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Genetic analysis of grain yield and oil content in two maize populations

ZVONIMIR ZDUNIĆ[1]
ALEKSANDRA NASTASIĆ[2]
ĐORĐE JOCKOVIĆ[2]
MILE IVANOVIĆ[2]
IVICA ĐALOVIĆ[2]
ANTO MIJIĆ[1]
MILAN JOCKOVIĆ[2]

[1]Agricultural Institute Osijek
Južno predgrađe 17
31000 Osijek, Croatia

[2]Institute of Field and Vegetable Crops,
Novi Sad, Maksim Gorki 30
21 000 Novi Sad, Serbia

Correspondence:
Zvonimir Zdunić
Department for Maize Breeding and
Genetics, Agricultural Institute Osijek
Južno predgrađe 17, 31000 Osijek, Croatia
E-mail: zvonimir.zdunic@poljinos.hr

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Abstract

Background and purpose: *The objectives of this study were to estimate correlations between kernel oil content and morphological traits in two studied maize populations, and to estimate direct and indirect effects of yield components on kernel oil content.*

Materials and methods: *The material for this study was developed by crossing progenies of high oil maize populations with two testers. The traits analyzed were kernel row number, 100-kernel weight, grain yield per plant and kernel oil content. Correlation coefficients were based on the ratio of joint variation and summary of individual variation of two traits (8). Standardized partial regression coefficients and levels of their significance were calculated according to the method of the inverse matrix (10).*

Results: *In B73 testcrosses, oil content was in negative, and medium strong correlations with all studied traits were observed. In the second population, relation between these traits was also negative, but medium strong and weak between oil content and kernel row number, and between oil content and other studied traits. Significantly positive coefficient of correlations was found between grain yield and 100-kernel weight in both estimated populations.*

Conclusions*: Coefficients of correlations between kernel oil content and other traits were estimated. Significantly negative direct effects were estimated of all studied traits to kernel oil content but indirect effects were significantly positive and negative.*

INTRODUCTION

Maize is one of the major cereal crops in the world *(1)*. Superior position of maize is due to its very widespread and various utilizations. It is used for human food, livestock feed, row industrial material, and as medical and ornamental plants *(2)*.

Most of maize breeders focus primarily on grain yield, as it is the most important agronomic trait of maize. However, besides permanent long lasting work on increasing grain yield of maize, increase in pathogen resistance, loading and increasing of many kinds of desirable traits, maize breeders are more and more concerned with changing its standard chemical composition. Chemical composition of maize kernel is very important especially if we take into consideration one of the basic ways of maize use in developing countries, as livestock feed *(3)*.

Poultry, swine and dairy cows require livestock feed with high calorie levels. Kernels of a modern maize hybrid contain about 4% oil, 9% protein, 73% starch, and 14% other constituents *(3),* which corresponds to the obtained results *(1)*. The calorie content of oil is approximately 2.25 times greater than that of starch *(4)*. Therefore, one way of providing high calorie livestock feed is by using high oil maize. High oil maize does not only increase oil content, but it also improves amino-acid balance. High oil hybrids have larger germs, and protein of better quality is concentrated in germs. In this way, selection of higher oil content increases the biological value of the kernel.

Most maize produced in industrialized countries is used as animal feed or for industrial purposes, but maize remains an important food sample in many developing regions, especially sub-Saharan Africa and Central America, where it is frequently the mainstay of human diets. High oil maize hybrids in human nutrition are very desirable because of the high unsaturated fatty acid content *(5)*. Maize oil is extremely stable, and because of that it is ideal for the production of various types of snacks, where extremely stable oils are required.

Lately, when increasing attention has been paid to environmental protection and due to a reduction of fossil fuel reserves, the possibility of bio fuel production based on vegetable oils has been of growing interest. Seen from this point of view, selection for increasing oil content in grain maize has become very topical.

Selection for oil content resulted in correlative response on other traits. Grain yield, as the most important agronomic trait, decreases as oil content increases. Because of that, one of the goals of this study was to confirm correlations between oil content and morphological traits. The relation between grain yield and yield components and the partitioning of the correlations into components with direct and indirect effects have been extensively studied. However, information about direct and indirect influence of yield components on kernel oil content is very limited. Because of that, one of the goals of this study was to determine the direct and indirect effects of yield components on kernel oil content.

MATERIALS AND METHODS

The genetic material evaluated in this study was developed by crossing progenies of high oil maize population after 16 cycles of recurrent selection, and two testers, B73 and 568/II NS. According to Bocanski and Petrovic *(6),* the original population, NSU$_1$, was made of single hybrids produced by cross breeding of eight domestic inbred lines, produced at the Institute of Field and Vegetable Crops (Novi Sad, Serbia), and four foreign line that originated from USA in 1967. The first cycles of selection started in 1968. Each cycle lasted for two years. In the first year, self-pollination was conduced on 500–600 F$_1$ plants with desirable habitat. From each population, approximately 100 ears were analyzed for the oil content. In the second year, 20 S$_1$ lines with the highest oil content were taken and sown for the purpose of recombination. In the fourth cycle of selection, oil synthetic Syn D.O., originating from the USA was included in order to improve population for oil content. After 16 cycles of phenotypic recurrent selection, progenies of NSU$_1$ population were crossed with two testers, B73 and 568/II NS, and for further work, 96 testcrosses, with both testers, were chosen.

During 2003 and 2004 testcrosses were evaluated in field experiments at one location, Rimski Sancevi (45° 15' N, 19° 51' E). The experiments were conducted using incomplete block design with replications within sets *(7)*. 96 genotypes were assigned at random to 4 sets. Two replications within a set were used and 20 plants per plot were grown. Each plot consisted of one 5 m long row, spaced 0.24 m between plants and 0.75 m between plots. The experiment was machine-cultivated and manually weeded as necessary for proper weed control. The standard maize growing technique was practiced. The harvest was done by hand.

Data were observed for kernel row number (KRN), 100-kernel weight (KW), grain yield per plant (GY) and kernel oil content (KOC). For KRN, KW and GY data were recorded on 10 randomly taken competitive plants. From 10 ears per replication, of each progeny, the same number of kernels was taken and used to form a group sample. These samples were used for determination of kernel oil content by nuclear magnetic resonance (NMR) spectroscope.

Analysis of variance and covariance was done by Nested Design [(random model; Cochran and Cox *(7)*]. Genetic and phenotypic correlation coefficients were based on ratio of joint variation and summary of individual variation of two traits *(8)*. Standardized partial regression coefficients (path coefficients; Wright *(9)* and levels of their significance were calculated according to the method of the inverse symmetric correlation matrix *(10)*.

RESULTS

In the testcross population where we used inbred line B73 as tester, average kernel oil content was 7.60% and ranged from 3.41% to 17.51%. In the second studied population, NSU$_1$ × 568/II NS, highly significant lower mean value for oil content was found (Table 1), with narrow interval of variation (2.22–8.60%). In the first studied population, NSU$_1$ × B73, higher mean values were also found for both kernel row number and grain yield. The mean of kernel row number was highly significant it was higher in this population than in NSU$_1$ × 568/II NS, while difference between mean values of grain yield was not significant. Mean value of 100-kernel weight was higher in population NSU$_1$ × 568/II NS, with wider interval of variation (22.40–48.70 g).

In the first studied population, NSU$_1$ × B73, medium strong and negative correlations were found between oil content and all other studied traits (Table 2). In the second testcross population (NSU$_1$ × 568/II NS), negative correlations were also found between these traits, but oil content was in medium strong correlation only with

TABLE 1

Mean values and standard errors for studied traits.

Population	Trait			
	KRN	KW (g)	GY (g)	KOC (%)
NSU$_1$ × B73	16.74 ± 0.063	33.23 ± 0.228	207.50 ± 1.252	7.60 ± 0.059
NSU$_1$ × 568/II NS	16.37 ± 0.063	35.57 ± 0.219	206.95 ± 1.544	7.15 ± 0.064

KRN: kernel row number, KW: 100-kernel weight, GY: grain yield, KOC: kernel oil content

TABLE 2

Genetic correlations for NSU$_1$ × B73 (above diagonal) and NSU$_1$ × 568/II NS (below diagonal).

Trait	KRN	KW	GY	KOC
KRN	1.000	–0.170	–0.347	–0.587
KW	–0.613	1.000	0.599*	–0.466
GY	0.801**	0.597*	1.000	–0.445
KOC	–0.346	–0.248	–0.293	1.000

KRN: kernel row number, KW: 100-kernel weight, GY: grain yield, KOC: kernel oil content
** – significant at P≤0.01
* – significant at P≤0.05

kernel row number, while low correlations were found between oil content and 100-kernel weight, and between oil content and grain yield.

Grain yield was in significant, medium strong and positive correlative relation with 100-kernel weight in both studied populations. In the population where we used line 568/II NS as a tester, we established highly significant, strong and positive coefficient of correlation between grain yield and kernel row number, while correlation between these two traits in the second population was medium strong and negative.

In both studied testcross populations, kernel oil content was in low and negative phenotypic correlation with kernel row number (Table 3). Low correlations were also found between oil content and other studied traits (100--kernel weight and grain yield), but in NSU$_1$ × B73 the correlation was negative, and in the second studied population these traits were positively correlated.

In testcross population where inbred line B73 was used as a tester, negative direct effect was found for all studied traits (Table 4), which is highly significant. Indirect influence of these traits on other studied traits was also significant, except for the 100-kernel weight via grain yield per plant.

In the second studied population, NSU$_1$ × 568/II NS, grain yield also showed highly significant and negative direct influence on kernel oil content. Indirect effect of grain yield via kernel row number and 100-kernel weight was positive and significant. Direct influence of other studied traits was significant (kernel row number) and highly significant (100-kernel weight), but it was positive.

DISCUSSION

Mean value of a trait of interest is one of the most important genetic parameters which are used to evaluate a population's genetic potential. If a trait has lower mean

TABLE 3

Phenotypic correlations for NSU$_1$ × B73 (above diagonal) and NSU$_1$ × 568/II NS (below diagonal).

Trait	KRN	KW	GY	KOC
KRN	1.000	–0.246	0.101	–0.100
KW	–0.338	1.000	0.442	–0.166
GY	0.156	0.230	1.000	–0.006
KOC	–0.052	0.104	0.133	1.000

KRN: kernel row number, KW: 100-kernel weight, GY: grain yield, KOC: kernel oil content

TABLE 4

Path coefficient analysis for kernel oil content based on genetic correlations.

Pathway	Population	
	$NSU_1 \times B73$	$NSU_1 \times 568/II$ NS
Kernel row number vs. Kernel oil content		
Direct effect	**–0.832****	0.157*
Indirect effect via 100-kernel weight	0.045	–0.094
Grain yield	0.200	–0.409
100-kernel weight vs. Kernel oil content		
Direct effect	**–0.262****	0.153**
Indirect effect via Kernel row number	0.142	–0.096
Grain yield	–0.345	–0.305
Grain yield vs. Kernel oil content		
Direct effect	**–0.577****	**–0.511****
Indirect effect via Kernel row number	0.289	0.126
100-kernel weight	–0.157	0.091
Coefficient of determination (R^2_{y123})	0.8665**	0.0575

** – significant at P≤0.01
* – significant at P≤0.05

value, more selection cycles will be necessary for its multiplication *(8)*. The changes in population mean value represent indirect selection success *(11)*. In population $NSU_1 \times B73$, highly significant mean values were observed for kernel row number and kernel oil content, while 100-kernel weight had highly significantly lower mean values in this population. According to Lonquist and Lindsay *(12),* significant differences which appear between used testers may be explained by the assumption that one of the testers has higher frequencies of desired dominance alleles, and therefore masks the influence of undesired alleles in the studied population. Therefore, 568/II NS is closer to the definition of a better tester given by Hull *(13)* for kernel row number and oil content, whereas B73 is a more suitable tester for 100-kernel weight.

One of the parameters that enable the determination of genetic population values is correlations between studied traits. Genetic correlations have a great importance in the selection, showing the direction of changes in studied traits influenced by the selection *(8)*.

The values of genetic correlation coefficients between kernel oil content and other studied traits obtained in this paper are partially in agreement with the results obtained by various authors in a previous study. El Rouby and Penny *(14)*, studying correlations between oil content and morphological traits, found low and negative correlations between oil content and 100-kernel weight and grain yield. The obtained results for 568/II NS testcrosses are in accordance with the results of the above mentioned authors. However, in another studied testcross combination ($NSU_1 \times B73$) we also obtained negative correlation coefficient between these traits but correlations were medium strong, which is opposite to the results of El Rouby and Penny *(14)*. Furthermore, results obtained in our research are partly similar to the results of Rosulj *et al. (15)*. These authors estimated changes in oil content and morphological traits in two synthetic populations of maize (DS7u and YuSSSu) after nine cycles of mass selection. In the initial cycles of selection, they found medium strong (in DS7uC0 $r_a = 0.48$) and no correlation (in YuSSSuC0 $r_a = 0.08$), but positive correlation between kernel oil content and grain yield, but after nine cycles of selection the relation between these two traits was also medium strong and low, but negative. Sumathi *et al. (16)* also found negative relation between oil content, and 100-kernel weight and grain yield, while our results are opposite to the results of Saleem *et al. (17),* who found low and positive correlation between oil content and grain yield.

In both studied populations, we found medium strong and significant values of genetic coefficient of correlations between grain yield and 100-kernel weight. These results are in accordance with the results of Sofi *et al. (18),* and partly similar with results of Sumathi et al. *(16)*. Sumathi *et al. (16)* also found medium strong correlations between these two traits, but in their research the correlation was negative. Contrary to our results, Alvi *et al. (19)* found a strong correlative relation between grain yield and 100-kernel weight, and Malik *et al. (20)* found a low relation between these two traits. In B73 testcrosses, grain yield was negatively correlated with kernel row number, which is opposite to the results of many authors *(16, 18, 19, 20),* while in the second studied population between these two traits a strong, highly significant correlation was found.

Mutual effect of genetic and environmental factors on the relation between traits is indicated by phenotypic correlation coefficient. The difference occurring between phenotypic and genetic correlation shows the modification of traits caused by environmental factors *(21)*.

In the first studied population (NSU$_1$ × B73), oil content was in a negative, low phenotypic correlative relation with all studied traits. In the second population (NSU$_1$ × 568/II NS), a positive correlation with all traits, except for kernel row number, was obtained. The results of our study are partially in accordance with the research of El Rouby and Penny *(14)*. They obtained a low, negative correlation between oil content and 100-kernel weight, and low positive, phenotypic correlations between oil content and grain yield. Mišević *et al. (22)* obtained negative, medium strong correlations between oil content and kernel weight for two high oil maize populations. For both test-cross populations, we obtained low correlation between oil content and kernel weight. Our results are partly similar to results of Lambert *et al. (23)* who found low negative correlation between oil content and kernel weight. The values of phenotypic correlation coefficient between oil content and 100-kernel weight, which were obtained for both studied populations, are low, but in the first studied population the coefficient of correlation is negative, and in the second population the correlation between oil content and 100-kernel weight is positive. Studying the genetic potential of two testcross combinations, Mittelmann *et al. (24)* obtained a low correlation between oil content and grain yield. According to this research, in NSU$_1$ × 568/II NS we obtained a low, positive phenotypic correlation between these two traits. For B73 testcrosses, a low but negative value of correlation coefficient was established.

In both studied populations, grain yield was in positive and low phenotypic correlations with kernel row number. Opposite to our results, Alvi *et al. (19)* found a medium strong phenotypic correlation between these two traits. Also, opposite to the results of this study, Rafique *et al. (25)* determined a strong correlation between grain yield and kernel row number. With 100-kernel weight, in the population where we used inbred line B73 like a tester, grain yield was in medium strong, positive correlations, which is in agreement with the results of Alvi *et al. (19),* but opposite to the research of Ojo *et al. (26)* who found a negative correlation between these two traits.

In both studied test-cross populations, path coefficient analysis showed highly significant and negative direct influence of grain yield per plant on kernel oil content. Indirect effect of grain yield via other studied traits (kernel row number and 100-kernel weight) was significant, and positive via all traits, except via 100-kernel weight in population where we used line B73 as a tester. In this population we also found highly significant, but undesirable direct influence of kernel row number and 100-kernel weight. In the second studied population, NSU$_1$ × 568/II NS, a significant (kernel row number) and highly significant (100-kernel weight) desirable effect was found. The value of genetic coefficient of determination for oil content and all morphological traits was highly significant, in the first evaluated population (NSU$_1$ × B73). It indicates that the studied traits, kernel row number 100-kernel weight and grain yield, have mutual influence on kernel oil content.

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