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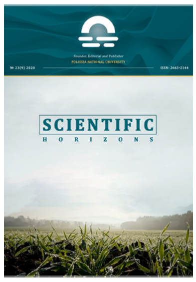

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Ecological plasticity and sustainability of cotton in the Southern Steppe of Ukraine

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Abstract. Depending on the length of the cotton growing season, the area of cultivation and its highest productivity potential are determined, and the prompt ripening of raw cotton allows for home-grown harvesting and high-quality soil preparation. The purpose of this study was to identify samples adapted to the conditions of the Southern

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Steppe of Ukraine from the cotton gene pool. The study used methods of plant variety expertise: phenological observations, morphological studies, and evaluation of breeding material for valuable traits. Based on the study results, parental components were selected to expand the process of forming early-ripening forms and productivity of raw cotton. The ability of cotton plants to grow in extreme conditions of the Southern Steppe of Ukraine was assessed and its homogeneity or stability, the index of growing conditions, the coefficient of variation – the difference in the numerical values of the trait duration of the period "germination – beginning of flowering" of plants in varieties with different growing season and their fluctuations around the average value were determined. It was found that according to the determined plasticity (b_i), the variance of stability (S_i^2), and the coefficient of variation of the duration of "germination – the beginning of flowering" higher tolerance to environmental factors was characterised by ultra-early ripening varieties. The average regression coefficient (b_i) was -0.36; the variation in the duration of the period by year was 10.1%, which is significantly lower compared to early-ripening varieties – -0.77% and 12.9%, mid-ripening varieties – -0.80% and 15.0%, and late-ripening varieties – -1.30% and 16.6%, respectively. The maximum average productivity to frosty raw cotton of 49.4 g/plant was formed by the sample Pidozerskyi 4 (UF0800003), the duration of the period "germination – beginning of flowering" was 47 days, and "germination – full ripening" – <103 days. The lowest raw cotton productivity of 21.2 g/plant was demonstrated by the late-ripening sample Joloten 32 (IU14056549) of Turkmen selection, the duration of the growing season of which was 145 days on average over the years of research. The findings of this study will be used in further breeding to create high-yielding cotton varieties with increased environmental plasticity and stability and high-quality fibre

Keywords: cotton samples; duration of the growing season; ripeness groups; plasticity; stability; coefficient of variation; productivity

INTRODUCTION

The length of the growing season depends on a range of properties that affect the formation of the variety's yield, its adaptive response to adverse environmental factors, the manifestation of disease symptoms, pest damage, and product quality. In this regard, it is necessary to create crop varieties, and cotton specifically, such that the length of the growing season determines the area of introduction of the variety and contributes to its maximum productivity.

The findings of long-term research by V. Borovyk *et al*. (2022) of the Institute of Climate-Smart Agriculture of the National Academy of Agrarian Sciences of Ukraine report that only early-ripening forms of cotton ripen under low temperature conditions. Thus, the extremely cold year of 1993, with a sum of effective temperatures above 10°C of 1397°C, had a positive impact on the differential strict culling of the collection material. In fact, only 30% of Bulgarian cotton varieties have been recorded as ripening before frost. They believe that the lack of heat in cotton cultivation in the Southern Steppe of Ukraine is one of the factors that affects the maturation of long-growing cotton. A. Hamid *et al*. (2020) and S. Majeed *et al*. (2021) suggest growing early-ripening varieties in such areas as well as in mountainous terrain.

The early ripeness of a variety, i.e., its ability to produce the bulk of the crop in a short time, is considered to be a valuable feature that determines the quantity and quality of the raw cotton harvest. O. Skripka *et al*. (2021) found that the onset of growth and development phases and their duration is determined by the biological characteristics of the variety and the agroclimatic conditions of the growing area. However, I. Njouenwet *et al*. (2021) note that high rainfall prolongs the duration of cotton developmental stages and shortens them under dry conditions.

J.L. Snider *et al*. (2022) proved that low temperature during the late growth period not only affects the time of ripening, but also leads to a decrease in yield. M. Yaşar (2023) points out that the length of the cotton growing season is an economic trait. According to M. Yan *et al*. (2021), it determines the degree to which plants adequately perceive changes in environmental conditions and depends on both it and genetic characteristics. One of the principal tasks of cotton breeding in the Southern Steppe of Ukraine is to increase the resistance of varieties to extreme environmental conditions, the level of genotype response to changing factors of growing conditions, and the selection of the best combinations of source material. M. Mubarik *et al*. (2020) argue that the attention of scientists is constantly drawn to the genotype-environment interaction, which is determined by plasticity and stability.

Ecological plasticity is the degree to which a trait responds to changes in environmental conditions, which is manifested in phenotypic variability; and ecological stability is the ability to form high productivity even under the influence of abiotic and biotic stresses, when environmental conditions change from optimal. According to S.I. Zandalinas *et al*. (2018), the "variety" factor is considered as a constant value, while abiotic factors can be weather conditions in the years of research, fertiliser doses, and sowing dates.

According to the findings of N. Leshchuk *et al*. (2021), the magnitude of the response of genotypes to changes in abiotic factors is determined by the coefficient of ecological plasticity (b_i), which indicates the deviation of individual sample parameters in relation to the average long-term indicators. The b_i value is proportional to the sensitivity of the variety to changes in environmental conditions. More often than not, the b_i coefficient is positive, and sometimes it is negative. Y. Huang *et al*. (2023) argue that when the regression coefficient b_i is zero or close to it, it indicates that the variety is weakly or not responsive to abiotic environmental factors. P. Arnold *et al*. (2019) report that the plasticity trait is an independent value and is controlled by specific genes. Stability variance – S_i^2 demonstrates how exactly the tested variety fits the plasticity determined by the regression coefficient b_i. Zero and close to zero values of S_i^2 show that there is the smallest difference between the empirical value of the characteristic and the theoretical one.

The simultaneous action of the traits "plasticity" and "stability" of the samples helps the genetic mechanism of plants to maximise the effects of the negative impact of abiotic factors, i.e., to show resistance to them. Thus, the purpose of this study was to identify samples from the cotton collection that are resistant to abiotic factors for further use in breeding.

MATERIALS AND METHODS

The study was conducted at the Institute of Climate-Smart Agriculture of the National Academy of Agrarian Sciences (NAAS) of Ukraine in 2012-2016. The subject of the study was 282 samples of cotton from the collection nursery of different ripeness groups. The agrotechnical conditions of the experiments were generally accepted for the Southern Steppe of Ukraine and were conducted on dark chestnut medium loamy slightly saline soils. Its predecessor is winter wheat. 100 kg/ha of ammonium nitrate was applied for pre-sowing cultivation. Sowing was carried out in the first decade of May, when the soil temperature at a depth of 5 cm reached 18-20°C. The plots of the collection nursery are single-row, 3 m long, with a distance of 15 cm in a row between plants. A standard was placed every 9 samples, which was the zoned cotton variety Dniprovskyi 5 of the Institute of Climate-Smart Agriculture of the NAAS of Ukraine. During the growing season, the crop was irrigated twice at a rate of 400 m^3 of water per hectare.

The trait assessment was carried out according to the methodology of Volkodav (2001). The morphological description and classification according to economic properties were made according to the "Broad Unified Classifier – Handbook of the genus *Gossypium hirsutum* L." (Vozhehova *et al.*, 2015). The coefficient of variation V (%), an indicator of the standard deviation of features, which is given as a percentage of the mean value, was calculated using the following formula:

$$V = b/m \times 100, \quad (1)$$

where V is the coefficient of variation, %; b is the standard (square) deviation; m is the arithmetic mean. If V<10%, the variation is considered weak, if V=11-25%, it is considered medium, and if V>25%, it is considered significant.

The weather conditions during the years of the study were typical for the Southern Steppe zone of Ukraine, and therefore an objective assessment of the cotton gene pool was carried out, and valuable samples were identified for their economic characteristics. The year 2012 was the warmest on record, driven by high average monthly temperatures in May (20.8°C), June (23.4°C), and July (23.6°C). Overall, the summer of 2012 was hot, with a shortage of rainfall and soil and air drought throughout the season.

The summer of 2015 was moderately hot, and the summer of 2016 was dry due to lower average monthly air temperatures than in 2012, by 3.8-4.6°C in May and by 3.2-2.2°C in July, respectively. Among the years under study, 2013 saw an extended growing season for cotton plants due to precipitation in June, which amounted to 79.1 mm and 64.4 mm, respectively.

According to the length of the growing season from germination to full ripeness, according to the 9-point scale of the Broad Unified Classifier-Guide to the genus *Gossypium hirsutum* (L.) distinguishes cotton plants: ultra-early ripening, or with a very short vegetation period <110 days (1 point), 111-115 (2 points), early-ripening – short vegetation period 116-120 (3 points), 125-130 (4 points), mid-ripening – medium 131-135 (5 points), 136-140 (6 points), late-ripening – long 140-145 (7 points), 146-150 (8 points), and very late-ripening – very long vegetation period >150 days (9 points). According to the germination–flowering period, cotton plants are divided into 5 groups: very short – <50 days (1 point), short – 50-55 days (2 points), medium – 55-60 days (3 points), long – 65-70 days (4 points), very long – >70 days (5 points) (Vozhehova *et al.*, 2015).

Experimental studies of plants (both cultivated and wild), including the collection of plant material, were following the institutional, national, or international guidelines. The authors adhered to the standards of the Convention on Biological Diversity (1992) and the Convention on Trade in Endangered Species of Wild Fauna and Flora (1979).

RESULTS AND DISCUSSION

The analysis of 282 collection samples by the duration of the cotton plant vegetation period showed that 29.0% of them were characterised by a very short ripening period, 25.1% – by a short one, 27.9% – by a medium one, and 18.0% – by a long one (Table 1).

***Table 1.** Distribution of cotton gene pool samples according to the duration of the growing season, days (2012-2016)*

Sign and level of its expression	Total weight		Sample name
	pieces	%	
Very short (ultra-early ripening) <110-115 days	81.8	29.0	Dniprovskyi 5 (UF0800009), Pidozerskyi 4 (UF080003), L 417u (UF080002), 500u (UF080000), 510u (UF0800226), Population 1 (UF0800193), Population 2 (UF0800020), Population 3 (UF080002), Population 3 opr. (UF080018), 170/2 (UF0800039), 2342u (UF0800032), Od 4 (UF0800119), K58 (UF0800114, K67 (UF0800036), K103 (UF0800118), K11 (UF0800107, 1718u (UF0800239) (UKR); 144F (UF0800105), 1135/94 (UF0800204), (UZB); 534 (UF0800535) (RUS); 4521Trakia (UF080006), Interspecific hybrid W64 (UF0800165), Avangard 264 (UF0800020), 32-73 (UF0800262) (BGR), etc.
Short (early-ripening) 116-125 days	70.8	25.1	L 191/13 (UF080028), 501 (UF0800221), 2307u (UF0800227), Population 5 (UF0800035), Line 452u opr. (UF0800190) (UKR); 1135/94 (UF0800204) (UKR); Sizhi 2 (UF0800098), 175F (UF0800063), Andijan 5 (UF0800071), Liniya 446 (UF0800086) (UZB); Beli Izvor 432 (UF0800015), Chirpan 603 (UF080001), Chirpan 539 (UF0800018), Helius (UF0800277), Ogosta 644 (UF0800017), Ogosta 644 opr. (UF0800181), Balkan 442 (UF0800178), Garant opr. (UF0800180) (BGR); Zeta 2 (UF0800057) (GRC); Maria (UF0800056), Makedonka 21 (055UF0800), Siocra 1-4-C (UF0800046), 115P (UF0800052), Plovdiv 15-81 (UF0800234) (YUG), Zun-Zhong (UF0800003) (CHN), etc.
Medium (mid-ripening) 126-135 days	78.7	27.9	An-Chillyaki (UF0800012), Andijan 4 (UF0800070), C4727 (UF0800067), C7085 (UF0800127), Namangan 77 (UF0800 064), (UZB); A-2 (UF0800054) (YUG); 611B (UF0800033) (RUS); Acra 60 (UF08001490), Acala 90 (UF0800159), Tomcot (UF0800157), Tomcot 1074 (UF0800160), Tomcot 2073 (UF0800158), Tomcot CAMDE (UF0800159), Deltapine ch5 (UF0800167), Delfos 53 (UF0800172), Cocer 100 (UF0800230) (USA); T 073 (UF0800125) (ROU); Varamin (UF0800053) (IRN); Simbabves (UF0800146) (ZWE), etc.
Long (late-ripening) 136-145 days	50.7	18.0	Kyrgyz 6-84 (UF0800082) (KGZ); Tabladilla 16 (UF080014), T 100 (UF080001) (ESP); Nazili 84 (UF0800058) (TUR); Cotton (UF0800279), Joloten 32 (IU14056549) (TKM); Argentina 1 (UF0800147), Argentina 2 (UF0800009), Argentina 3 (UF0800148), Fizinerdo (UF0800007) (ARG); S9 (UF0800024) (SYR), etc.
Total:	282	100	

***Source**: compiled by the authors of this study*

When studying the trait "duration of the growing season" of cotton gene pool samples, not only "germination-full ripeness", but also "germination-beginning of flowering" were considered – the phase of active growth and development of the plant, formation of fruiting organs, since, according to U. Khan (2003), it is in this phase that the value of the future yield is determined. The shortest germination – flowering period, which lasted from 47 to 50 days, was observed in ultra-early ripening samples in 2012, and slightly longer – in 2015 (49-52 days) and 2016 (48-51 days). A longer growing season was observed in 2013 (48-52 days) and 2014 (49-53 days). Based on the results of the observations, the environmental plasticity and stability, the index of growing conditions, and the coefficient of variation of the traits of the collection samples by the duration of the period "germination-flowering" of plants in varieties with different growing seasons: ultra-early ripening, early-ripening, mid-ripening, and late-ripening (Table 2).

***Table 2.** The influence of biotic factors of the year on samples of the cotton gene pool in terms of ecological plasticity (b_i), stability (S_i^2), the index of growing conditions (I_j), and the coefficient of variation (V)*

Sample name	Duration of the period "germination – beginning of flowering", days					$\overline{X}$	V, %	Indicators	
	2012	2013	2014	2015	2016			b_i*	S_i^2
Ultra early-ripening – <110-115 days									
Pidozerskyi 4 (UF080003) (UKR)	46	47	48	48	47	47	5.4	-0.07	1.94
Interspecific hybrid W64 (UF0800165)	49	51	52	49	50	50	9.1	-0.35	5.12
L 417u (UF080002) UKR	46	49	49	48	47	48	10.5	-0.31	5.20
4521Trakia (UF080006) BGR	48	51	50	51	48	50	10.2	-0.38	4.99
1135/94 (UF0800204) UZB	48	51	51	49	49	50	15.4	-0.65	8.75
$\overline{X}$	47	50	50	49	48	49	10.1	-0.36	5.20

Table 2. Continued

Sample name	Duration of the period "germination – beginning of flowering", days					X	V, %	Indicators	
	2012	2013	2014	2015	2016			b_i*	S_i^2
I_j							–	–	–
Early-ripening – 116-125 days									
Beli Izvor 432 (UF0800015) (BGR)	51	56	55	54	54	54	9.1	-0.43	4.54
Ogosta 644 opr. (UF0800181) (BGR)	51	55	57	55	52	54	10.3	-0.51	0.49
501 (UF0800221) (UKR)	53	53	55	53	53	53	13.7	-0.64	2.13
Makedonka 21 (055UF0800) (YUG)	50	55	58	54	51	54	16.9	-1.09	1.12
175F (UF0800063) (UZB)	52	58	58	55	55	56	14.7	-1.16	1.02
$\overline{X}$	52	56	57	55	53	54	12.9	-0.77	1.86
Mid-ripening – 126-135 days									
C7085 (UF0800127) (UZB)	55	55	58	56	55	56	11.3	-0.52	4.50
T 073 (UF0800125) (ROU)	56	63	62	62	59	60	18.9	-1.17	1.81
An-Chillaki (UF0800012) (UZB)	57	56	63	59	57	58	14.7	-0.70	2.05
$\overline{X}$	56	60	61	59	57	59	15.0	-0.80	2.79
I_j							–	–	–
Late-ripening – 136-145 days									
Tabladilla 16 (UF080014) (ESP)	66	69	71	68	66	68	12.9	-0.68	5.75
Cotton (UF0800279) (TKM)	67	70	71	69	67	69	18.5	-1.59	3.62
Joloten 32 (IU14056549) (TKM)	70	73	76	72	72	73	16.2	-1.28	4.30
Nazili 84 (UF0800058) (TUR)	69	72	73	71	71	72	18.7	-1.53	5.72
$\overline{X}$	68	71	73	70	69	70	16.6	-1.30	4.85
I_j							–	–	–
LSD 05	6.4								

Note:* *b_i is the coefficient of regression (plasticity); S_i^2 is the stability variance; I_j is the index of environmental conditions; $\bar{x}$ is the average duration of the period; V is the coefficient of variation*
Source: *calculated by the authors of this study*

The results of the study presented in Table 2 show that according to the obtained data of plasticity (b_i), variances of stability (S_i^2) and coefficient of variation, cotton plants of the ultra-early ripening group in the phase "germination – the beginning of flowering" were less sensitive to abiotic factors. The average regression coefficient (b_i) was -0.36; the variation in the length of the growing season by year was 10.1%, which is significantly less compared to early-ripening varieties – -0.77% and 12.9%, mid-ripening varieties – -0.80% and 15.0%, and late-ripening varieties – -1.30% and 16.6%, respectively.

Among the varieties of the ultra-precocious group, the sample Pidozerskyi 4 (UF080003) (UKR) was more adapted to growing conditions (b_i=-0.07; S_i^2=1.94; V=5.4%), among the early-ripening – Beli Izvor (UF0800015) (BLG) (b_i=-0.43; S_i^2=4.54; V=9.1%), among the mid-ripening – C7085 (UF0800127) (UZB) (b_i=-0.52; S_i^2=4.50; V=11.3%), late-ripening – Tabladilla 16 (UF080014) (ESP) (b_i=-0.68; S_i^2=5.75; V=12.9%). Sample of 1135/94 (UF0800204) (UZB) (b_i=-0.65; S_i^2=8.75; V=15.4%) was the most sensitive to growing conditions among the ultra-early ripening varieties, the early-ripening – Makedonka 21 (055UF0800) (YUG)) (b_i=-1.09; S_i^2=1.12; V=16.9%); mid-ripening – T 073 (UF0800125) (ROU) (b_i=-1.17; S_i^2=1.81; V=18.9%), and late-ripening – Cotton (UF0800279) (TKM) (b_i=-1.59; S_i^2=3.62; V=18.5%).

The maximum average productivity to frosty raw cotton of 49.4 g/plant was formed by Pidozerskyi 4 (UF0800003) (UKR), whose duration of the period "germination-beginning of flowering" was 47 days, and "germination-full ripening" – <103 days. The lowest raw cotton productivity of 21.2 g/plant was demonstrated by the sample of the late-ripening group Joloten 32 (IU14056549) (TKM), the duration of the growing season of which was 145 days on average over the years of research. Particular attention was paid to samples of ultra-early and early-ripening groups, as the main obstacle to the introduction of cotton in the Southern Steppe of Ukraine is the limit of temperature conditions, as mentioned earlier.

Among the ultra-early ripening group, there were some varieties with shorter or equal vegetation periods than the standard variety Dniprovskyi 5, which contributed to the formation of high productivity, these are Pidozerskyi 4 (UF080003) (UKR), 144 F (UF0800062) (UZB), L 417u (UF080002), 500u (UF080000), 510u (UF0800226), Population 1 (UF0800193), Population 2 (UF0800020), Population 3 opr. (UF080018), Population 9 (UF0800241), 3737u (UF0800228) (UKR); 4521Trakia (UF080006), Interspecific hybrid W64 (UF0800165), Avangard 264 (UF0800020) (BGR), etc., that were used in hybridisation as the mother form in most cases in both direct and back crosses (Table 3).

Table 3. *Duration of the growing season of parental forms involved in hybridisation for early ripening and productivity (2012-2016)*

Sample name, No. in the National Catalogue	Country of origin	Duration of the growing season, days		Productivity	
		days	V, %	g/plant	V, %
Ultra-early ripeness group (<110-115 days)					
Dniprovskyi 5 (UF0800009) St	UKR	107	8.2	42.6	26.9
Pidozerskyi 4 (UF0800003)	UKR	103	5.7	49.4	22.8
144 F (UF0800062)	UZB	102	5.2	39.6	24.8
L 417u (UF080002)	UKR	104	6.9	46.8	26.0
500u (UF080000),	UKR	104	6.9	46.9	20.1
510u (UF0800226)	UKR	105	5.4	47.1	26.2
Population 1 (UF0800193)	UKR	105	5.1	46.2	26.8
Population 2 (UF0800020)	UKR	103	6.9	46.9	22.3
Population 3 opr. (UF080018)	UKR	104	4.4	45.1	20.1
Population 9 (UF0800241)	UKR	105	3.0	38.9	22.4
3737u (UF0800228)	UKR	105	2.5	39.8	18.8
4521Trakia (UF080006)	BGR	103	4.5	39.5	30.5
Interspecific hybrid W64 (UF0800165)	BGR	103	6.9	41.1	37.5
Avangard 264 (UF0800020)	BGR	104	6.8	38.9	36.7
OD 4 (UF0800119)	UKR	114	4.5	39.7	22.4
K58 (UF0800114)	UKR	115	3.5	39.9	35.2
K67 (UF0800036)	UKR	114	4.6	39.1	36.4
K103 (UF0800118)	UKR	113	5.1	39.8	31.0
K11 (UF0800107)	UKR	115	5.8	38.9	24.5
Early-ripening group (116-125 days)					
1135/94 (UF0800204)	UZB	116	5.3	37.9	23.8
Line 452u opr. (UF0800190)	UKR	116	3.1	39.2	37.1
501u (UF0800221)	UKR	117	2.2	47.1	39.9
Beli XXXIzvor 432 (UF0800015)	BGR	117	4.2	36.8	30.6
Chirpan 603 (UF080001)	BGR	116	3.6	37.1	42.4
Chirpan 539 (UF0800018)	BGR	116	3.4	36.7	32.4
Population 5 (UF0800035)	UKR	116	4.5	36.8	35.6
L 191/13 (UF0800283)	UKR	116	5.1	37.5	23.1
Maria (UF0800056)	YUG	118	4.6	41.1	31.1
Garant opr. (UF0800180)	BGR	118	4.7	35.9	33.6
Ogosta 644 (UF0800017)	BGR	117	3.7	35.8	32.1
Balkan 442 opr. (UF0800178)	BGR	116	3.5	36.7	37.8
Helius (UF08000277)	BGR	117	5.4	37.4	39.1

Table 3. Continued

Sample name, No. in the National Catalogue	Country of origin	Duration of the growing season, days		Productivity	
		days	V, %	g/plant	V, %
Zong Zhong (UF0800003)	CAN	123	6.1	35.8	32.8
2307u (UF0800227)	YUG	125	2.6	36.2	26.6
Line 446 (UF0800086)	UZB	125	3.6	37.8	31.0
175F (UF0800063)	UZB	125	5.1	36.1	27.5
Population 3 (UF080002)	UKR	125	4.3	47.8	33.8
Siocra 1-4-C (UF0800046)	AUS	125	4.6	35.4	32.1
Plovdiv 15-81 (UF0800234)	BGR	125	3.7	35.7	31.0
Zong Zhong (UF0800003)	CHN	125	4.8	25.6	31.7
Makedonka 21 (055UF0800)	YUG	125	5.7	43.1	38.3
Mid-ripening group (125-135 days)					
Acala 90 (UF0800159)	USA	128	5.4	30.7	31.5
Tomcot 1074 (UF0800160)	USA	135	6.2	29.2	36.8
Cocer 100 (UF0800230)	USA	132	9.1	31.1	22.1
611b (UF0800033)	RUS	132	3.5	31.8	35.0
An-Chillaki (UF0800012)	UZB	131	3.8	31.5	12.0
A-2 (UF0800054)	YUG	134	6.3	25.5	22.2
Andijan 4 (UF0800070)	UZB	134	5.2	25.2	22.1
Delfos 53 (UF0800172)	USA	137	6.2	26.0	21.8
Simbabves (UF0800146)	ZWE	135	5.9	25.1	22.8
T100 (UF0800014)	ESP	132	6.2	25.2	40.1
Late-ripening group (136-145 days)					
Nazili 84 (UF0800058)	TUR	144	4.3	25.0	22.5
Cotton (UF0800279)	TKM	145	4.5	24.1	36.7
Joloten 32 (IU14056549)	TKM	145	4.8	21.2	22.1
Argentina 1 (UF0800147)	ARG	142	10.1	24.8	21.0
Fizinerdo (UF0800007)	ARG	144	5.2	24.8	12.1
Kyrgyz 6-84 (UF0800082)	KGZ	141	4.8	24.7	32.1
LSD_{05}		0.25		1.8	

***Source**: compiled by the authors of this study*

Samples of the collection with a vegetation period of more than 131 days, which were distinguished by lower plant productivity, but had a large boll, high-quality fibre, and were characterised by a lower coefficient of variation over the years than early-ripening varieties, were used as parents, including Tomcot 1074 (UF0800160), Acala 90 (UF0800159), Cocer 100 (UF0800230) (USA), 611b (UF0800033) (UKR), An-Chillaki (UF0800012) (UZB), A-2 (UF0800054) (YUG), Andijan 4 (UF0800070), Delfos 53 (UF0800172), Simbabves (UF0800146), T100 (UF0800014), Nazili 84 (UF0800058) (TUR), Cotton (UF0800279), Joloten 32 (IU14056549) (TKM), Argentina 1 (UF0800147), Fizinerdo (UF0800007) (ARG), Kyrgyz 6-84 (UF0800082) KGZ, etc. Thus, when creating new cotton varieties, samples with the traits "ultra-early ripeness" and "early ripeness" with high productivity were used as the mother form, and samples of mid- and late-ripening groups, but with a large boll and high-quality fibre, were used as the father form.

Among the local breeding samples, Dniprovskyi 5 and Pidozerskyi 4 are noteworthy – these are varieties developed at the Institute of Climate-Smart Agriculture of the NAAS of Ukraine for the Southern Steppe of Ukraine. They are characterised by a short ripening period and high yield potential of up to 3.2 t/ha. Their short ripening period allows them to be used even as a precursor for sowing winter crops. These two varieties are listed in the Catalogue of Crop Varieties and Hybrids of the Institute of Irrigated Agriculture (now the Institute of Climate-Smart Agriculture) (2019).

The average duration of the period "germination-full ripeness" of the samples of the early ripeness group was 9-8 days longer than that of the ultra-early ripeness group, but the variation during the study was much smaller and the coefficient of variation was 2.2-6.1% versus 2.5-8.2%. As for the years of the study, in 2013 and 2014, the longest "germination-flowering" period was observed in plants, regardless of the ripeness group, including 47-50 days in ultra-early ripening samples, 56-57 days – in early-ripening samples, 60-61 days – in mid-ripening and 71-73 days in late-ripening samples, respectively. The "germination-flowering" period was the shortest in all samples of the cotton gene pool in 2012 – 47, 52, 56, and 68 days, respectively, in the ripeness groups.

Summarising the results of determining the duration of vegetation periods over the years of research (2012-2016), it can be noted that the "germination-beginning of flowering" period of samples of the late-ripening group was 21 days longer than that of the ultra-early ripening group. In addition, samples of this ripeness group were characterised by a higher coefficient of variation over the years – 16.6% versus 10.1%. The "germination-full ripeness" phase in late-ripening samples occurred 38 days later than in ultra-early ripening samples.

To create new varieties, ultra-early ripening samples from Bulgaria were used for crossing – 4521Trakia (UF080006), Interspecific hybrid W64 (UF0800165), Avangard 264 (UF0800020), which were 3-4 days ahead of Dniprovskyi 5 in terms of the total growing season with a lower coefficient of variation – V=4.5-6.9%, compared to 8.2% for Dniprovskyi 5 (UF0800009). In terms of productivity, they had the same value as the standard, but differed by a higher coefficient of variation over the years – from 30.5% to 37.5%, which is almost one and a half times lower than the adaptability of the standard variety.

Among the early-ripening group of gene pool samples, the best was the promising line 501u (UF0800221) of Ukrainian selection, which flowered, on average over the years of research, in 53 days with a coefficient of variation of 13.7%, which is 6 days later than the average performance of ultra-early ripening samples. The total vegetation period of the sample was 10 days longer, but it stood out for the highest productivity (47.1 g/plant), compared to the standard Dniprovskyi 5 (UF0800009) – 42.6 g/plant. Therefore, this sample was actively used in backcrosses.

Table 3 shows samples of the gene pool used in crosses to develop more productive ultra-early and early ripening varieties. As a result of the hybridisation, more than 24 promising cotton lines were created, characterised by a short ripening period and high yields of home-grown medium-fibre raw cotton – 2.4-3.2 t/ha – and meeting the quality indicators of type V fibre. The cotton gene pool is a valuable source for developing varieties adapted to the extreme conditions of the Southern Steppe of Ukraine. Climate change towards warming is helping it to take a leading position in the risky farming zone among conventional crops.

For the introduction of cotton in the Southern Steppe of Ukraine, early-ripening varieties are needed. Cotton production in this zone is closely linked to meteorological conditions. Manufacturers in other countries face similar problems. C. Li *et al.* (2021) argue that weather conditions are region-specific, and with regard to climate change over the past 50 years and frequent extreme events, they advise that, after assessing their impact on cotton production in different locations, regionally adaptive varieties should be used.

R. Baumhardt *et al.* (2018) emphasise that air temperature is a crucial factor affecting the development of cotton. They have shown through research that low temperatures (<12°C) at an early stage lead to stunted growth and development, while hot temperatures (>35°C) at the mid-growth stage can negatively affect the fertilisation process and lead to bud drop. Low temperatures during the late growth period prolong the ripening period, which leads to a decrease in yield.

Cotton is a perennial indeterminate crop, and cultivated species are generally not sensitive to photoperiodicity. Therefore, S. Minoli *et al.* (2019) and Y. Jans *et al.* (2021) argue that higher temperatures will increase the rate of plant development, but not necessarily shorten the length of the growing season, if temperature seasonality is the limiting factor and sufficient water and nutrients are available. Although the plant is widely adapted to a variety of environments, the growth and demand for water for cotton irrigation may be challenged by future climate change.

The data obtained from the study showed that in the Southern Steppe of Ukraine, hot temperature conditions not only accelerate plant development, but also affect the reduction of plant maturation. Characteristic of this zone is that early ripening forms of the collection material generate higher productivity than plants with a long growing season. This is caused by a higher number of open prefrost bolls. Samples of the late-ripening ripeness group form a high total yield of cheese, i.e., home-grown and post-frost, but they are inferior to early-ripening forms in terms of home-grown cheese yield.

Other conclusions based on the study results were made by C.İ. Cevheri (2021), who states that higher yields were obtained by introducing varieties with a long growing season. Ensuring crop ripeness is essential for yield maximisation, quality, and economic return. According to L.-M. Chevin and A.A. Hoffmann (2017), plasticity may be non-adaptive to extreme conditions if there are no strong genetic correlations between extreme and non-extreme environmental conditions and the optimal phenotype changes smoothly under its influence. When phenotypic plasticity is adaptive, it can withstand the harmful effects of extreme conditions.

Organismal plasticity can be considered as the response of cotton to environmental conditions or to biological and developmental traits. It helps plants maintain homeostasis in response to changing climatic conditions. According to F.A. Dar *et al.* (2022), the action of biotic factors that cause plastic reactions can to some extent affect the development and timing of the formation of reproductive organs. In the Southern Steppe zone of Ukraine, where the sum of positive temperatures above 10°C can drop to 1397°C, with a norm of 1492°C, it is necessary to introduce cotton varieties characterised by functional plasticity – the ability of the organism to move functions from one tissue to another as a result of paralogous genes. Y. Huang *et al*. (2023) share a similar opinion. Studies have shown that the samples of the collection of ultra-early ripeness group have greater plasticity and stability compared to early-, mid-, and late-ripening varieties. The same samples were more productive.

However, analysing the findings of this study, it can be stated that the authors do not have a consensus on the influence of environmental factors on the formation of the duration of the cotton growing season for a particular region, and therefore the research conducted on Ukrainian modern varieties in the agroclimatic zone of the South of Ukraine is relevant and deserves further investigation to create new adaptive, plastic varieties that will be characterised by resistance to environmental changes.

CONCLUSIONS

As a result of the study, the ecological plasticity, stability, index of growing conditions, coefficient of variation of samples from the cotton collection on the basis of the duration of the period "germination-beginning of flowering" of plants in varieties with different growing seasons were determined. To increase the genetic potential of the variety trait, samples were selected that were characterised by high values of b_i and low S_i^2, which will contribute to the creation of new source material for varieties with increased ecological plasticity and stability.

It was found that according to plasticity indicators (b_i), stability variance (S_i^2) and the coefficient of variation of the duration of the "germination-beginning of flowering" period, ultra-early ripening varieties were less sensitive to growing conditions. Pidozerskyi 4 (UF080003) (UKR) was characterised by greater plasticity to growing conditions among the studied samples of the ultra-early ripeness group, Beli Izvor (UF0800015) (BLG) among the early-ripening group, C7085 (UF0800127) (UZB) among the mid-ripening group, and Tabladilla 16 (UF080014) (ESP) among the late-ripening group.

To extend the process of forming early ripening forms and productivity of raw cotton, parental components with shorter vegetation periods by years were selected from the cotton gene pool, than that of the standard variety Dniprovskyi 5 or on the same level, these include Pidozerskyi 4 (UF080003) (UKR), 144 F (UF0800062) (UZB), L 417u (UF080002), 500u (UF080000), 510u (UF0800226), Population 1 (UF0800193), Population 2 (UF0800020), Population 3 opr. (UF080018), Population 9 (UF0800241), 3737u (UF0800228) (UKR); 4521Trakia (UF080006), Interspecific hybrid W64 (UF0800165), Avangard 264 (UF0800020) (BGR), etc. The average duration of the "germination-full ripeness" vegetation period in the samples of the early ripeness group was 8-9 days longer than in the ultra-early ripeness group, but the coefficient of variation over the years was much lower – 2.2-6.1% versus 2.5-8.2%.

A promising area for further research is the enrichment of the genetic diversity of the cotton gene pool to create valuable source material with high productivity, increased environmental plasticity and stability.

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CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

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Екологічна пластичність та стійкість бавовнику в умовах Південного Степу України

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Анотація. Залежно від тривалості періоду вегетації бавовнику, визначається зона впровадження сорту та його найвищі показники потенціалу продуктивності, а своєчасне дозрівання бавовни-сирцю дозволяє провести збір доморозного врожаю, якісно підготувати ґрунт. Мета дослідження – виділити з генофонду бавовнику зразки адаптовані до умов Південного Степу України. При дослідженні використовувалися методики проведення експертизи сортів рослин: фенологічні спостереження, морфологічні дослідження, оцінку селекційного матеріалу за цінними ознаками. За результатами досліджень відібрані батьківські компоненти для розширення процесу формування скоростиглих форм і продуктивності бавовни-сирцю. Проведена оцінка здатності рослин бавовнику до вирощування в екстремальних умовах Південного Степу України та визначена його однорідність або стабільність, індекс умов вирощування, коефіцієнт варіації – різницю у числових значеннях ознаки тривалість періоду «сходи – початок цвітіння» рослин у сортах з різним періодом вегетації та їх коливання навколо середньої величини. Установлено, що за визначеною пластичністю (b_i), варіансою стабільності (S_i^2) та коефіцієнтом варіації тривалості «сходи – початок цвітіння» більшою толерантністю до факторів середовищ характеризувались ультра ранньостиглі сорти. Середній коефіцієнт регресії (b_i) складав – -0,36; варіювання тривалості періоду за роками – 10,1 %, що значно менше, у порівняні зі скоростиглими сортами – -0,77 і 12,9 %, середньостиглими – -0,80 і 15,0 % та пізньоьостиглими – -1,30 і 16,6 %, відповідно. Максимальну середню продуктивність до морозного бавовно-сирцю 49,4 г/рослину сформував зразок Підозерський 4 (UF0800003) тривалість періоду «сходи – початок цвітіння» якого складав 47 днів, а «сходи – повне достигання» – <103 дня. Найменшу продуктивність бавовни-сирцю 21,2 г/рослину продемонстрував зразок пізньостиглої групи стиглості Joloten 32 (IU14056549) туркменської селекції, тривалість періоду вегетації якого в середньому за роки досліджень дорівнювала 145 днів. Результати досліджень будуть використані у подальшій селекції при створенні високопродуктивних сортів бавовнику з підвищеною екологічною пластичністю і стабільністю та якісним волокном

Ключові слова: зразки бавовнику; тривалість періоду вегетації; групи стиглості; пластичність; стабільність; коефіцієнт варіації; продуктивність