of full ripeness.

RESULTS AND DISCUSSION

The observations showed that, on the study average over two years (2020–2021 and 2021–2022), the maize plants' density reached 80,000 plants per ha, and the field germination was 92%. The durability of leaves, compactness of linear growth, panicle structure, early flowering, and grain ripening depended upon the plant density. However, by the end of the growing season, the plant density slightly decreased by 2200–4300 plants/ha, and the plants survival was 86%. This indicator also depends upon the high root biomass and, accordingly, the grain yield (Comas *et al*., 2013).

The cumulatively expressed morphological and physiological variations in the maize plants represent certain phases of growth and development. The calendar dates for the onset of phenological phases in maize depended on the weather conditions. Early-maturing maize hybrids are less demanding on environmental conditions, and the plant development stages become more compact and do not stretch out in time (Buhiniček *et al*., 2021).

Late germination of seeds is a characteristic feature of the Akmola Region. In soil temperatures, the variations of 8 °C to 10 °C and even more in mid-May were evident. At the beginning of the growing season, the temperature regime and the degree of moisture were greatly important for the growth and development of maize. The optimum temperature for seedling growth is 20 °C and a wider range (20 °C–35 °C) for germination. Seed size also influences the amount of water needed for germination. The optimum range of water for seed germination is 0.06–5.30 ml and 25%–225% of the 1000-grain weight. The optimum range of water for seedling growth was 2.35–7.75 ml. As temperature increases, the optimum range for water amount narrows; for example, at 20 °C, it is wider than required at the 25 °C (Khaeim *et al.*, 2022). The maize plants were at the 3–5 leaves on June 04, and the plants went into the tube beginning June 23. Maize plants showed increasing demands on moisture and nutrients during the period of panicle ejection. During this period, the photosynthetic activity of the maize plants decreases (Vennam *et al*., 2023).

The threshold levels of the high temperature from germination to paniculation and at the flowering and grain filling were 39.2 °C, 37.3 °C, and 36.0 °C, respectively, depending on the maize genotypes (Kamkar *et al*., 2023). During the pollination period, pollen viability decreases due to heat stress. Likewise, damages were notable to the ear pollen tube, fertilization efficiency, and, accordingly, the grain yield decreased (Lizaso *et al*., 2018). During flowering and initial grain-filling stages, the maximum daily temperature has a more considerable effect on grain yield (R^2 = 0.689) than solar radiation (R^2 = 0.265) and precipitation (R^2 = 0.288) (Dong *et al*., 2021). In the study observations, it was noteworthy that maize cobs in the milky ripeness stage of grain (20.08) became partially damaged by the frosts (-2 °C to -3 °C). Researchers from Wisconsin, USA, recommended using earlier sowing of maize in the first 10 days of May to avoid early autumn frosts and achieve the full ripeness of the grains on the cobs (Lindsey *et al*., 2024).

The duration of the vegetation cycle is one of the most crucial features that determine the adaptability of a hybrid to the existing environment. Maize hybrids with a vegetation period of 100–110 days can provide fully fledged grains and good yield (Djaman *et al*., 2020). In the presented study, the early maturity of the maize hybrids was reliant upon the genetic characteristics and meteorological conditions, and the full grain-ripening period ranged from 113 to 129 days. The early-ripening hybrid KizURAKS-150-SV had a vegetation period of 113 days, while the hybrid Budan-237-MV had a longer period of 129 days. The hybrid Tselinny-160-SV has an intermediate value in grain-ripening period (121 days). The maize grain yield consisted of its components (cob length, cob unfilled part, grain rows per cob, grains per row, cob weight, grain weight per cob, cob grain yield, and 1000-grain weight). Overall, the cob length varied from 13.6 cm (KizURAKS-150-SV) to 16.3 cm (Tselinny-160-SV) (Table 1). The cob length, as one of the growth variables, considerably affects the cob weight by 77.8% (Arsyad and Basunanda, 2020).

The length of the cob's unfilled part also varied in these maize hybrids, varying from 1.3 to 1.7 cm. The cob traits, including the grain rows per cob and grains per row, have a special effect on the grain yield. The highest number of grain rows per cob resulted in the hybrid Tselinny-160-SV (17). The ultimate number of grains per cob appeared in the hybrids KizURAKS-150-SV-237 and Sary-Arka-150-ASV (240 grains cob^{-1}), and the inferior hybrids were Budan-237-MV (220 grains cob^{-1}) and Tselinny-160-SV (232 grains cob^{-1}) (Table 2, Figure 2). Unfavorable environmental conditions during the cobs pollination negatively affected the number of grains in hybrid cobs. Accelerated flowering of panicles leads to aborting nuclei in maize (Edreira *et al*., 2011). Resulting from a decrease in the number of grains per cob in maize plants, the grain yield can lower by 14% (Santos *et al*., 2023).

The heaviest cob weight and grain weight per cob were remarkable in the hybrid Tselinny-160-SV (172 and 131 g, respectively) (Table 2). The difference in these traits from the standard was 2%, respectively. The lowest values of the traits cob weight and grain weight per cob were evident in the hybrid Budan-237-MV (159 and 124 g, respectively), with a difference to the standard of 6% and 3%, respectively. The grains per cob in the studied hybrids were 75%–78%. The highest 1000-grain weight emerged in the maize hybrid Tselinny-160-SV (300 g), identical to the standard genotype. In hybrids Budan-237-MV and KizURAKS-150-SV, the 1000-seed weight was minimal (220 and 230 g, respectively), which was 70% to 80% less than the standard hybrid. Along with the grains per cob, the grain weight per cob is also a determining factor in managing the maize grain yield, which starts to form within 30 days during the flowering-grain ripening period (Kiniry and Otegui, 2024).

Table 1. Maize hybrids with cob traits at the Akmola Region during 2020–2022.

Maize hybrids	Cob length (cm)	Unfilled part of cob (cm)	Grain rows per cob	Grains per cob row	Grains per cob
Sary-Arka-150-ASV(St)	15.1	1.6	15	16	240
Budan-237-MV	14.5	1.5	14	16	220
KizURAKS-150-SV	13.6	1.3	13	18	237
Tselinny-160-SV	16.3	1.7	17	14	232
M±SEM	14.8 ± 1.13	1.52 ± 1.29	14.7 ± 1.70	16 ± 1.63	232 ± 8.80

Table 2. Maize hybrids with cob and yield-related traits at the Akmola Region during 2020–2022.

Maize hybrids	Cob weight (g)	Grain weight per cob (g)	Grains proportion in cob (%)	1000-grain weight (g)
Sary-Arka-150-ASV (St)	169	128	76	298
Budan-237-MV	159	124	75	220
KizURAKS-150-SV	160	125	75	230
Tselinny-160-SV	172	131	78	300
$LED_{0.05}$.	4.18	3.27		6.6
M±SEM			76 ± 1.41	

Table 3. Maize hybrids with grain yield and grains' dry matter content (full ripeness) at the Akmola Region during 2020–2022.

Maize hybrids	Grain yield (t/ha)	Grains dry matter content (%)
Sary-Arka-150-ASV (St)	4.5	74
Budan-237-MV	3.0	70
KizURAKS-150-SV	3.3	72
Tselinny-160-SV	4.4	75
$LED_{0.05}$.	0.96	
M±SEM		73 ± 2.21

The maize grain yield's determinants are the genotypes, environments, and the genotype-environment interactions (GEI) effects. Before harvesting the cobs, it is necessary to check the grain moisture content, which also depends upon its degree of maturity. Maize slowly releases moisture content for developing dry matter content in the grains. The moisture content varies during the grain-maturity period, from milky (22.9%) to milky-waxy (27.5%) to waxy ripeness (28.1%) of the maize grains (Parvej *et al*., 2020).

The rate of moisture loss in the grains depends upon the climatic conditions. At higher relative humidity and low air temperature, the moisture content decreases from 0.21% to 0.35% per day, and under favorable hydrothermal conditions, 0.52%–0.72% of moisture is lost. Grain dehydration occurs in two stages in the field, such as during ripening and after ripening in maize (Fan *et al*., 2021). When the grains reach physiological maturity, the starch and protein assimilates displace water molecules (Martinez-Feria *et al*., 2019). Grains in the milky-wax ripeness were non-adaptable to low temperatures, and therefore, frost damage occurs in 15% of maize plants (Sotchenko *et al*., 2021).

Grain yield depends upon the number of plants per linear meter, cobs per plant, grains per cob, and the 1000-grain weight. The grain yield of early-maturing maize hybrids proved significantly correlated with the number of grains per cob (r = 0.90) and the grain weight per cob (r = 0.76) (Tsimba *et al*., 2013). A comparative assessment of the early-maturing maize hybrids by grain yield showed that the highest grain yield resulted in the hybrid Tselinny-160-SV (4.4 t/ha), which was 0.1 t/ha less than the standard Sary-Arka-150-ASV (4.5 t/ha). The average grain yield was noticeable in the hybrid KizURAKS-150-SV (3.3 t/ha), while the lowest was in the hybrid Budan-237-MV (3.0 t/ha), and the differences with the standard were 1.2 and 1.5 t/ha, respectively (Table 3). The dry matter content in maize grains varied from 72% to 75%. The minimum dry matter content appeared in the hybrid Budan-237-MV (70%), while the maximum was in the maize hybrid Tselinny-160-SV (75%) as compared with the standard hybrid (74%).

CONCLUSIONS

Early-ripening maize hybrids, as selected for the introduction of feed corn into production in the Northern Kazakhstan Region, used zonal technology. The earliest-maturing hybrid with an average grain yield was the KizURAKS-150-SV hybrid (113 days and 3.3 t/ha, respectively). The most productive hybrid with an extended vegetation period was the Tselinny-160-SV (4.4 t/ha^{-1} and 121 days, respectively). Therefore, the study highly recommended widely cultivating the early-maturing maize hybrids in Northern Kazakhstan.

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