INTRODUCTION

Soy *Glycine max* (L.) Merr. is one of the main protein-oil legumes with a wide variety of substituents: food, feed, technical, medical, and textile (Ko et al., 2013; Qi & Lee, 2014). Because of the high nutritional quality and protein content, soy is defined as a strategic culture.

World soy production is growing annually. In 2019, soy acreage amounted to 125.6 million ha (USDA, 2020). Currently, three countries – the United States, Brazil, and Argentina – account for more than 80% of global soy production (American Soybean Association, 2018). Over the past ten years, soy acreage in Kazakhstan has grown more than 2.5 times from 53.6 thousand ha in 2009 to 139.5 thousand ha in 2019. However, the increase in crop yields over this period was only slight from 18.0 kg/ha to 20.7 kg/ha (Ministry of National Economy, 2020).

Currently, 48 soybean varieties are registered in the State Register of Breeding Achievements approved to be cultivated in the Republic of Kazakhstan, 17 of which are varieties of Kazakh breeding created in the Kazakh Research Institute of Agriculture and Plant Growing (KazRIAPG) (Minister of Agriculture of the Republic of Kazakhstan, 2019). The main region in the Republic of Kazakhstan for soy cultivation is the irrigated field of the Almaty region (107 thousand ha). The limiting factors for increasing the acreage in the republic are vegetation period, photoperiodic response, resistance to adverse climatic factors, freezing resistance, salt resistance, and drought resistance (Didorenko, Erzhebaeva, & Amangeldiyeva, 2018).

Studies showed significant differences among legumes in terms of their ability to adapt to drought, which is measured by their ability to maintain high crop yields after a period of water shortage (Fried, ...
Moisture stress was identified as the main environmental factor that limits soy yields in the United States and other regions of the world (Abate et al., 2012; Battisti & Sentelhas, 2015; 2017; Kunert et al., 2016; Mertz-Henning et al., 2018; Zipper, Qiu, & Kucharik, 2016). Depending on the genotype, soy plants consume about 450-700 mm of water during the vegetation period. Plants use different mechanisms to control water shortage, which are regulated by a combination of various factors. The response of a plant to drought is very complex and involves the interaction between various molecular, biochemical, and physiological processes (Hossain, Liu, Qi, Lam, & Zhang, 2014; Iqbal et al., 2019; Zhao, Aleem, & Sharmin, 2017).

Atmospheric precipitation is of overriding importance in the hydrological regime of the agricultural ecosystem. According to several studies, precipitation accounts for less than 25-40% of water from water consumption (EOS, 2019; Novikov, 2014). Depending on the soy cultivation area, water consumption in the CIS countries varies from 4,000 to 6,000 m$^3$/ha. The irrigation requirement for soy varies from 800 to 5,300 m$^3$/ha. In the south Ukraine and Moldova, it varies from 1,700 to 3,500 m$^3$/ha. In the Krasnodar Territory (Russia), irrigation requirement is 1,000–2,000 m$^3$/ha in a year with average precipitation and 3,000–4,000 m$^3$/ha in a dry year. The irrigation requirement for the Rostov Region (Russia) is 2,800–4,500 m$^3$/ha (Agro-archive, 2014a).

Studies showed that soy consumes 20-25 m$^3$/ha of water per day during its initial phases of growth and development. The most intensive water consumption in soy occurs during the blooming phase, formation and filling of beans, that is, in the second half of the vegetation period. During this period, the studied soybean varieties consumed about 70% of the total water consumed during the vegetation period. During the blooming-bean filling period the daily water expenditure reaches 50 m$^3$/ha (Agro-archive, 2014b). In the lysimetric studies conducted in Rajasthan, India, during the cultivation period of 108 days, soy evapotranspiration (ET) was 662 mm, 6.12 mm/day in average. In Turkey, soy ET amounted to 574–619 mm, and in Lebanon, soy ET was 725–800 mm (AgroDialog, 2015).

Soy drought resistance has been studied for more than ten years in Kazakhstan. Methods for assessing drought resistance using laboratory diagnostics (Li et al., 2013), anatomical-morphological and physiological tests (Amangeldiyeva et al., 2019; Erzhebaeva, Didorenko, & Daniyarova, 2015; and field experiments (Didorenko, Erzhebaeva, & Amangeldieva, 2018; Erzhebaeva, Didorenko, Kudaibergenov, Daniyarova, & Amangeldieva, 2019) have been carried out over the years.

The research aimed to assess 98 soybean varieties of the KazRIAPG working collection for all production characters in the fields of the Almaty region of the Republic of Kazakhstan with and without irrigation and to distinguish the most significant production characters as markers for drought resistance assessment.

**MATERIALS AND METHODS**

Field experiments were conducted using a split plot design with irrigation as the main plot (two levels – with or without irrigation) and genotype as a sub-plot factor (98 soy genotypes). Combinations of irrigation and genotype were organized in a 2 x 98 factor experiment design (one linear meter plot, 25 seeds in each). Sowing was randomized with three replications.

Sowing was conducted on 1 May 2019. Agrotechnological manipulations on crop tending (irrigation, ploughing row spacing, killing of weeds) were carried out. Gravity vegetative irrigation in the irrigation area was carried out three times on June 25, July 15, and August 7 with an rate of 1,200 (m$^3$/ha). Harvesting was carried out manually as the samples ripened.

The analysis of the yield structure of samples of soybean varieties was carried out according to the following elements: plant height, height of the lowest bean, number of lateral branches, number of productive nodes, number of beans from the plant, seed weight from the plant, seed weight from the plot, weight of 1,000 seeds. Plant height (cm) was the length of the stem from the surface of the soil to the top. The number of productive nodes was the number of nodes carrying beans during ripening. The weight of 1,000 seeds (g) was measured at 12% humidity.

Phenological observations were performed for the main phases of development: sowing, seedlings (VE), triple leaf development (V1), blooming (R2), bean formation (R4), bean filling (R6), ripening (R8) (Licht, 2014).
The soy accessions used in this study consisted of 98 soy genotypes. The material included varieties from Japan, Latvia, China, Canada, Hungary, France, Georgia, Brazil, Sweden, Moldova, Romania, Tajikistan, Poland, and Cuba. Soy genotypes belonged to six maturity groups (MG) 00, 0, I, II, III, IV, which are recommended for cultivation at a latitude of 40-50° N. Kazakh varieties and genotypes described in the literature as sources of drought resistance were selected for the collection (Posylaeva, & Kirichenko, 2014). The material was collected as a result of exchange of collections with various breeding centers and received from the Vavilov Research Institute of Plant Industry (St. Petersburg, Russia) and the US National Plant Germplasm System.

Experimental Site, Weather and Climate Conditions During the Year of the Study

Collection samples of soy varieties were studied in 2019 at the KazRIAPG field stations located in the Almaty region, at an altitude of 740 m above sea level, at the coordinates 43° 15′ N, 76° 54′ E. This zone is characterized by continental climate (mild and cool winter, chilly spring, hot and dry summer, warm and dry autumn). The average duration of frostless season is 170-180 days with temperature fluctuations. However, ground frosts often recurring in late spring and early autumn often reduce the frostless season to 140-150 days, which leads to winterkilling of late-ripening soy varieties.

The thermal resources of summer are quite high in the zone. The average accumulated positive temperatures are 3,500-4,000°C. Such a thermal regime makes it possible to grow many thermophilic crops, including soy.

The distribution of precipitation in the dry steppe zone can be unstable. According to the data from the weather station, the long-term annual average precipitation is 414.6 mm with the following distribution by season of the year: 70.8 mm in winter; 166.9 mm in the spring; 101.8 mm in the summer, and 75.1 mm in the fall. In the summer, the main part of precipitation occurs in June and amounts to 53.9 mm. The soil mantle is light-chestnut, clay loam, and rarely sandy loam soils.

According to the data of the KazRIAPG meteorological station, environmental conditions of the 2019 study period in the research area differed significantly from the long-term annual average. The temperature from May to October was 0.5-3.2°C higher than the long-term annual average (Table 1). High temperatures, during both the day and the night, led to drought during the soy reproductive periods.

Precipitation 3.5 times higher than the long-term annual average in April had a positive effect on moisture supply and subsequent seedlings growth. The abundance of precipitation in August, and especially in September and October, led to the plant lodging, both in irrigated and non-irrigated farming area. The vegetation period was so long that it was not possible to accurately determine the duration of vegetation for several late-ripening varieties. The main phases of development took place during a period of moisture stress. May, June, July, and the first half of August were characterized by an unstable distribution of precipitation (Fig. 1).

<table>
<thead>
<tr>
<th>Month</th>
<th>Temperature (°C)</th>
<th>Atmosphere precipitation (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Actual</td>
<td>Long-term annual average</td>
</tr>
<tr>
<td>April</td>
<td>+12.4</td>
<td>+10.4</td>
</tr>
<tr>
<td>May</td>
<td>+16.9</td>
<td>+16.4</td>
</tr>
<tr>
<td>June</td>
<td>+22.3</td>
<td>+21.2</td>
</tr>
<tr>
<td>July</td>
<td>+26.9</td>
<td>+24.1</td>
</tr>
<tr>
<td>August</td>
<td>+24.9</td>
<td>+22.1</td>
</tr>
<tr>
<td>September</td>
<td>+18.5</td>
<td>+16.0</td>
</tr>
<tr>
<td>October</td>
<td>+11.5</td>
<td>+8.3</td>
</tr>
</tbody>
</table>

Table 1. Average monthly air temperature and precipitation during the vegetation period (2019)
Over the entire soy vegetation period, early-ripening varieties had 160.9 mm of precipitation, mid-ripening varieties had 250.0 mm of precipitation, and late-ripening varieties had 317.3 mm of precipitation.

Statistical data processing was performed using the open source software environment [R, version 3.6.1 (2019-07-05) “Action of the Toes”] as part of the GNU project. Language and environment were available under the GNU GPL, distributed in the form of source codes, as well as compiled applications for a number of operating systems: FreeBSD, Solaris. Welch’s Two-Sample t-Test (t.test) included in the built-in package {stats} was performed. The matrix of linear Pearson correlation coefficients (cor (..., method = “pearson”)) included in the built-in package {stats} was calculated, charts for them (corrplot) were constructed using the {corrplot} package.

RESULTS AND DISCUSSION

Phenological Phases of Development of Soy Varieties from the Collection with and without Irrigation

According to the results of estimating the duration of the vegetation period in the southeast Kazakhstan, the studied collection material was divided into six maturity group (MG) with irrigation and seven MG without irrigation, depending on accumulated positive temperatures during the vegetation period (Table 2).

In our studies, we observed a general tendency for a reduction of the duration of the phenological development phases R4-R6 and R6-R8 in the experiment (without irrigation) compared to the control (with irrigation) in all MG. Ultimately, this affected the duration of the entire vegetation period VE-R8 (Fig. 2). For MG 00, MG 0, and MG IV, the reduction of the vegetation period duration (VE-R8) averaged 12.4, 12.9, and 14.8 days, respectively. For MG I, MG II, and MG III, the vegetation period was reduced by 4.3-6.8 days.

In our studies, irrigation was carried out on certain dates – June 25, July 15, and August 7, with no regard to the phenological phases of development. As a result, it was recorded that irrigation occurred at different phases depending on the MG. For example, for early-ripening samples, the three vegetative irrigations occurred separately in each phase: blooming, bean formation, and bean filling. In groups MG I and MG II, two vegetative irrigations were carried out in the blooming phase, and the last one was in the bean formation phase. In MG III, the first irrigation was carried out before blooming, and two irrigations were performed in the blooming phase, and in the MG IV group, the first two irrigations were carried out before the blooming phase (Fig. 2).
The reproductive stage is often the most critical phase that affects crop yields. The results of studies (Daryanto, Wang, & Jacinthe, 2015) showed that drought during the reproductive stages especially from blooming to ripening, led to a decrease in yield by 43.4%. In a situation where drought took place during the entire vegetation period, yield decreased by 42.1%. Drought in the early reproductive stage (R2) resulted in more damage than drought in the late generative stage (R6-R8) (Daryanto, Wang, & Jacinthe, 2015).

According to literature data, plant productivity is evaluated using a number of characteristics that affect yield. Characteristics such as plant height, height of the lowest plant, number of lateral branches, number of beans, number of seeds per plant, weight of 1,000 seeds, seed weight per plant, and number of four-seed beans on a plant are the main production characters. A decrease in productivity under moisture stress occurs due to a decrease in branching, the number of beans and a decrease in the seed weight and the number of seeds in the bean (Tolokonnikov, Koshkarova, Kancer, & Plusheva, 2019).

We studied all the basic productivity elements of various MG (plant height, height of the lowest plant, number of lateral branches, number of beans, number of seeds per plant, weight of 1,000 seeds, seed weight per plant, and number of four-seed beans on a plant).
seeds, seed weight per plant, seed weight per plot, seed plumpness) on two contrasting backgrounds (with and without irrigation). The characters most impacted by the moisture stress were the seed weight per plot, the weight of 1,000 seeds, and seed plumpness.

**Elements of Productivity of Collection of Soy Varieties with and without Irrigation**

Seed weight per plot is one of the most objective indicators of crop yield. The lowest yields with irrigation in the study area were obtained for collection samples of MG 00, MG 0 and MG IV (71.7 g/m, 98.2 g/m, 78.7 g/m, respectively). Such results were expected, as early-ripening groups (MG 00, MG 0) are genetically characterized by lower yields compared to mid-ripening groups. MG IV samples showed poor adaptability to the southeast zone of the Republic of Kazakhstan and did not go through the entire seed and bean ripening stage. High values of the seed weight from the irrigated plot were observed at MG II (173.9 g/m). Apparently, this is due to the fact that the first two irrigations in MG II were carried out during the period R2-R4, which increases the set of seeds.

The effects of the soil and atmospheric drought on different soy MG in the experiment without irrigation were varied. The absence of irrigation led to a decrease in the average seed weight from a plant in the group from 15.5% in MG IV to 48.5% in MG 0. On average for all the studied samples, the absence of irrigation reduced the seed weight from a plant by 31.1% (Fig. 3).

![Fig. 3. Yield per plot (g/m) of soy samples of different MG with and without irrigation](image)
The results of the variance analysis allowed to establish a statistically significant difference in the character values of the seed weight from a plot in the experiments with and without irrigation in almost all MG, with the exception of MG IV (Table 3). The most significant effect of moisture stress was recorded in samples of MG II (p-value = 1.948e-05) (Table 3). This is due to the fact that soy plants of MG II entered the phase of blooming and formation and filling of beans during the drought condition (Fig. 1).

Data on the effect of drought on seed weight from a plot for MG IV had the largest range. From 55 samples in this MG, 25 showed an increase in the seed weight per plot (from 3 to 981%) in the experimental samples compared to the control, while 28 samples without irrigation, the decrease of the seed weight per plot ranged from 3 to 82% compared to the control. However, only two samples from the first group (Fuji No. 4, 5695) which showed an increase in seed weight per plant by 11.0 and 24.3%, respectively, and six samples of the second group (Hakka zashi, KSHI 713, 6575, Shiheigo Kuroheso, Hakuchuta, Kaigen Shirobana), for which the yield decrease was within 14.8-36.1% compared to the control, were selected as perspective.

In the remaining MG, only two samples (Nhat, Ji-ti 4) were characterized by an increase of seed weight per plot (10-15.2% and 4-11.8%, respectively) compared to the control. The selected samples (Krasivaya mechta, Fiskeby 4, Zhansaya, Zen, Sousei, Xinjiang D11-252, Magheva, Harmony, Xinjiang D10-135, Grignon 5, Desna) had 0.3-26.0% lower seed weight per plot than control.

The weight of 1,000 seeds does not always directly correlate with the yield. However, among the varieties with the same number of seeds per plant. The varieties with larger seed size will be considered as more perspective. Collection varieties (regardless of maturity group) were divided into four groups by weight of 1,000 seeds: small-seeded (60-100 g), medium-seeded (105-170 g), large-seeded (175-225 g) and very large-seeded (over 230 g). Varieties Cha ye sheng tou, Kormovaia 15, Huang bao zhu, and Blaen Small were considered small-seeded. While Pamyat YuGK, Cheremosh, Dindone, Koushurei 235, Huang ke, Nin zhen No. 1, S-62, Shimizu 1-8-1, and 6575 were considered large-seeded varieties.

Correlation analysis of the dependence of the weight of 1,000 seeds on the seed weight per plot showed a positive correlation: $r = 0.368$ in the experiment with irrigation and $r = 0.374$ without irrigation (Fig. 4). During the experiment, we found a tendency to a decrease in the weight of 1,000 seeds in the varieties that were grown without irrigation in all groups except MG IV (Fig. 5). On average, in the MG, the decrease in seed weight was from 6.8 to 16.6% with a range from 63.4% to-45.4%. In early-ripening groups, the highest decrease in the weight of 1,000 seeds was observed in MG 0 (14.1%) and MG 00 (9.1%), and it was within 5% in groups MG I, MG II, MG III compared to the control with irrigation.

The variance analysis showed a significant difference in the values of the weight of 1,000 seeds per plot in experiments with and without irrigation for samples MG 0 and MG II. For other MG, the effect of moisture stress on the weight of 1,000 seeds was not significant (Table 4).

Table 3. Variance analysis of the effect of moisture stress on the weight of soy seeds from a plot

<table>
<thead>
<tr>
<th>Maturity group</th>
<th>t-statistic</th>
<th>Degree of freedom (df)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>MG 00</td>
<td>3.0436</td>
<td>9.0647</td>
<td>0.01382</td>
</tr>
<tr>
<td>MG 0</td>
<td>3.0576</td>
<td>9.2246</td>
<td>0.01325</td>
</tr>
<tr>
<td>MG I</td>
<td>2.4234</td>
<td>7.4256</td>
<td>0.04391</td>
</tr>
<tr>
<td>MG II</td>
<td>5.0242</td>
<td>31.358</td>
<td>1.948e-05</td>
</tr>
<tr>
<td>MG III</td>
<td>2.5087</td>
<td>10.372</td>
<td>0.03022</td>
</tr>
<tr>
<td>MG IV</td>
<td>1.5351</td>
<td>71.025</td>
<td>0.1292</td>
</tr>
</tbody>
</table>
Remarks: W – irrigation; NW – without irrigation; Yield – seed yield; M1,000 – weight of 1,000 seeds; Cmpltn – plumpness; VP – vegetation period

**Fig. 4.** Correlation analysis of soy production characters and the vegetation period of soy samples: a – with irrigation; b – without irrigation

**Fig. 5.** The weight of 1,000 seeds (g) of collection soy samples in different MG with and without irrigation
Seed Plumpness

During the grain filling period, a decrease in assimilate distribution and enzyme activity of starch synthesis (sucrose synthase, adenosine diphosphate glucose pyrophosphorylase, starch synthase and starch branching) occurs in the absence of irrigation (Farooq, Wahid, Kobayashi, Fujita, & Basra, 2009). The underdeveloped state of seeds is the result of a distortion of the influx of plastic substances to the forming and filling grain. Most often, the cause of this disruption is a rapid decrease in grain moisture to 40-50%, which leads to colloid coagulation. The underdeveloped state of seeds worsens the yield, if it is associated with deformation of the glume and decrease in the weight of 1,000 grains. Frost-damaged seeds become completely unsuitable for sowing (AgroDialog, 2020). In our studies, we explain the underdeveloped state of seeds in early-ripening groups (82.0-83.0%) by the reduction in the duration of the period R6-R8 (by 7-10 days).

With irrigation, the seed plumpness in all MG averaged 98.3-96.6% with the exception of MG IV. Soybean plants of this group have an increased duration of the main phases of development (Fig. 2). Due to autumn frosts with irrigation in MG IV, the seed plumpness was only 91.8%, and in some samples, it was as low as 6.2%. Analysis of the plumpness of soy seeds grown without irrigation showed that the proportion of underdeveloped seeds increased sharply compared with the control, especially in early-ripening groups (Table 5). The percentage of underdeveloped seeds in individual samples reached 80.4-83.0%, and averaged 43.3-48.1%. In the mid- and late-ripening groups, seed plumpness was higher, and the proportion of underdeveloped seeds was only 9.9-21.0%. A correlation analysis of the dependence of seed plumpness on the vegetation period duration showed a positive correlation coefficient (r = 0.579) in the experiment without irrigation (Fig. 4).

As a result of studies, varieties, for which seed plumpness without irrigation was on the same level as that with irrigation with a deviation of 0-2%, were identified. These varieties include Zhansaya, Selecta 302, Sponsor, Nin zhen No. 1, Jilin No. 10, Gong jiao 6308-1, Kaigen Shirobana, Pulaska Zolta Wczesna, Kiio Shokuzu, Fuji No. 4, Mizukuguri, Monbetsu Nagaba daizu, Krasivaya mechta, Kindaizu, S-62, Xinjiang D10-130, Tun san bai can ker, Sousei, Y-48, Ustya, 5694, and Bukuria.

Using the structural analysis data for production characters, yield from a plot, the weight of 1,000 seeds and seed plumpness were taken as the basis for the determination of drought-resistant varietal samples. Based on a comprehensive assessment of the working collection, the following soy genotypes with high drought resistance were identified: MG 00 – Krasivaya mechta (Russia), MG 0 – Ustya (Ukraine), Sptna (Ukraine), MG I – Ji-ti 4 (China), MG II – Bukuria (Moldova), Zhansaya, Hybrid 670, (Kazakhstan), Vilana (Russia), Zen (Switzerland), Skytnea (Moldova), MG III – Sponsor (France), Nin zhen No. 1 (China), Sousei (Japan), MG IV – Fuji No. 4 (Japan), KSHI 713 (Moldova), Kaigen Shirobana (China), Shiheigo Kuroheso (Japan), 5695 (China), Hakuchuta (North Korea), 6575 (China), Hakzha zashi (Japan).
CONCLUSION

Ninety eight varieties and collection samples of soy Glycine max (L.) Merr. of six MG were evaluated based on production characters in the field conditions of Almaty region with and without irrigation. Based on a comprehensive assessment of the working collection, the following soybean genotypes with high drought resistance were identified: MG 00 – Krasivaya mechta (Russia), MG 0 – Ustya (Ukraine), Sprtna (Ukraine), MG I – Ji-ti 4 (China), MG II – Bukuria (Moldova), Zhansaya, Hybrid 670, (Kazakhstan), Vilana (Russia), Zen (Switzerland), Skytnea (Moldova), MG III – Sponsor (France), Nin zhen No. 1 (China), Sousei (Japan), MG IV – Fuji No. 4 (Japan), KSHI 713 (Moldova), Kaigen Shirobana (China), Shiheigo Kuroheso (Japan), 5695 (China), Hakuchuta (North Korea), 6575 (China), Hakka zashi (Japan).

Varieties of the MG 00 can be cultivated in the Almaty region without irrigation and this genotype was also recommended for cultivation in non-irrigated areas of Eastern and Northern Kazakhstan.

The highest productivity potential in the Almaty region was found in variety of MG II. Without irrigation, however, the variety tends to have maximum decrease in yield. The cultivation of varieties of the MG IV in the Almaty region was considered impractical, since the vegetation period does not allow the yield to be formed before the autumn frosts.

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