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Inheritance of traits in F_1 hybrids of diploid einkorn wheat of the spring crop

Hao Fu, L.O. Atramentova

Diploid einkorn wheat (2n = 14) is an ancient crop that people cultivate for 10 thousand years. The grain of this wheat is a valuable product for a healthy diet, which determines the increasing interest in einkorn wheat by scientists and agricultural producers. Meanwhile, the wide use of this crop is hindered by several shortcomings that complicate the usage of modern technologies: low yield, ear fragility, a tendency to lodging, and difficult grain threshing. Nevertheless, there are some preconditions for improving the agronomic properties of this crop. We carried out crosses in seven combinations with the use of three wheat species (*T. boeoticum*, *T. monococcum*, *T. sinskajae*) to improve the diploid einkorn wheat in terms of productivity and threshing. In total, the hybrid seed set in the crosses varies from 6.3 % to 79.7 %. In the combination of cultivated wheat *T. sinskajae* with wild *T. boeoticum*, differences in the results of reciprocal crosses are observed specifically in the hybrid seed set (in the forward cross it equals 6.3 %; in the reverse one, 48.9 %). Hybrids from reciprocal crosses of *T. monococcum* var. *sofianum* UA0300649 and *T. sinskajae* f. *aristata* were equivalent in seed set (72 and 82 %) and inheritance patterns and had similar quantitative traits. In other combinations, the seed set varied from 12.5 to 45.6 %. Hybrid depression was the most frequent (22 cases out of 49) inheritance type of the F_1 quantitative traits in einkorns; dominance of the parent form with a large trait manifestation was registered in 11 cases, and heterosis in four cases. In hybrids, the inheritance of spike length is correlated with the inheritance type of the ear number (r = 0.92) and the grain number (r = 0.78) per spike. The dominance degrees after these two traits are also highly correlated (r = 0.89). The combination UA0300400 *T. boeoticum* var. *thaoudar* ARM / UA0300224 *T. sinskajae* var. *sinskajae* RUS, which manifested heterosis for kernel number per spike (*Hp* = 1.2), the weight of spike (*Hp* = 11.8) and weight of kernels per spike (*Hp* = 5.4) is of particular interest. The combination UA0300222 *T. monococcum* var. *hohensteinii* / UA0300224 *T. sinskajae* var. *sinskajae* is promising for creating easily threshed material.

Key words: *einkorn wheat, productivity elements, hybrids, degree of dominance*.

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Introduction

Diploid einkorn wheat (2n = 14) is an ancient crop that mankind has been cultivating for 10 thousand years (Heun et al., 1997). The grain of this wheat is a valuable product for a healthy diet (Hidalgo, Brandolini, 2014). It may also be beneficial for people with wheat gluten sensitivity (Di Stasio et al., 2020). All this determines the increasing interest in einkorn wheat of scientists and agricultural producers. Meanwhile, the wide use of this crop is hindered by a number of shortcomings that make it difficult to use modern technologies: low yield, tendency to lodging, fragility of ear, difficult grain threshing. Nevertheless, there are preconditions for improving the technological qualities of this crop. For example, threshing can be facilitated by using for hybridization a species *Triticum sinskajae* A. Filat. et Kurk. with easy threshing although not highly productive (Filatenko, Kurkiev, 1975). It is possible to predict the effectiveness of hybridization for the genetic improvement of einkorn wheat by manifestation of traits in F_1 hybrids (Kostylev, Nekrasova, 2015), which is also important for the development of commercial heterotic hybrids.

The purpose of the research is to find out the trait inheritance modes in F_1 hybrids of einkorn wheat accessions and to identify promising hybrid combinations for a prospective increase of subsequent generations' productivity.

Materials and methods

Seven hybrid combinations involving representatives of three einkorn wheat species were used as

the material for the study. Among them, there were two reciprocal combinations (1/2 and 5/6, Table 1). The studies were carried out in the experimental field of the Plant Production Institute named after V.Ya. Yuryev of the National Academy of Agrarian Sciences of Ukraine (eastern forest-steppe).

Table 1. Crossability of einkorn wheat

№	Maternal form ♀	Paternal form ♂	C %	CI
1	UA0300649*, *T. monococcum* var. *sofianum***, BLR***	*T. sinskajae* f. *aristata***, UKR***	81.9	73.5–88.1
2	*T. sinskajae* f. *aristata***, UKR***	UA0300649*, *T. monococcum* var. *sofianum***, BLR***	72.2	65.6–78.0
3	UA0300113*, *T. monococcum* var. *macedonicum***, SYR***	UA0300224*, *T. sinskajae* var. *sinskajae***, RUS***	19.7	12.3–30.0
4	UA0300222*, *T. monococcum* var. *hohensteinii*** GEO***	UA0300224*, *T. sinskajae* var. *sinskajae***, RUS***	45.6	37.9–53.6
5	UA0300224*, *T. sinskajae* var. *sinskajae***, RUS***	UA0300400*, *T. boeoticum* var. *thaoudar***, ARM***	6.3	3.4–11.1
6	UA0300400*, *T. boeoticum* var. *thaoudar***, ARM***	UA0300224*, *T. sinskajae* var. *sinskajae***, RUS***	48.9	39.1–58.9
7	UA0300401*, *T. boeoticum* var. *kurbagalensense***, UKR***	UA0300221*, *T. monococcm* var. *monococcum***, AZE***	12.5	3.5–36.0

*Note: * – number of the National Catalog of Ukraine, ** – species and variety, *** – country of origin, C – Crossability, CI – Confidence interval at the probability level of 95 %.*

The soil of the experimental field is chernozem (black soil). During the growing season in 2021 from March to July, the average temperature was +14℃ and the total precipitation was 188 mm whereas the long-term temperature is of +13℃ and the total precipitation is 219 mm. Thus, the year is characterized as dry.

The "single cross" method was used to create the hybrids. At least 10 spikes were pollinated in each combination, at least 200 flowers in total. The F_1 hybrid seeds were sown manually in blocks according to the scheme: mother–hybrid–father. The row length was 1 m, and the row spacing was 15 cm. The number of rows depended on the number of available seeds in each hybrid combination. The evaluation of hybrids by biological and economic characteristics was carried out according to the guidelines (Merezhko et al., 1999).

Hullness (*H*) is calculated by the formula:

$$H = \frac{WS - WKS}{WS} \times 100\% \quad (1)$$

where *WS* – weight of spike, *WKS* – weight of kernels per spike.

Crossability (*C*) is determined by the formula:

$$C = \frac{PFN - SS}{PFN} \times 100\% \quad (2)$$

where *PFN* – pollinated florets number, *SS* – seed setting.

The degree of dominance (*Hp*) of the trait in F_1 hybrids was determined by the Griffing formula (Griffing, 1956):

$$Hp = \frac{F_1 - Mp}{P_{max} - Mp} \quad (3)$$

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Where F_1 – arithmetic mean value of a trait in a hybrid F_1, M_p – arithmetic mean value of a trait in a parental form, P_{max} – the best parental form for the trait under study. At $Hp > 1$, the expressiveness of the trait is designated as heterosis i.e. overdominance of the parent with a higher value of the trait. *Hp* value < –1 is designated as hybrid depression or overdominance of the parent with a lower value of the trait. The value $–1 < Hp < 1$ indicated intermediate dominance, i.e., incomplete dominance. The value $Hp = 1$ indicates the complete dominance of the parent with a higher value of the trait, $Hp = –1$ indicates the complete dominance of the parent with a lower value of the trait.

Results

Crossability. In plant breeding, crossability serves as a guideline for the selection of parental pairs. This indicator in hybrid combinations of einkorns varies from 3 to 88 % (Table 1). When *T. sinskajae* is taken as the maternal form and wild wheat *T. boeoticum* is taken as the paternal form (combination 5), the lowest crossability is obtained – an average of 6 %. In the reciprocal cross (combination 6), the setting percentage was 49 %. Both reciprocal combinations *T. monococcum* var. *sofianum* UA0300649 / *T. sinskajae* f. *aristata* showed high seed setting (72–82%) (1 and 2 in Table 1). In other combinations, the crossability was at the level of 13–46 %, which is a good result for the dry conditions of spring 2020.

Table 2. Degree of dominance (*Hp*) of the traits in F_1 hybrids

№	Spike length	Spikelet number in spike	Kernel number per spike	1000 kernel weight	Spike weight	Kernel weight per spike	Proportion of husks
1	–0.07	–0.6	–5.2	–3.0	–1.8	–12.6	0.8
2	–0.03	–1.0	–5.0	–1.4	–4.8	–6.6	0.6
3	–1.9	–2.0	–1.3	–8.9	–3.2	–3.4	52.9
4	–0.2	0.5	0.4	–0.2	0.5	0.7	–143.4
5	–0.4	1.0	0.4	–0.5	0.0	–0.01	–0.04
6	0.8	0.8	1.2	–0.3	11.8	5.4	0.4
7	–4.3	–4.5	–13.8	–1.5	–2.1	–1.7	–5.7

Note: No – the cross number in the Table 1.

Degree of dominance. Of the 49 indicators (Table 2), in four cases there is a overdomination of the parent with higher trait index: in the combination 3 it is shown for proportion of husks, in the combination 6 – for grain number per spike, for weight of spike, for grain weight per spike. In 22 cases there is overdomination of the parent with lower trait index, in five – no dominance (*Hp* is close to zero) is observed, in 11 – dominance of the parent with higher trait index, in seven – dominated the parent with lower trait index. In the combination 7, overdomination of the parent with lower trait index is observed for all traits.

Table 3. Correlation coefficients between the trait dominance degrees in F_1 einkorns hybrids

Traits	a	b	c	d	e	f
Spikelet number in spike (b)	0.92**					
Kernel number per spike (c)	0.78*	0.89**				
Thousand kernel weight (d)	0.31	0.38	0.02			
Spike weight (e)	0.45	0.50	0.47	0.40		
Kernel weight per spike (f)	0.05	0.27	0.40	0.35	0.71	
Proportion of husks (g)	–0.21	–0.33	–0.19	–0.58	–0.11	–0.25

*Note: a – Spike length, b – Spikelet number in spike, c – Kernel number in spike, d – thousand kernel weight, e – Spike weight, f – Kernel weight per spike, g – Proportion of husks, * $p \le 0.05$, ** $p \le 0.01$.*

It should be noted that in reciprocal combinations 1 and 2, the inheritance patterns of all traits are similar. In contrast, in reciprocal combinations 5 and 6, the inheritance patterns for five of the seven traits are not the same, and only two – the spikelet number in spike and the mass of 1000 grains – are near. This result is consistent with crossability in these combinations and points to the role of crossing direction.

Among all the combinations, No. 6 (UA0300400 *T. boeoticum* var. *thaoudar* ARM / UA0300224 *T. sinskajae* var. *sinskajae* RUS) stood out, in which heterosis was manifested by the kernel number per spike (*Hp* = 1.2), for weight of spike (*Hp* = 11.8) and for kernel weight per spike (*Hp* = 5.4).

The analysis shows a correlation between the dominance degrees of the traits. It is established (Table 3) that dominance for the spike length is near to the dominance for spikelet number (r = 0.92) and for kernel number per spike (r = 0.78). The degrees of dominance in the latter two traits are also closely correlated (r = 0.89).

Discussion

The inheritance of quantitative traits in bread and durum wheat including their hybrids is well studied whereas for einkorns such studies are rare (Kuspira et al.,1989). In F_1 hybrids of spring polyploid wheat, overdomination of the best parent is often observed for productivity elements, (Ljubičić et al., 2014; Valekzhanin, Korobeynikov, 2016; Mukhordova, 2018). In our experiments with diploid wheat, this type of inheritance was observed in only one combination. This phenomenon requires more thorough analysis in special experiments.

From a practical point of view, combination 6 is of interest because it is more likely than other combinations to select relatively more productive forms in subsequent generations.

Conclusions

1. In the combination of cultivated *T. sinskajae* / wild *T. boeoticum*, differences in hybrid grain setting are observed: in direct cross it equals 6 %, in reciprocal cross it equals 49 %. In other combinations, the index varied from 13 % to 46 %. Both reciprocal crosses between *T. monococcum* var. *sofianum* UA0300649 and *T. sinskajae* f. *aristata* showed high seed setting (72–82 %) (1 and 2 in Table 1).

2. In F_1 hybrids of einkorn wheat, the inheritance pattern of the spike length is similar to the inheritance patterns of the spikelet number per spike and kernel number per spike (the correlation coefficients are 0.92 and 0.78, respectively). Also closely correlated are the dominance degrees in the last two traits (r = 0.89).

3. The combination UA0300400 *T. boeoticum* var. *thaoudar* ARM / UA0300224 *T. sinskajae* var. *sinskajae* RUS is of interest for breeding as showing heterosis for kernel number per spike (*Hp* = 1.2), for spike weight (*Hp* = 11.8) and for kernel weight per spike (*Hp* = 5.4); the combination UA0300222 *T. monococcum* / UA0300224 *T. sinskajae* is valuable for developing easily threshing material.

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Успадкування ознак у гібридів F_1 диплоїдних пшениць однозернянок у ярій культурі

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Диплоїдна однозернянка (2n = 14) — давня культура, яку людство вирощує 10 тисяч років. Зерно цієї пшениці є цінним продуктом для здорового і профілактичного харчування. Це зумовлює зростання інтересу науковців і виробничників до однозерної пшениці. Між тим, широкому використанню цієї культури перешкоджає низка недоліків, які ускладнюють використання сучасних технологій: низька врожайність, схильність до вилягання, ламкість колосу, важкий вимолот зерна. Тим не менш, є передумови для покращення технологічних якостей цієї культури. Для поліпшення диплоїдної пшениці однозернянки (2n = 14) за продуктивністю та вимолочуваністю проведено схрещування у семи комбінаціях за участі трьох видів цих пшениць (*T. boeoticum*, *T. monococcum*, *T. sinskajae*). Загалом схрещуваність у комбінаціях гібридів однозернянки коливається від 6,3 % до 79,7 %. У комбінації культурної пшениці *T. sinskajae* з дикою *T. boeoticum* спостерігаються реципрокні відмінності щодо зав'язування гібридних зерновок (у прямій комбінації 6,3 %; у зворотній 48,9 %). Реципрокні комбінації *T. monococcum* var. *sofianum* UA0300649 та *T. sinskajae* f. *aristata* були подібні за схрещуваністю (72 and 82 %) та характером спадкування і близькі за кількісними показниками. У решті комбінацій зав'язуваність становила 12,5–45,6 %. Найчастішим (22 випадки з 49) типом успадкування кількісних ознак F_1 однозернянок була гібридна депресія, домінування батьківської форми з більшим проявом ознаки відзначено в 11 варіантах, гетерозис у чотирьох. У гібридів успадкування довжини колоса корелює з типом успадкування кількості колосків у колосі (r = 0,92) та кількістю зерен у колосі (r = 0,78). Ступені домінування за цими двома ознаками також пов'язані між собою (r = 0,89). Селекційний інтерес представляє комбінація UA0300400 *T. boeoticum* var. *thaoudar* ARM / UA0300224 *T. sinskajae* var. *sinskajae* RUS, яка проявила гетерозис за кількістю зерен у колосі (*Hp* = 1,2), масою колосу (*Hp* = 11,8) та масою зерен з колосу (*Hp* = 5,4). Для створення матеріалу, що легко вимолочується, перспективною є комбінація UA0300222 *T. monococcum* var. *hohensteinii* / UA0300224 *T. sinskajae* var. *sinskajae*.

Ключові слова: *пшениця однозернянка, елементи продуктивності, гібриди, ступінь домінування.*

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