IRSTI 68.35.03 https://doi.org/10.52081/bkaku.2025.v74.i3.284

EVALUATING DIFFERENT LIGHT DISTANCES ON YIELD COMPONENTS OF WHEAT UNDER INDOOR SPEED BREEDING

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Annotation. In Kazakhstan, where the agricultural sector faces serious challenges such as climate change, pest outbreaks, declining grain yields, and restrictive land-use policies, the establishment of a speed breeding platform and developing its protocol represent a timely and strategically important step forward. Although Kazakh wheat plays a vital role in ensuring regional and global food security, the industry is under threat due to inefficiency and the reduction of cultivated areas caused by economic and political constraints. Accelerated development of wheat varieties with enhanced drought tolerance, disease resistance, and improved yield potential may become a sustainable solution to these pressing issues.

However, one of the main limitations in modern plant breeding is the prolonged period required to develop new crop varieties. To address this issue, speed breeding has emerged as a method aimed at significantly shortening the breeding cycle. By adjusting environmental parameters, it promotes rapid plant growth and reproduction.

The main objective of this study was designing a protocol for determining the most effective light spectrum distribution to support optimal wheat development under indoor Speed Breeding. The identified 1.5 m light-bench distance was found to be suitable for growing wheat and had a significant positive impact on ETN and SN.

Keywords: speed breeding, wheat, LED grow lights, treatment, yield components.

Introduction. With the global population projected to reach almost 10 billion by 2050, the food demand is expected to rise significantly to meet the nutritional needs of a growing population [1]. If this challenge is combined with changes in climate like floods, prolonged droughts and extreme temperatures, it further poses a significant threat on the global food security [2]. Moreover, the primary impact of stagnant or declining agricultural productivity, caused by adverse climate effect, could be particularly deleterious for low-income countries that face rising population pressures [3]. Therefore, enhancing agricultural productivity with rapid development of new crop varieties with improved grain yield and quality, based on the use of advanced technologies, is a critical component of safeguarding the future global food security [4].

One of the primary constraints in modern plant breeding is the prolonged period required to develop new crop varieties with exceptional adaptive traits. Conventional breeding of new and enhanced cultivars for annual crops can take as long as 12-14 years, from the initial crossing of parental genotypes to the commercial release of new cultivars. To address this challenge, the "Speed Breeding" technique has emerged as a powerful approach to accelerate genetic gain in plant breeding [5]. To accelerate plant growth cycle, the light is one of the vital components of Speed Breeding method. The quality and spectral distribution can significantly influence plant growth and development, affecting specific morphological traits such as stem elongation, plant height, and root growth and flower development [6], [7]. Moreover, the daily quality of light has a significant impact on photosynthesis rate, gas exchange, transpiration, stomatal activity, and various other plant developmental processes [8].

The variation in temperature and soil nutrient availability is also important for plants to transition from vegetative to reproductive stages under accelerated growth [9]. As plants grow rapidly, the requirement for essential macronutrients such as nitrogen, phosphorus and potassium also rise. Therefore, the preparation of a nutrient-rich potting mix is crucial to ensure that plants receive balanced nutrition they need for healthy development and optimal performance.

Initially, the “Speed Breeding” protocol was developed for long-day crops such as barley, wheat, chickpea, and canola by extending the photoperiod to nearly a full day cycle (typically 22 hours of light and 2 hours of darkness) with temperature regimes of 22°C during the day and 18°C at night [10]. In addition, seeds are harvested at the immature stage in Speed Breeding, further reducing the generation time. This integrated approach enables a reduction in crop generation cycles, for example, shortening the wheat life cycle from approximately 120 – 140 days to around 60 – 70 days, potentially reducing the pre-breeding time from 8 to approximately 2 years. Recently, the Speed Breeding protocol was also successfully adapted for short-day crops such as soybean, rice, and amaranth by modifying LED light quality and implementing a 10-hour photoperiod enriched with blue and far-red light spectra [11].

Currently, research centers manly in developed countries have established the “Speed Breeding” facilities and successfully integrated the technology into existing wheat improvement programs. Each protocol is tailored with specific modifications to suit local genotypes, environmental conditions and breeding objectives [12]. Therefore, the primary aim of this study was to evaluate Speed Breeding as a method to shorten the spring wheat growth cycle and to assess how light intensity, influenced by the distance from the light source, affects wheat plant development and yield performance. Here, we report that we established the first “Speed Breeding” facility in Kazakhstan, as the country is a key regional and global wheat grain producer, and adapted its protocol to local conditions. We identified the optimum distance between LEDs and wheat plant canopy under the indoor Speed Breeding facility at Zhetysu University named after I. Zhansugurov. The identified distance was suitable for wheat cultivars with different photoperiod sensitivity parameters that are adapted to wide range of environments.

Material and methods. The Speed Breeding experiment was conducted on three spring wheat varieties (*Paragon, Pirsbak-21 and CN*x*Borlaug-16*) adapted to different environmental conditions. *Paragon* represents UK’s spring wheat gene pool that is considered as bread making benchmark. The wheat genotypes *Pirsbak-21* and *CNxBorlaug-16* were obtained from the wheat breeding program at the National Agricultural Research Centre (NARC), Pakistan. The growing protocols of these genotypes were optimised for outdoor, but not indoor, Speed Breeding conditions in their respective countries, which was a key factor in their selection for this study.

Two seeds of each variety were sown in 1L pots with customised potting mixture (containing 65% of peat, 18% perlite, 12% sand and 7% bio humus) and grown under two different growing conditions in an indoor Speed Breeding facility at Zhetysu University named after I. Zhansugurov, Taldykorgan. Plants were supplemented with a foliar spray of calcium nitrate when calcium deficiency symptoms appeared. Plants were hand watered regularly once a day, without causing waterlogging issue, providing enough aeration for normal root development. The plants were not watered when grain filling is over to accelerate the ripening.

The growing treatments included two different distances (1.5 and 2 meters) between top of the bench and light, excluding the pot height. These distances were chosen to generate variation in light intensity received by the wheat plants, allowing for its evaluation on growth and development parameters. The research was carried out in an indoor Speed Breeding facility equipped with Heliospectra LED grow lights (Sweden). Light intensity was adjusted to 500nm wavelength, from germination to late tillering and early booting phases, for each light component – white, red, blue and far-red (Fig. 1A). From early booting onwards, the light intensity was set to 700nm till full maturity. The photoperiod was extended to 22 hours of light and 2 hours of night per day. The temperature at the Speed Breeding facility was maintained at around 22°C during the daytime and 17°C at night (Fig. 1B). Yield components such as thousand grain weight (TGW), effective tiller number (ETN), seed number (SN), seed length (SL) and seed width (SW) were assessed. For the evaluation of TGW, SN, SL and SW the Marvin (Germany) seed phenotyping platform was used. Statistical analysis included two-sample test and was conducted in R using "t.test" function. The figures were generated using "boxplot" function in R.

Results and discussion. One of the most significant factors in Speed Breeding for normal plant growth, development and productivity is light. For instance, red light promotes photosynthesis and biomass accumulation and stimulates flowering and photoperiod responses in plants; blue enhances vegetative growth and leaf expansion and also improves stomatal opening and chlorophyll production; far-red is used in combination with red light to mimic natural daylight conditions and thus helps to regulate shade avoidance and flowering; white light (Full-Spectrum) provides a balanced spectrum suitable for overall growth through mimicking the natural sunlight, beneficial for general plant development (Fig. 1) [13], [14].

In this study, we demonstrated that light intensity, regulated by two different distances between plants and the LED light source, has a significant effect on the productivity and morphological traits of spring wheat grown under indoor Speed Breeding conditions.

The light intensity (within the 400–700 nm spectrum depending on wheat developmental phase) and temperature conditions (22°C and 17°C during daytime and night respectively), and quality of customized potting mixture used in this study were all suitable for growing healthy wheat plants under an indoor Speed Breeding (Fig. 2 and 3). Earlier, the same light intensity was shown to effectively promote early flowering and seed development in major crops such as barley, wheat, chickpea, canola, and others [5]. In this study, the entire growing period (till early maturity) accounted for ~65 days which is compatible with research results published earlier (Fig. 3).

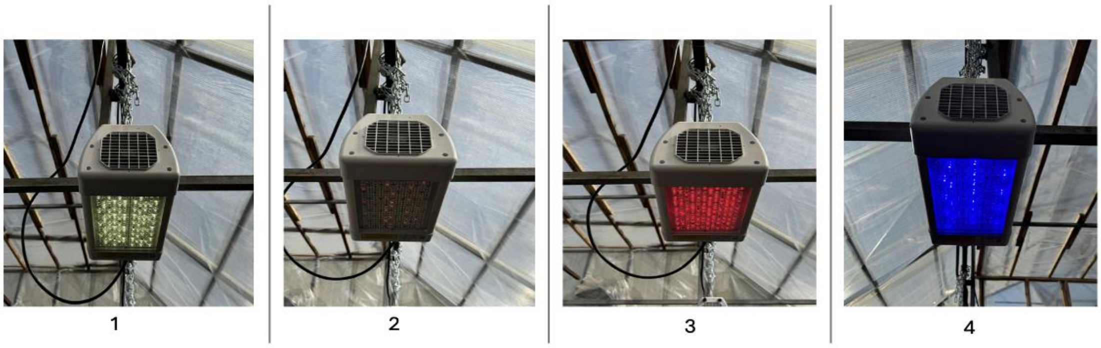

Figure 1 - Critical light components for plant development: 1- While, 2-Far-Red, 3-Red and. 4-Blue

Throughout the growing period, from the germination and to early tillering phase, wheat plants displayed similar growth dynamics without any clear noticeable phenotypic differences. However, after the tillering stage, phenotypic differences between the treatments became pronounced, especially in spike formation and plant height. Plants under the 2.0 m light treatment exhibited a noticeable delay in development at the flowering stage.

Interestingly, plants of the UK variety – *Paragon*, grown under 2.0 m light treatment were taller than that of under 1.5 m light treatment till grain filling stage after which the physiological development was balanced between two treatments. Comparatively, plants of Pakistani wheat genotypes – *Pirsbak-21* and *CNxBorlaug-16* – that are subjected to longer light distance were significantly taller. However, from flowering onwards these plants were slow in development compared to plants exposed to 1.5 m light treatment (Fig. 3). These differencies in developoment that resulted in the variation in plant height could stem from the genes controlling photosensitivity and plant height in these two different gene pools. For instance, *Paragon* carries tall alleles at the historic *Rht* genes and is photosensitive at certain level. Pakaistani lines, however, should carry short alleles at this genes and less photosensitive, based on the breeding efforts made after "green revolution" was introduced to the South Asia [15].

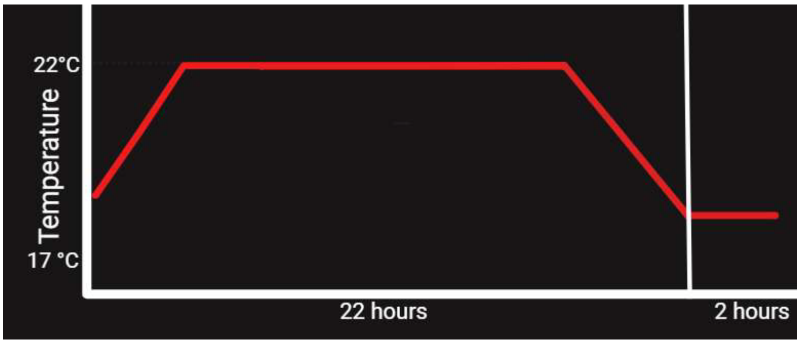

Figure 2 - The photoperiod and temperature setup under Speed Breeding

Among assessed yield components, a variation in the number of effective tillers between two treatments was statistically significant (p=0.008). The plants exposed to the 1.5 m light treatment produced more tillers compared to those grown under 2.0 m (Fig. 4). Likewise, LED grow lights installed at 1.5 m had a direct and significant positive impact on the total seed number per plant (p=0.003). These findings can be generalized for wheat genotypes having different photoperiod sensitivity parameters and that are adapted to wide range of environments.

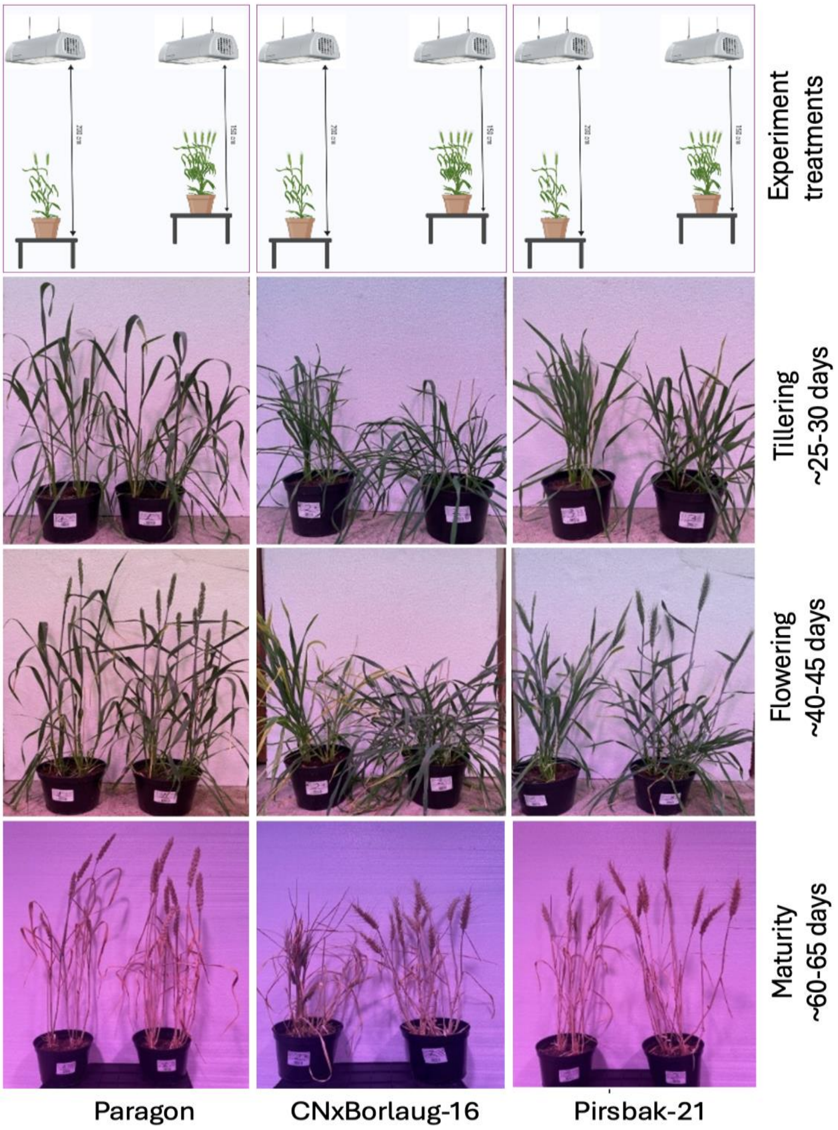

Figure 3 – Two light treatments and a full "seed to seed" cycle of three wheat genotypes – Paragon, CNxParagon and Pisbak-21 under Speed Breeding

The distance between the lights and bench had no effect on SL and SW. As shown, the seed parameters such as variance, mean, upper and lower confidence intervals were almost the same between two light treatments for SL and SW with p-values of 0.9 and 0.2 respectively (Fig. 4). However, TGW demonstrated a tendency toward higher values under higher light intensity, indicating a potential positive effect of light proximity on grain weight with p-value being close to significant (p=0.08) (Fig. 4).

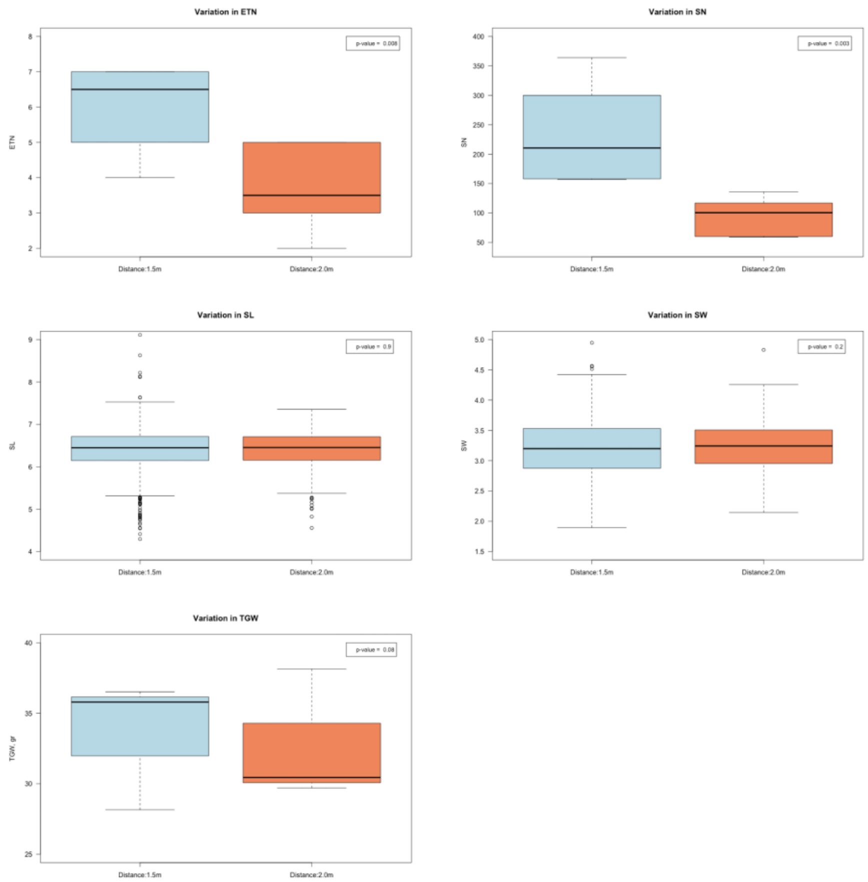

Figure 4 – Variation in ETN, SN, SL, SW and TGW under two treatments in an indoor Speed Breeding facility and their corresponding results from significance testing

Conclusion. This study demonstrated that the tested spring wheat genotypes – *Paragon*, *CNxBorlaug-16*, and *Pirsbak-21* – showed enhanced productivity when grown under a 1.5 m distance between the LED light source and the plant canopy. At this distance, the plants exhibited accelerated development, particularly in tillering, and produced a significantly higher number of effective tillers and total seeds per plant. The increased light intensity likely enhanced photosynthetic activity and tillering potential, thereby improving overall yield.

Genotypic differences in plant height and developmental dynamics were also observed between the UK cultivar *Paragon* and the Pakistani lines *CNxBorlaug-16* and *Pirsbak-21*, which may be attributed to variations in *Rht* alleles and differences in photoperiod sensitivity.

These findings highlight the importance of optimising light intensity to improve wheat growth and productivity under indoor Speed Breeding conditions. The results could positively contribute to the future wheat breeding and phenotyping strategies by enabling the adjustment of environmental parameters according to genotype-specific requirements for accelerated crop development.

Funding. The research was carried out under the Program-targeted funding of the Ministry of Science and Higher Education of the Republic of Kazakhstan for 2024-2026, BR24992903 “Practical implementation of modern molecular genetic, physiological, biochemical, biotechnological methods and digital phenotyping in breeding of economically important agricultural crops” and Grant Funding of the Ministry of Science and Higher Education of the Republic of Kazakhstan for 2024-2026, AP23488859 “Adding values to the Central Asian wheat through the means of whole genome scanning, automated phenotyping and intensive selection”.

References:

[1] **Hickey, L.T.** *et al.* Breeding crops to feed 10 billion. *Nature Biotechnology – 2019*. vol. 37, no. 7, pp. 744–754. doi: 10.1038/s41587-019-0152-9.

[2] **Buckner, C.A.** *et al.* Speed Breeding: A Propitious Technique for Accelerated Crop Improvement. *Intech 2016*. vol. 11, no. tourism, p. 13. https://www.intechopen.com/books/advanced-biometric-technologies/liveness-detection-in-biometrics

[3] **Ray, D.K.,** Mueller N.D., West P.C., and Foley J.A.. Yield Trends Are Insufficient to Double Global Crop Production by 2050. *PLoS One – 2013*. vol. 8, no. 6. doi: 10.1371/journal.pone.0066428.

[4] **Voss-Fels, K.P.,** Stahl A., and Hickey L.T.. Q&A: Modern crop breeding for future food security 07 Agricultural and Veterinary Sciences 0703 Crop and Pasture Production 06 Biological Sciences 0607 Plant Biology 06 Biological Sciences 0604 Genetics. *BMC Biology, – 2019*. vol. 17, no. 1, pp. 1–7.

[5] **Watson, A.** *et al.* Speed breeding is a powerful tool to accelerate crop research and breeding. *Nature plants 2018*. vol. 4, no. 1, pp. 23–29. doi: 10.1038/s41477-017-0083-8.

[6] **McMahon, M.J.,** Kelly J.W., Decoteau D.R., Young R.E., and Pollock R.K.. Growth of Dendranthema ×grandiflorum (Ramat.) Kitamura under Various Spectral Filters. J. Amer. Soc. Hort. Sci – 2019. pp. 950-954. doi: 10.21273/jashs.116.6.950.

[7] **Cummings, I.G.** *et al.* Red to far-red ratio correction in plant growth chambers. *Acta Horticulturae – 2011.* vol. 907, no. July, pp. 145–150. doi: 10.17660/actahortic.2011.907.19.

[8] **Yang, L.** *et al.* A new resistance gene against potato late blight originating from solanum pinnatisectum located on potato chromosome 7. *Frontiers. Plant Science – 2017.* vol. 8, no. October, pp. 1–10. doi: 10.3389/fpls.2017.01729.

[9] **Hatfield, J.L.** and J.H. Prueger. Temperature extremes: Effect on plant growth and development. *Weather and Climate Extremes – 2015.* vol. 10, no. October, pp. 4–10. doi: 10.1016/j.wace.2015.08.001.

[10] **Watson, A.** *et al.* Speed breeding is a powerful tool to accelerate crop research and breeding. *Nature plants 2018*. vol. 4, no. 1, pp. 23–29. doi: 10.1038/s41477-017-0083-8.

[11] **Jähne, F.,** Hahn V., Würschum T., and Leiser W.L. Speed breeding short-day crops by LED-controlled light schemes. *Theoretical and Applied Genetics – 2020.* vol. 133, no. 8, pp. 2335–2342. doi: 10.1007/s00122-020-03601-4.

[12] **Choi, H.** *et al.* Development of a speed breeding protocol with flowering gene investigation in pepper (Capsicum annuum). *Frontiers. Plant Science – 2023.* vol. 14, no. September, pp. 1–13. doi: 10.3389/fpls.2023.1151765.

[13] **Ghosh, S.** *et al.* Speed breeding in growth chambers and glasshouses for crop breeding and model plant research. *Nature. Protocols – 2018.* vol. 13, no. 12, pp. 2944–2963. doi: 10.1038/s41596-018-0072-z.

[14] **Harrison, D.** *et al.* Effect of light wavelength on soybean growth and development in a context of speed breeding. *Crop Science – 2021.* vol. 61, no. 2, pp. 917–928. doi: 10.1002/csc2.20327.

[15] **Hedden, P.** *et al.* The genes of the Green Revolution. *Trends Genet 2003.* vol. 19, no. 1, pp. 5–9. doi: 10.1016/S0168-9525(02)00009-4.

ЖАБЫҚ SPEED BREEDING ЖАҒДАЙЫНДА ЖАРЫҚ ҚАШЫҚТЫҒЫНЫҢ БИДАЙ ӨНІМДІЛІГІНЕ ӘСЕРІ

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Аңдатпа. Қазақстанда аграрлық сектор климаттың өзгеруі, зиянкестердің көбеюі, астық өнімділігінің төмендеуі және жер пайдалану саласындағы шектеулі шаралар сияқты күрделі мәселелерге тап болуда. Осындай жағдайда жеделдетілген селекция (Speed Breeding) платформасын құру және оның протоколын әзірлеу – уақыт талабына сай және стратегиялық маңызды қадам болып табылады. Қазақстандық бидай аймақтық әрі жаһандық азық-түлік қауіпсіздігін қамтамасыз етуде маңызды рөл атқарғанымен, экономикалық және саяси шектеулер салдарынан егіс алқаптарының қысқаруы мен тиімсіздіктің әсерінен бұл сала үлкен қауіп алдында тұр.

Құрғақшылыққа төзімді, ауруларға шыдамды әрі жоғары өнім беретін бидай сорттарын жылдам шығару– осы өзекті мәселелерді шешудің тиімді жолдарының бірі болып табылады. Жаңа сорттарды шығару барысында селекциялық циклдің ұзақтығы – үлкен шектеу болып қала береді. Speed Breeding әдісі бақыланатын ортада өсімдіктердің өсуі мен дамуын бақыланатын ортада тиімді жағдай жасау арқылы жеделдетуге мүмкіндік береді.

Осы зерттеудің мақсаты – жабық Speed Breeding жағдайында жаздық бидай сорттарын өсіру үшін ең тиімді жарық спектрін анықтауға мүмкіндік беретін протокол әзірлеу болды. Зерттеу нәтижесінде жарық пен өсімдік арасындағы 1,5 метр қашықтықтың өнімді сабақтар саны мен масақтағы дәндер санының артуына оң әсер ететіндігі анықталды.

Тірек сөздер: speed breeding, бидай, жарықтандыру, жарық режимі, өнімділік компоненттері.

ВЛИЯНИЕ РАЗЛИЧНОГО РАССТОЯНИЯ ОСВЕЩЕНИЯ НА КОМПОНЕНТЫ УРОЖАЙНОСТИ ПШЕНИЦЫ В УСЛОВИЯХ ЗАКРЫТОГО SPEED BREEDING

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Аннотация. В Казахстане аграрный сектор сталкивается с серьезными проблемами, такими как изменение климата, вспышки вредителей, снижение урожайности зерна и ограничительные меры в сфере землепользования. Создание платформы ускоренной селекции (speed breeding) и разработка соответствующего протокола представляют собой своевременный и стратегически важный шаг. Несмотря на ключевую роль казахстанской пшеницы в обеспечении региональной и глобальной продовольственной безопасности, отрасль находится под угрозой из-за неэффективности и сокращения посевных площадей вследствие экономических и политических ограничений.

Ускоренная селекция сортов пшеницы с повышенной засухоустойчивостью, устойчивостью к болезням и улучшенным урожайным потенциалом может стать эффективным решением этих актуальных проблем. При выведении новых сортов продолжительность селекционного цикла остаётся серьёзным ограничением. Метод «Speed Breeding» предлагает решение этой задачи за счёт ускорения цикла и развития растений путём регулирования условий выращивания в контролируемой среде.

Целью данного исследования было разработать протокол, позволяющий определить наиболее эффективный спектр освещения для выращивания пшеницы в условиях закрытого Speed Breeding. Установлено, что расстояние между источником света и растений — 1,5 метра является подходящим для выращивания пшеницы и оказывает значительное положительное влияние на количество эффективных продуктивных побегов (ETN) и число зерен на растении (SN).

Ключевые слова: speed breeding, пшеница, светодиодное освещение, режим освещения, компоненты урожайности.