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Phenotypic, Genotypic and Environmental Correlations of Quantitative Characters in Winter Wheat

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Abstract. In the experiment with 18 winter varieties the genotypic, phenotypic and environmental correlations were estimated in all combinations between the pairs of 11 quantitative characters.

Both yield of grain with its components and further characters were evaluated, of which flag leaf size and leaf angle of the last but one leaf are of importance for the utilization of light energy and consequently for receiving maximum rates of photosynthesis.

In simple genotypic and phenotypic correlations their different stability with regard to mineral nutrition, eventually to the date of sowing was proved.

In the discussion the limited signification of simple correlation for the statement of complicated processes in plants caused by multiplied associations of characters was pointed out. In the example of yield components of the plant at the application of 60 kg N per hectare it was shown that also further unknown variable factors might participate in the genotypic correlation. It may be concluded that the inclusion of them when constructing the selection indexes will give further foundations for handling yield as a breeding or genetic character, and for the causal analysis of yield formation in wheat.

Knowledge of interrelationships between the pairs of quantitative characters is widely utilized in many branches of science.

In plant breeding it may be one of the guides, which facilitate the interpretation of achieved results and may form foundations for planning the programmes in the future. Thus, for example, in selecting high-yielding individuals the correlation between a yield component with low heritability and other high heritable character, though unimportant from an economic point of view, makes it possible that selection may be performed for this second character as indicator for keeping the first character, i.e. for the component of yield. In early hybrid generations, the correlations together with the heritability determine, on the basis of what characters the selection may be performed, the individuals with otherwise desired characters not to be removed before they could be analysed for them.

Evidence was given by plant physiologists and geneticists, that economic yield might be influenced to a certain extent by a number of characters play-

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ing a role in the formation of biological yield through the functions participating in the high photosynthetic efficiency of plants, and that changes might occur due to environmental conditions.

In cereals most frequently the relationships between the yield and its components and quality characters were evaluated. These relationships were estimated both in varietal trials and hybrid combinations or lines (GRAFIUS and BROWN 1954, NORDEN and FREY 1959, NEI 1960, LEBSOCK et al. 1964, HEHN and BARMOORE 1965, RASMUSSON and GLASS 1965, STOSKOPF and REINBERGS 1966).

Of interest to many authors is the variation of correlations within the pair of quantitative characters. VLACH (1966) and FORAL and APLTAUEROVÁ (1967) observed in East and West-European wheat varieties and in Czechoslovak and foreign spring barley varieties, respectively, that many correlations in these varietal groups differentiated not only in the value, but also in the sign. Also RASMUSSON and GLASS (1965) in estimating phenotypic and genotypic correlations in various F_3 hybrid combinations of spring barley and NEI (1960) in testing varieties and hybrids of rice in different environments (at different dates of sowing) came to the same conclusions. The action of locations and years upon the observed relationships between the characters is also known. These variations of correlations are explained by NEI (1960) through the interaction of genotype and environment and on the basis of differences in the genetic structure of tested populations. From the breeders' point of view only such phenotypic correlations are utilizable to which also high genotypic correlations are corresponding.

Morphological observations are completed with considerations about interrelations between physiological functions of individual parts and organs of plants in evolution (FIEDLER 1952, STOY 1962, 1965, COOPER 1965, PŘIKRYL 1965), thus laying the foundation for the causal analysis of yield formation (NEČAS 1966). BEZDĚK (1965, 1966) follows the relationship between the dynamics of fundamental nutrient reception (NPK) in some parts of wheat and their relation to dry matter increase, lodging and yield of grain. JENNINGS and BEACHELL (1964) recorded the relationship of a great number of quantitative characters in rice from the point of view of appropriate possibility of the utilization of mineral nutrients and nitrogen.

So far most works have been based on observed or phenotypic rather than genotypic correlations. Knowledge of genotypic correlations and relationships of modifying activity of mineral nutrients between the pairs of quantitative characters through environmental correlations in cereals is so far limited.

Material and Methods

In this experiment artificially constructed wheat population of 18 perspective winter wheat varieties was used, distinguishing morphologically in grain quality and height of yield. The varieties used were as follows: Anti, Berthold, Bezostaja 1, Breustedt Werla, Caro, Carsten VI, Carsten VIII, Consul, Diana I, Florian, Format, Jubilar, Kaštická osinatka, Mironovskaja 808, Moisson, Record, Stabil and Tenor. In field randomised block design each variety was seeded in 5×15 cm spacing in six-row plots, with three replications. Two levels of mineral nutrents and two dates of sowing were used, which formed experimental variants I—IV. Variant I was made on the basis of the application of 60 kg N per hectare and additional fertilizers in the ratio $N : P_2O_5 : K_2O = 1 : 1{\cdot}2 : 1{\cdot}6$. In variant II 100 kg N was used and supplemented with P_2O_5 and K_2O in the same ratio. The date of sowing in variants I and II was October 4, 1965. Variants III and IV received the same amounts of fertilizers as I and II, but the sowing was made three weeks later and this may be characterized in Kroměříž conditions as relatively late sowing.

During the growing period the measurements conducted were as follows: the last leaf blade area of the main stem 14 days after ear emergence (sq.cm), leaf angle in the last but one leaf from the top on the main stem in heading time (°), the length of the plant in ear emergence measured on the main stem from the ground to the last leaf (cm), and lodging (1 = prostrate — 5 = erect). After harvesting the length of the plant was measured (cm), ear length of the main tiller (cm), number of ears per plant, grain weight per plant — yield of grain (g), stem weight per plant (g), number of grains per ear, and one grain weight (mg). Quantitative characters with the exception of the lodging were measured in 10 randomly selected plants per plot, all of them were evaluated on a plot mean basis.

For the estimation of correlations the components from analyses of variance and covariance were used, provided that the observed variance of a quantitative character was expected to be $\sigma_p^2 = \sigma_g^2 + \sigma_e^2$. Correlations were computed according to SEARLE (1963) and LEGG, MATZINGER and MANN (1965) in all possible pairs of characters.

Results and Discussion

High genotypic correlations were received in many pairs of characters and not only in the association of yield with its components. The association between some pairs of characters existed in a single experimental variant only, whereas in other pairs it was found in a greater number of variants and was linked to either the level of N or the date of sowing.

As can be seen from Tables 1 and 2, the phenotypic correlation equal both in the sign and relative magnitude to genotypic correlation was found in individual experimental variants in relationships between the following characters: positive in flag leaf size and number of grains per ear at an early sowing date and 100 kg N and also at 60 kg N and a relatively late date of sowing.

The relationship between the angle of the last but one leaf and length of plant (in heading time) at an early date of sowing and 100 kg N and at 60 kg N and a relatively late date of sowing was positive. The relationship with the length of plant (in maturity) was equal at 100 kg N and early sowing.

The last leaf area and the angle of the last but one leaf at 60 kg N and a relatively late sowing date were found inverse to grain number per ear and to one grain weight.

Table 1
Genotypic correlations in individual experimental variants

Correlated character	Experimental variant I	II	III	IV
Flag leaf size				
Number of grains per ear	0·5556	0·6229	0·5533	0·4023
Weight of 1 grain	−0·7320	−0·3819	−0·5349	−0·3645
Leaf angle+				
Length of plant++	0·3912	0·7670	0·5760	0·0965
Length of plant+++	0·4761	0·5811	0·2430	−0·0854
Number of grains per ear	0·0908	0·1047	0·8193	0·3760
Weight of 1 grain	−0·1014	−0·3970	−0·6502	−0·4474
Length of plant++				
Length of plant+++	0·8822	0·9179	0·8904	0·9074
Ear length	0·5521	0·4515	0·4911	0·5785
Number of ears	0·4510	0	−0·8789	−0·1169
Grain weight per plant	−0·6367	−0·1234	(x)	−0·3169
Weight of 1 grain	−0·4030	−0·5662	−0·3209	−0·2211
Lodging	−0·6205	−0·6389	−0·6144	−0·7683
Length of plant+++				
Ear length	0·5335	0·6776	0·7159	0·7680
Number of ears	−0·3148	0	−0·8158	−0·1776
Grain weight per plant	−0·7041	−0·9787	(x)	0·0070
Lodging	−0·8912	−0·7686	−0·6840	−0·8837
Ear length				
Number of grains per ear	−0·6831	−0·4700	−0·2950	−0·1387
Weight of 1 grain	0·6492	0·2206	0·3292	0·3368
Lodging	−0·5375	−0·5729	−0·4462	−0·5825
Grain weight per plant				
Weight of 1 grain	0·7553	0·8631	0·9114	0·3940
Number of grains per ear				
Weight of 1 grain	−0·5622	−0·7330	−0·7510	−0·6646

+ last but one leaf
++ in ear emergence
+++ in maturity

(x) the genotypic correlation > 1
0 Because estimate of σ_g^2 for number of ears in variant II was negative, a nonpositive square root occurred.

The plant length in heading time and that in maturity were in negative relationship with ear number per plant at 60 kg N and a relatively late date of sowing and with the yield at an early date of sowing and 60 kg N. The correlation between the plant length in heading time and one grain weight was negative at 100 kg N and early date of sowing.

The relationship between ear length and grain number per ear was negative at 60 kg N and early date of sowing and positive with one grain weight.

In some cases the genotypic and phenotypic correlations were more stable. The correlations between plant length in ear emergence and plant length in maturity were found to be high and equalled the sign (+) in all experimental variants. The plant length (in heading time) was in positive relationship with the ear length at 60 kg N and both dates of sowing, as well as at a relatively

Table 2
Phenotypic correlations in individual experimental variants

Correlated character	Experimental variant I	II	III	IV
Flag leaf size				
Number of grains per ear	0·4406	0·5410	0·4753	0·3057
Weight of 1 grain	−0·4296	−0·4449	−0·4730	−0·3160
Leaf angle				
Length of plant++	0·4036	0·7171	0·5486	0·0958
Length of plant+++	0·4357	0·5505	0·2352	−0·1089
Number of grains per ear	0·0606	0·1086	0·6787	0·3852
Weight of 1 grain	−0·0626	−0·3518	−0·5880	−0·3972
Length of plant++				
Length of plant+++	0·8530	0·8964	0·8526	0·9004
Ear length	0·5407	0·4302	0·4726	0·5550
Number of ears	−0·3308	−0·0517	−0·5617	−0·1154
Grain weight per plant	−0·4865	−0·5119	−0·5689	−0·1774
Weight of 1 grain	−0·3479	−0·5065	−0·2899	−0·2063
Lodging	−0·4987	−0·5929	−0·5740	−0·7222
Length of plant+++				
Ear length	0·5247	0·6443	0·6920	0·7499
Number of ears	−0·2105	−0 0766	−0·5027	−0·1579
Grain weight per plant	−0·4722	−0·4273	−0·5792	−0·0074
Lodging	−0·7142	−0·7027	−0·6661	−0·8231
Ear length				
Number of grains per ear	−0·5728	−0·3990	−0·2609	−0·1074
Weight of 1 grain	0·5295	0·2174	0·2959	0·3224
Lodging	−0·4762	−0·5140	−0·4272	−0·5353
Grain weight per plant				
Weight of 1 grain	0·5220	0·5405	0·4959	0·3610
Number of grains per ear				
Weight of 1 grain	−0·4842	−0·6033	−0 6101	−0·5777

+ last but one leaf
++ in ear emergence
+++ in maturity

Phenotypic correlations of 0·4683 and 0·5897 are necessary to be significant at the 5% and 1% levels, respectively

late date of sowing and both 60 and 100 kg N. The ear length and plant height in maturity were in positive relationship in all experimental variants. A higher plant in ear emergence as well as in maturity was assumed to be more susceptible to lodging.

Grain weight per plant (yield) was in positive relationship with one grain weight at both dates of sowing at 60 kg N and grain number per ear was in negative relationship with one grain weight in all environments.

From the environmental correlations in Table 3 it can be seen that high correlation with positive sign occurred especially in relationships between the pairs of low heritable characters (SMOČEK 1968), such as ear number per plant with grain weight per plant (yield) and the yield with stem weight.

The positive genotypic and phenotypic correlation of ear number per plant with stem weight at 100 kg N and a relatively late date of sowing is accompanied with high environmental correlation ($r_e = 0{\cdot}8625$). Similarly in Table 3 in the relationship between yield and one grain weight the environmental correlation shows difficulties, resulting from the modifying influence of applied fertilizer of 100 kg N at both dates of sowing. This correlation indicates the difficulty in selections at higher levels of mineral nutrients in one grain weight in association with yield.

Table 4
Genotypic single correlations, partial and multiple (R_g) correlation coefficients, coefficients of determination (r^2) . 100 of yield components in experimental variants I and III

Correlated characters		Experimental variant I	III
$r_{g9,6}$		$-0{\cdot}5962^{++}$	$-0{\cdot}5894^{+}$
	$(r_g^2) . 100$	35·5454	34·7392
$r_{g9,10}$		$-0{\cdot}5622^{++}$	$-0{\cdot}7510^{++}$
	$(r_g^2) . 100$	31·6069	56·4001
$r_{g6,10}$		$0{\cdot}6257^{++}$	0·3094
$r_{g9,6 \cdot 10}$		$-0{\cdot}3789^{++}$	$-0{\cdot}5686^{+}$
$r_{g9,10 \cdot 6}$		$-0{\cdot}3021$	$-0{\cdot}7402^{++}$
$R_{g9 \cdot 6,10}$		0·6436	0·8395
	$(R_g^2) . 100$	41·4221	70·4760

Correlation coefficients are significant at the 5% (+) and 1% (++) levels.
Characters: X_6 = number of ears,
X_9 = number of grains per ear,
X_{10} = weight of 1 grain.

From the results presented it is evident that in many cases the genotypic correlations were higher than the phenotypic ones. The same observation has been made previously by WEBER and MOORTHY (1952), JOHNSON et al. (1955), NEI (1960) and KWON and TORRIE (1964). This fact can be explained by means of relationships within the phenotypic correlation, as shown by SEARLE (1963).

In several cases (Table 1) the value of genotypic correlation was higher than 1. These correlations were marked with x. A similar case, when r_g exceeded 1 was also found by HARRIS (1963) and WILLIAMS et al. (1965).

From existing experience in plant breeding and from research knowledge it is known that interactions among characters and physiologic processes in the plant as an integrated system are possible. On the basis of partial and multiple correlation coefficients it is considered, to what extent such interaction can be comprised in the present genotypic correlations of the three yield components and simultaneously the differentiality of this action in applying 60 kg N in association with the early date of sowing (experimental variant I) and the same amount of N with a relatively late sowing date (experimental variant III). The yield components in the plant are the following characters: X_6 = ear number per plant, X_9 = grain number per ear, and X_{10} = 1 grain weight (Table 4).

Table 3
Environmental correlations in individual experimental variants

Correlated character	Experimental variant I	II	III	IV
Grain weight per plant				
Number of ears	−0·5667	0·8151	0·7925	0·7823
Stem weight per plant	0·8982	0·9088	0·8872	0·5212
Weight of 1 grain	0·2149	0·6127	0·3720	0·4812

From genotypic simple correlations it can be seen that grain number per ear had a negative effect in relation to the other two yield components. The differences in grain number per ear (X_9) in variants I and III were caused at a rough estimate in 35·54% and 34·74% respectively, by ear number per plant (X_6) and in correlation $r_{g9,10}$ in variants I and III roughly in 31·61% and 56·40% respectively, by one grain weight. Thus it may be assumed that also further variable quantities are participating in differences in grain number per ear besides characters X_6 and X_{10}.

From the comparison of the partial correlation coefficient $r_{g9,6\cdot10}$ and $r_{g9,6}$ results show that at an early sowing date and the amount of 60 kg N the magnitude in this simple correlation was influenced by one grain weight (X_{10}), whereas at a relatively late date of sowing this correlation was influenced by variable X_{10} only slightly and therefore, the genetic action of unknown variable characters, other than X_{10} may be assumed.

When comparing $r_{g9,10\cdot6}$ and $r_{g9,10}$ results show that at an early date of sowing and 60 kg N the magnitude of this simple correlation was influenced by ear number (X_6), because in the partial correlation coefficient where the genetic action of the variable X_6 was excluded, its value was insignificant. At a relatively late sowing date this simple correlation was influenced by the variable X_6 only slightly and thus the genetic action of further unknown variable quantities may be presupposed.

From the multiple correlation coefficient $R_{g9\cdot6,10}$ expressing the common action of both independent variables X_6 and X_{10} and its coefficient of determination results show that at early dates of sowing it would be suitable to include still further independent variable characters. It is evident that in some cases simple correlations cannot express clearly enough the complications of interactions in plant characters and the changes occurring in such an association in the changed environment. More and more frequently conclusions have been reached that in an effort to achieve high grain yields, the selections in plant breeding need to be completed with specific plant features, such as leaf angle, leaf area and height of plant (STOSKOPF and REINBERGS 1966). These specific aspects should be included, as they enable a more effective utilization of light energy necessary for maximum rates of photosynthesis. When the yield components are regarded as more precise indicators of a complex of metabolical and physiological processes than grain yield as it is now, a further broadening of views may be expected on the basis of some yield prerequisites, including factors participating in the photosynthetic capacity of the plant. The judgement of their selective fitness in the selections for the best wheat genotypes for yield and inclusion in characters used in selection index construction may be one of the possibilities for the genetic analysis of the potential yield capacity of wheat as well as a guide for overcoming the present yield barriers.

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J. SMOČEK, Výzkumný ústav obilnářský, Kroměříž: **Korelace fenotypové, genotypové a korelace prostředí kvantitativních znaků ozimé pšenice.** — Biol. Plant. 10 : 146—155, 1968.

V pokusu s 18 odrůdami ozimé pšenice byly odhadnuty genotypové, fenotypové a korelace prostředí u všech kombinací mezi dvojicemi 11 kvantitativních znaků.

Hodnoceny byly jak výnos a jeho složky, tak i další znaky, z nichž sklon listu a plocha posledního listu jsou důležité pro využití světelné energie, a tím pro dosažení vysokých hodnot fotosynthesy.

U jednotlivých genotypových a fenotypových korelací byla prokázána jejich různá stálost s ohledem na minerální výživu, popřípadě na termín výsevu.

V diskusi bylo poukázáno na omezující význam jednoduchých korelací pro vyjádření složitých procesů, probíhajících v rostlinách a projevujících se v mnohonásobném spojení znaků. Na příkladu složek výnosu rostliny při aplikaci 60 kg N/ha bylo ukázáno, že na genotypové korelaci se mohou podílet ještě další neznámé proměnné. Je možno usoudit, že jejich začlenění při konstrukci selekčních indexů poskytne další podklady pro manipulaci s výnosem jako šlechtitelským nebo genetickým znakem a pro kausální analýsu tvorby výnosu u pšenice.

Я. СМОЧЕК, Исследовательский институт зернового хозяйства, Кромержиж: **Фенотипические, генотипические и зависящие от среды корреляции количественных признаков у озимой пшеницы.** — Biol. Plant. 10 : 146—155, 1968.

В опыте с 18 сортами озимой пшеницы были найдены корреляции для всех комбинаций между парами 11 количественных признаков.

Оценивали как урожай и его составные признаки, так и другие признаки, среди которых наклон листовой пластинки и площадь последнего листа важны для использования световой энергии и тем самым для достижения высоких значений фотосинтеза.

Для отдельных генотипических и фенотипических корреляций установлена различная их устойчивость в связи с различиями минерального питания и сроков посева.

В дискуссии указано на ограниченное значение простых корреляций для описания сложных процессов, происходящих в растениях, проявлением которых является многообразная связь признаков. На примере составных компонентов урожая растений при применении 60 кг азота/га показано, как в корреляции генотипа могут участвовать

другие неизвестные переменные. Можно думать, что их включение при конструкции селекционных индексов принесет новое обоснование для манипулирования с урожаем как с селекционным или генетическим признаком и для причинного анализа образования урожая у пшеницы.

XI INTERNATIONAL BOTANICAL CONGRESS

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