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A broad concept of heritability and genetic advance in selections for flax powdery mildew

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ABSTRACT
The objectives of the present study were to evaluate the resistance to powdery mildew of three flax collections introduced from Russia, Belgium, and Holland compared with a collection of Egyptian cultivars. Broad sense heritability (h^2) and genetic advance expressed as a percentage of mean were also evaluated for powdery mildew severity, seed weight, and straw weight within each collection. Powdery mildew severity of Russian and Egyptian collections, seed weight of Russian and Dutch collections, straw weight of all collections except the Russian one exhibited high h^2 coupled with high genetic advance expressed as percentage of mean indicating that each of these characters is controlled by additive gene action and simple selection could be effective in improving these characters. Powdery mildew severity of each of the Belgian and Dutch collections showed high h^2 with moderate genetic advance indicating that the powdery mildew severity of each collection is controlled by non-additive gene action. Therefore, this character could be improved by intermating superior genotypes of segregating populations developed from recombination breeding. On the other hand, seed yield exhibited medium and low h^2 in the Belgian and Egyptian collections, respectively, and straw weight of the Russian collection also showed low h^2. These results indicated that each of these characters was strongly influenced by environmental changes, thus, it cannot be utilized as a selection criterion in breeding programs.
Keywords: Flax, powdery mildew, heritability, genetic advance.

INTRODUCTION

Flax (*Linum usitatissimum* L.), (2n=2x=30) is a major oilseed and fiber crop in Egypt (Aly *et al*., 2021). Flax is a member of the genus *Linum* within the family Linaceae with 14 genera and over 200 species. Out of these only *L. usitatissimum* possess both agronomic and economic properties and is being exploited for both industrial and human consumption purposes (Singh *et al*., 2016). Flax is reported to be of Indian origin and was first domesticated in the area of Middle East (Singh *et al*., 2016). Flax has been classified into three main types, namely fiber and oil (linseed) type as well as an intermediate type. These types differ considerably in morphology, growth habit, and agronomic traits. Fiber-type plants are usually taller and have fewer branches while oil-type is often shorter have more branches and produce more seeds (You *et al*., 2017). The Egyptian flax cultivars are dual-purpose cultivars (El-Refaie *et al*., 2011).

Almost every part of flax plant is commercially utilized either directly or after processing. Flax seed is rich in fat, protein, and dietary fiber, it contains about 41% fat, 28% dietary fiber, 21% protein, three percent carbohydrates and is also an important source of magnesium, potassium, zinc, and B vitamins, soluble fibers (25%) and insoluble fibers (75%) (Rajanna *et al*., 2020). Flax oil is considered to be the most widely available botanical source of Omega-3 among all plants. Alpha-linolenic acid (ALA), an important Omega-3 fatty acid, constitutes up to 65% of total fatty acid composition in flaxseed oil (Worku *et al*., 2015). However, low linolenic acid-containing cultivars of flax have been also developed, which are directly used for edible oil (Rowland, 1995).

The oil cake is a good feed for milch cattle and is also used as organic manure to maintain soil fertility as well as to prevent unwanted microbes due to its germicidal properties (Rajanna *et al*., 2020). Flaxseed oil also possesses superior drying qualities due to its high linolenic acid content, which renders it an indispensable ingredient in paint and varnish (Singh *et al*., 2016). The flax stem yields fibers of good quality having high strength, non-elasticity, flexibility, and low density, which make it very attractive and suitable for use as a rope and thread (Jhala and Hall, 2010).

Powdery mildew is a common disease of flax in all flax-growing areas in Egypt (Aly *et al*., 2021). The perfect state of the causal fungus of flax powdery mildew has not been observed in Egypt and therefore, the causal fungus has been identified as *Oidium lini* Skoric based on the characteristics of its conidial stage (Aly *et al*., 1994). *O. lini* is a biotrophic parasite of flax and obtained nutrients through haustoria. Under strong selection pressure, *O. lini* can develop physiological races when disease-resistant cultivars are sown over larger areas (Sran *et al*., 2021).

Disease spreads through asexual conidia produced on the infected plant parts. Disease initiates in the form of small grayish-white powdery patches that occurs on young plant leaves and their shape can be circular or irregular. Soon they cover all the foliage viz., flowers, leaves, branches, stems, and capsules hence reducing photosynthesis area and activity (Sran *et al*., 2021). Flax powdery mildew can reduce yield and quality of seed and fiber raw materials, with most losses resulting from premature ripening and loss of seed during harvest, although a reduction in seed number per plant can occur with early infection (Stafecka *et al*., 2019). Yield losses reached 12-38% in India, 18%in the United Kingdom, and 10-20% in Canada (Rashid and Duguid, 2005). In Egypt, yield losses from flax powdery mildew have not been determined; however, significant negative correlations have been observed between disease severity and yield (Aly *et al*., 2021).

The negative association between flax yield and susceptibility to powdery mildew (Aly *et al*., 2021) indicated that susceptibility to powdery mildew could be one of the possible reasons for the wide gap already exists between the potential yield of flax and the yield attained by farmers' fields. Effective fungicides for controlling the disease are commercially available in Egypt (1994); however, farmers rarely utilized them for controlling the disease because they are expensive. In addition to the cost, fungicides can be hazardous and associated with environmental concerns (Dhirhi *et al*., 2017). Therefore, genetic resistance in the form of resistant cultivars is a necessary component of any successful program for controlling flax powdery mildew.

All the commercial flax cultivars in Egypt are susceptible to the disease (Aly *et al*., 2002); cultivars with varying levels of resistance to the disease have been observed in the introduced germplasm (Mansour *et al*., 2003). These introductions could be utilized as a source of resistance. Resistant genes from these introductions could be incorporated into the susceptible Egyptian genotypes to provide durable resistance overtime against the changing virulence of the pathogen population, thus minimizing the yield losses from powdery mildew epidemics. Therefore, the objectives of the present study were to evaluate the resistance to powdery mildew of three flax collections introduced from Russia, Belgium, and Holland compared with a collection of Egyptian flax cultivars. Broad-sense heritability and genetic advance were also evaluated for powdery mildew severity, seed yield, and straw yield within each collection.

MATERIALS AND METHODS

Disease assessment:

Seeds of the tested flax cultivars were planted on 25 November 2020 in natural soil and dispensed in 25 cm-diameter clay pots (20 seeds/pot). The pots were distributed outdoors in a randomized complete block design of four replicates (Blocks). Powdery mildew was allowed to develop naturally. Disease severity was rated visually on 20 April 2021. Disease severity was measured as a percentage of infected leaves/plants in a random sample of 10 plants/pot (Nutter, 1991). Reaction classes of the tested cultivars were determined based on disease severity according to the following scale: Highly resistant (HR)=0, Resistant (R)=1-10, moderately resistant (MR)=11-25, moderately susceptible (MS)=26-50, susceptible (S)=51-75, and highly susceptible (HS)=76-100 (Dhirhi *et al*., 2017). At harvest, seed and straw weights were recorded for each plant.

Genetic parameters:

1. Heritability in the broad sense (h^2) was calculated according to the following formula:

$$H^2 = \frac{\text{Genotypic variance } (\sigma^2{}_g)}{\text{phenotypic variance} (\sigma^2{}_{ph})} \times 100 \qquad \text{(Miller } et\ al., \text{ 1958)}$$

Where: $\sigma^2_g = ((\sigma^2_e + r\sigma^2_g) - \sigma^2_e)/r$

$\sigma^2_{ph} = (\sigma^2_e + r\sigma^2_g)/r$

2. Genetic advance expected from selection (G. A.) was calculated according to the following formula:

$(\sigma^2_g/\sigma^2_{ph})\ K\times\sqrt{\sigma^2{}_{ph}}$ where k = 2.06 at 5% selection intensity (Miller *et al*., 1958).

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Statistical analysis of the data:
The experimental design of the present study was a randomized complete block with four replicates. The least significant difference (LSD) was used to compare cultivar means. Analysis of variance (ANOVA) was carried out by the software package SPSS 10.0.

RESULTS

The present study was conducted in the 2020/2021 growing season to evaluate the performance of 25 exotic and indigenous flax cultivars (**Table 1**). Powdery mildew severity (PMS), seed yield and straw yield/ plant were used as criteria to evaluate the tested cultivars.

Table 1. Exotic and indigenous flax cultivars used in the present study.

Serial no.	Geographic origin	Name
1	Russia	unknown
2	Russia	unknown
3	Russia	unknown
4	Russia	unknown
5	Russia	unknown
6	Russia	unknown
7	Belgium	Avian R_3
8	Belgium	Vesta R_3
9	Belgium	Lisette R_3
10	Belgium	Suzanne R_3
11	Russia	unknown
12	Russia	unknown
13	Russia	unknown
14	Belgium	Aretha R_3
15	Russia	unknown
16	Holland	Vesta C_3
17	Holland	Calista C_3
18	Holland	Avian C_3
19	Holland	Leste C_3
20	Holland	Christne C_3
21	Egypt	Sakha 3
22	Egypt	Sakha 5
23	Egypt	Sakha 6
24	Egypt	Giza 11
25	Egypt	Giza 12

Cultivars components of variance of PMS were highly significant sources of variation in the Russian and Egyptian collections indicating that extensive genetic variation of PMS was present within these two collections (**Tables 2 and 3**). On the other hand, cultivars were a nonsignificant source of variation in the Belgian and Dutch collections (Tables 2 and 3). Thus, the Russian collection included three MR cultivars, five MS cultivars, and two S cultivars. The Belgian collection included one S cultivar and four HS cultivars. All cultivars of the Dutch collection were HS. The Egyptian collection included one R cultivar and four S cultivars (**Table 4**).

Table 2. Form and expected mean squares for analysis of variance of powdery mildew severity data from two collections of flax cultivars screened for relative resistance in an open-air pot experiment at Giza in 2020-2021.

Source of variation	Russian collection				Belgian collection				Expected mean squares[a]
	D. F.	M. S.	F. value	P>F	D. F.	M. S.	F. value	P>F	
Replication	3	2673.893	10.090	0.000	3	348.122	3.035	0.071	$\sigma_e^2+g\sigma_r^2$
Cultivar	9	1383.312	5.220	0.000	4	345.766	3.015	0.062	$\sigma_e^2+r\sigma_g^2$
Error	27	265.009			12	114.687			σ_e^2

[a] σ_e^2, σ_r^2 and σ_g^2 are variances due to experimental error, replications, and cultivars, respectively, while g and r are no. of cultivars and no. of replications, respectively.

Table 3. Form and expected mean squares for analysis of variance of powdery mildew severity data from two collections of flax cultivars screened for relative resistance in an open-air pot experiment at Giza in 2020-2021.

Source of variation	Dutch collection				Egyptian collection				Expected mean squares[a]
	D. F.	M. S.	F. value	P>F	D. F.	M. S.	F. value	P>F	
Replication	3	41.637	0.613	0.619	3	370.664	1.315	0.315	$\sigma_e^2+g\sigma_r^2$
Cultivar	4	194.267	2.861	0.071	4	2675.554	9.494	0.001	$\sigma_e^2+r\sigma_g^2$
Error	12	67.907			12	281.815			σ_e^2

[a] σ_e^2, σ_r^2 and σ_g^2 are variances due to experimental error, replications, and cultivars, respectively, while g and r are no. of cultivars and no. of replications, respectively.

Table 4. Powdery mildew severity data from four collections of flax cultivars[a] screened for relative resistance in an open-air pot experiment at Giza in 2020-2021.

Russian collection		Belgian collection		Dutch collection		Egyptian collection	
Cultivar no.	Mean (%)	Cultivar no.	Mean (%)	Cultivar no.	Mean (%)	Cultivar no.	Mean (%)
1	29.55	7	80.91	16	78.64	21	51.82
2	46.82	8	77.95	17	92.04	22	5.91
3	15.00	9	90.68	18	94.55	23	64.55
4	63.18	10	85.91	19	96.37	24	72.73
5	68.18	14	66.14	20	89.70	25	51.59
6	17.27						
11	17.73						
12	43.64						
13	33.87						
15	39.55						
LSD (P≤0.05)	25.32		N.S.		N.S.		27.30

[a] Names of cultivars are shown in Table 1.

Cultivars of the Russian collection were significant sources of variation in seed weight while in the Belgian collection, cultivars were a nonsignificant source of variation in seed weight (**Table 5**).

Table 5. Form and expected mean squares for analysis of variance of seed weight data from two collections of flax cultivars screened for relative resistance to powdery mildew in an open-air pot experiment at Giza in 2020-2021.

Source of variation	Russian collection				Belgian collection				Expected mean squares[a]
	D. F.	M. S.	F. value	P>F	D. F.	M. S.	F. value	P>F	
Replication	3	6600.158	2.559	0.076	3	4171.000	1.942	0.177	$\sigma_e^2+g\sigma_r^2$
Cultivar	9	6836.058	2.650	0.024	4	5088.425	2.369	0.111	$\sigma_e^2+r\sigma_g^2$
Error	27	2579.436			12	2147.792			σ_e^2

[a] σ_e^2, σ_r^2 and σ_g^2 are variances due to experimental error, replications, and cultivars, respectively, while g and r are no. of cultivars and no. of replications, respectively.

In the Dutch collection, cultivars were very highly significant sources of variation in seed weight while cultivars in the Egyptian collection were nonsignificant sources of variation in seed weight (**Table 6**).

Table 6. Form and expected mean squares for analysis of variance of seed weight data from two collections of flax cultivars screened for relative resistance to powdery mildew in an open-air pot experiment at Giza in 2020-2021.

Source of variation	Dutch collection				Egyptian collection				Expected mean squares[a]
	D. F.	M. S.	F. value	P>F	D. F.	M. S.	F. value	P>F	
Replication	3	599.517	7.122	0.005	3	16981.600	7.792	0.004	$\sigma_e^2+g\sigma_r^2$
Cultivar	4	469.950	5.582	0.009	4	3061.825	1.405	0.291	$\sigma_e^2+r\sigma_g^2$
Error	12	84.183			12	2179.392			σ_e^2

[a] σ_e^2, σ_r^2 and σ_g^2 are variances due to experimental error, replications, and cultivars, respectively, while g and r are no. of cultivars and no. of replications, respectively.

In the Russian collection, cultivar no. 6 showed the highest seed yield while cultivar no. 4 showed the lowest seed yield. The other cultivars showed variable levels of seed weight between these two extremes. In the Dutch collection, cultivars no. 16 and no. 17 showed the extreme seed weights (**Table 7**).

Table 7. Seed weight data (mg/plant) from four collections of flax cultivars[a] screened for relative resistance in an open-air pot experiment at Giza in 2020-2021.

Russian collection		Belgian collection		Dutch collection		Egyptian collection	
Cultivar no.	Mean	Cultivar no.	Mean	Cultivar no.	Mean	Cultivar no.	Mean
1	99.50	7	41.25	16	28.00	21	141.75
2	77.25	8	37.00	17	2.50	22	108.25
3	139.75	9	54.58	18	12.25	23	177.50
4	61.25	10	50.83	19	4.50	24	165.50
5	137.25	14	34.83	20	21.00	25	130.00
6	206.25						
11	127.00						
12	125.25						
13	90.25						
15	144.50						
LSD (P≤0.05)	75.42		N.S.		13.62		N.S.

[a] Names of cultivars are shown in Table 1.

Cultivars were nonsignificant sources of variation in straw weight of the Russian collection while they were significant sources of variation in the Belgian collection (**Table 8**).

Table 8. Form and expected mean squares for analysis of variance of straw weight data from two collections of flax cultivars screened for relative resistance to powdery mildew in an open-air pot experiment at Giza in 2020-2021.

Source of variation	Russian collection				Belgian collection				Expected mean squares[a]
	D. F.	M. S.	F. value	P>F	D. F.	M. S.	F. value	P>F	
Replication	3	19319.200	0.846	0.481	3	37797.650	2.435	0.115	$\sigma_e^2+g\sigma_r^2$
Cultivar	9	25712.489	1.125	0.379	4	55577.625	3.581	0.038	$\sigma_e^2+r\sigma_g^2$
Error	27	22849.126			12	15520.692			σ_e^2

[a] σ_e^2, σ_r^2 and σ_g^2 are variances due to experimental error, replications, and cultivars, respectively, while g and r are no. of cultivars and no. of replications, respectively.

In the Dutch collection, cultivars were a very highly significant source of variation in straw weight while they were significant sources of variation in the Egyptian collection (**Table 9**).

Table 9. Form and expected mean squares for analysis of variance of straw weight data from two collections of flax cultivars screened for relative resistance to powdery mildew in an open-air pot experiment at Giza in 2020-2021.

Source of variation	Dutch collection				Egyptian collection				Expected mean squares[a]
	D. F.	M. S.	F. value	P>F	D. F.	M. S.	F. value	P>F	
Replication	3	38387.117	6.623	0.007	3	69430.267	4.097	0.032	$\sigma_e^2+g\sigma_r^2$
Cultivar	4	33341.550	5.752	0.008	4	53859.575	3.178	0.054	$\sigma_e^2+r\sigma_g^2$
Error	12	5796.450			12	16945.642			σ_e^2

[a] σ_e^2, σ_r^2 and σ_g^2 are variances due to experimental error, replications, and cultivars, respectively, while g and r are no. of cultivars and no. of replications, respectively.

All collections, except the Russian one, showed different levels of variation in straw weight (**Table 10**).

Table 10. straw weight data (mg/ plant) from four collections of flax cultivars[a] screened for relative resistance to powdery mildew in an open-air pot experiment at Giza in 2020-2021.

Russian collection		Belgian collection		Dutch collection		Egyptian collection	
Cultivar no.	Mean	Cultivar no.	Mean	Cultivar no.	Mean	Cultivar no.	Mean
1	464.50	7	292.75	16	318.00	21	150.50
2	366.75	8	353.00	17	188.50	22	274.25
3	412.25	9	260.75	18	223.50	23	325.00
4	616.25	10	226.75	19	160.00	24	461.00
5	454.00	14	525.50	20	377.25	25	376.25
6	499.25						
11	427.00						
12	368.00						
13	335.60						
15	439.00						
LSD (P≤0.05)	N.S.		193.80		118.44		202.51

[a] Names of cultivars are shown in Table 1.

In the present study, PMS of the Russian and Egyptian collections exhibited high h^2 coupled with high genetic advance expressed as a percentage of mean indicating that PMS of each collection is controlled by additive gene action and simple selection could be effective in improving this character PMS of each of the Belgian and Dutch collections showed high h^2 with moderate genetic advance (**Table 11**).

Table 11. Broad sense-heritability (h^2) and genetic advance are expected from selection (GA) of four collections of flax cultivars.

Variable[a]	Geographic origins of the tested flax cultivars											
	Russia			Belgium			Holland			Egypt		
	h^2	GA	GA(%)[b]	h^2	GA	GA(%)	h^2	GA	GA(%)	h^2	GA	GA(%)
Disease severity	80.84	30.97	82.63	66.83	12.80	15.94	65.04	9.34	10.35	89.47	47.66	96.63
Seed weight	62.27	53.03	43.89	57.79	42.46	97.16	82.08	18.33	134.29	28.82	16.43	11.36
Straw weight	11.14	18.40	4.20	72.07	175.00	52.75	82.61	155.37	43.96	68.54	163.84	51.62

[a] Variable used in evaluating relative resistance to powdery mildew of the tested cultivars.

[b] $GA(\%) = \frac{GA}{X} \times 100$ where X is the character mean in the F_2 population.

DISCUSSION

Heritability is a good index of transmission of characters from the parent to its progeny. Heritability is classified as low (< 30 %), medium (30-60 %), and high (> 60 %) (Reddy *et al*., 2013). Genetic advance is a useful indicator of the progress that can be expected as a result of exercising selection on the pertinent population. Genetic advance is classified as low (< 10 %), moderate (10-20 %), and high (> 20 %) (Reddy *et al*., 2013). Heritability and genetic advance are two complementary concepts. The estimations of h^2 alone without genetic advances have little importance. Therefore, it is necessary to exploit both in combination for selection (Rastogi and Shukla, 2018).

In the present study, PMS of the Russian and Egyptian collections exhibited high h^2 coupled with high genetic advance expressed as a percentage of mean indicating that PMS of each collection is controlled by additive gene action and simple selection could be effective in improving this character PMS of each of the Belgian and Dutch collections showed high h^2 with moderate genetic advance. Therefore, this character could be improved by intermating superior genotypes of segregating populations developed from recombination breeding (Samadia, 2005; Reddy *et al*., 2013).

As to seed yield/plant, the Russian collection as well as the Dutch collection showed high h^2 in conjunction with high genetic advance (Table 11). Therefore, seed weight of these two collections is controlled by additive gene action and simple selection could be effective in improving this character in the two collections (Reddy *et al*., 2013). On the other hand, seed yield exhibited medium and low h^2 in the Belgian and Egyptian collections, respectively, which indicated that this character in the two collections was strongly influenced by environmental changes, thus, this character cannot be utilized as a selection criterion in breeding programs (Rastogi and Shukla, 2018).

Straw weight of the Russian collection showed low h^2 (Table 11), which indicated that this character was strongly influenced by changes in the environmental conditions, thus, it cannot be utilized as a selection criterion in breeding programs (Rastogi and Shukla, 2018). On the contrary, straw weight of all the other collections showed high h^2 accompanied by high genetic advance (Table 11). Therefore, straw weight of any of these collections is controlled by additive gene action and simple selection could be effective in improving this character (Reddy *et al*., 2013). Flax is grown mainly in humid environments where powdery mildew can easily develop and spread among crops; hence, resistance against this disease has been one of the main objectives when selecting lines for breeding purposes because PM reduces seed weight substantially. Despite this fact, it appears from the research that environment plays more of an influential role than genetics do regarding PM tolerance levels within varieties of flax – meaning traditional methods used by breeders may no longer suffice if they are looking specifically at selecting resistant lines solely based on their genetics rather than their environment too.

CONCLUSION

The results of a recent study conducted on flax (*Linum usitatissimum*) suggest that environmental changes have a strong influence on the characters used to select plants for breeding programs. The study found that resistance to powdery mildew, which is an important disease in flax production, was not linked with genetic variation and instead seemed to be largely influenced by environmental conditions. This result has implications for how plant breeders choose varieties when creating new cultivars as it cannot be utilized as a selection criterion in breeding programs.

In order to keep up with current trends while still maintaining desired traits such as seed yield or straw weight quality during line selection processes, researchers recommend using crosses between resistant linseed varieties combined with genomic selection techniques which allow them greater accuracy over what type of genetic material will provide better yields while also preserving those desired qualities mentioned previously like straw weight or seed yield levels across all selected lines regardless if they possess higher natural resistances towards diseases like PM or not . All-in-all these findings demonstrate how much importance should be placed upon understanding both internal (genetics) and external factors (environmental conditions) equally when choosing suitable candidates during future breeding cycles so desirable characteristics can continue being passed down through generations without sacrificing any other necessary qualities needed within modern day agriculture practices today.

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تصور للتوريث بالمفهوم الواسع و العائد الوراثى من الإنتخاب للبياض الدقيقى فى الكتان

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هدفت الدراسة الحالية إلى تقييم المقاومة لمرض البياض الدقيقى فى ثلاث مجموعات من أصناف الكتان، المستوردة من روسيا و بلجيكا و هولندا، مقارنة بمجموعة من الأصناف المصرية. قيم أيضا معامل التوريث و العائد الوراثى المتوقع من الإنتخاب معبراً عنه كنسبة مئوية من المتوسط، لكل من شدة البياض الدقيقى و وزن البذرة و وزن القش، لكل مجموعة أصناف. أظهرت شدة البياض الدقيقى فى المجموعتين المصرية و الروسية، و وزن البذرة فى المجموعتين الروسية و الهولندية، و وزن القش فى جميع المجموعات عدا الروسية، قيم مرتفعة لكل من معامل التوريث و العائد الوراثى المتوقع من الإنتخاب، مما يدل على أن كل صفة من الصفات موضع الدراسة تتحكم فيها عوامل وراثية ذات تأثير جمعى، كما أن الإنتخاب البسيط هو طريقة فعالة لتحسين هذة الصفات. أظهرت شدة الإصابة بالبياض الدقيقى فى المجموعتين البلجيكية و الهولندية قيم مرتفعة لمعامل التوريث مع قيم متوسطة للعائد الوراثى المتوقع من الإنتخاب، مما يدل على أن شدة البياض الدقيقى فى أى من المجموعتين تتحكم فيها عوامل وراثية ذات تأثير غير جمعى، و على ذلك فان هذه الصفات يمكن تحسينها عن طريق التهجين بين التراكيب الوراثية المتفوقة، و التى يمكن العثور عليها فى الأجيال الإنعزالية. من ناحية اخرى، فقد أظهر محصول البذرة قيم متوسطة و منخفضة لمعامل التوريث فى المجموعتين البلجيكية و المصرية، على التوالى، كما أظهر محصول القش قيم منخفضة لمعامل التوريث فى المجموعة الروسية، تدل هذة النتائج على أن الصفات موضع الدراسة تتأثر بشدة بالتغيرات فى الظروف البيئية، و على ذلك فانها لا تصلح كمعايير إنتخاب فى برامج التربية

كلمات مفتاحية: كتان، بياض دقيقى، معامل التوريث، العائد الوراثى