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Relationships between selected traits of maize cultivars differing in leaf blade senescence rates

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Abstract. Analysis of relationships between traits is an important stage in research. These results determine the decisions taken at further stages of research as well as those made when realising successive experiments. The paper presents results of an analysis of relationships between twelve traits of two types of maize (*Zea mays* L.) cultivars differing in leaf blade senescence rates: ES Palazzo and ES Paroli SG. Analysed traits: assimilation surface area (ASA), ear weight (EW), ear weight fraction (EWF), leaf area index (LAI), leaf area ratio (LAR), leaf weight (LW), leaf weight fraction (LWF), number of leaves (NL), plant weight (PW), specific leaf area (SLA), stem weight (SW) and stem weight fraction (SWF). Recorded results indicate positive correlations between: LW–SW, LW–PW, EW–SW, PW–SW, EW–PW, EW–EWF, SLA–LAR and negative correlations of LW–SLA, LAR–SW, PW–SLA, PW–LAR, SWF–EWF for both types of maize cultivars in all the three years of experiments.

Keywords: correlations, *Zea mays* L., scatterplot

INTRODUCTION

Contemporary crop cultivars exhibit a much greater yielding potential in comparison to cultivars developed in the past (Bocianowski et al., 2011; Bocianowski and Seidler-Łożykowska, 2012; Seidler-Łożykowska et al., 2013; Skuza et al., 2013). This results first of all from genetic progress, and increasingly from the insight gained into cultivation technology and practical application of technical change by agricultural producers. Selection of the right maize variety for the specific farming area does not involve additional production expenses, while it can bring material benefits of up to 20% in increased seed yields.

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However, it needs to be remembered that all maize cultivars offered in farming are heterotic hybrids. For this reason they have to be renewed annually, since self-reproduction results in grain yield reduction by as much as 20–30% and inferior grain ripening. For several years now in the selection of maize cultivars stay-green type cultivars have been available, in which grain ripening occurs on a green stem (Thomas and Howarth, 2000; Bekavac et al., 2002). Thomas and Smart (1993) characterised the stay-green character as phenotypes exhibiting delayed senescence and having higher water and chlorophyll contents in leaf blades in comparison to conventional cultivars.

Individual variation in different maize cultivars and their response to specific habitat conditions have been studied for several years now at the Department of Agronomy, the Poznań University of Life Sciences (Szulc, 2010; Szulc and Bocianowski, 2011a,b). Among the multitude of investigated problems studies concerning morphology of stay-green plants, particularly in terms of their growth and development, have been scarce (Szulc, 2009). Morphological and developmental traits, being components of the genetically determined life strategy of a given type of cultivars, are key parameters in the identification of interrelationships between different types of maize cultivars. The index analysis is a method applied in studies of plant growth, consisting in the determination of changes in the accumulation of dry matter and assimilation surface area throughout ontogenesis and calculation of special indices that are a combination of measurable traits. This method comprises calculations of growth rate and the rate of accumulation of organic matter, mainly dry matter, as well as the growth rate of assimilation organ area and indices pertaining to the structure of plants or their individual parts. The application of mathematical methods in the index analysis of growth facilitates studies on the dynamics of productivity and makes it possible to model the course of growth and accumulation of dry matter. The hypothesis of the experiment assumed that the genetic profile of a hybrid shapes the morphological characteristics of plants and the relations between them.

The aim of this study was to analyse interdependencies between several morphological traits of two types of maize cultivars, i.e. ES Palazzo and stay-green type ES Paroli.

MATERIAL AND METHODS

Material for the study comprised two types of maize varieties – ES Palazzo [FAO 230-240] and ES Paroli [FAO 250] of the "stay-green" type (photo 1). They are cultivars differing in the rate of leaf blade senescence. Samples for analyses were collected each year at the cob flowering stage (BBCH 67). Each experimental plot consisted of four rows. Samples for analyses were taken from two middle rows of each plot, treating the outer rows as the so-called sowings (isolation).

Photo 1. The difference in the appearance of two types of maize in adolescence.

The field experiment was performed at the Department of Agronomy of the Poznań University of Life Sciences, in the fields of the Experimental and Teaching Station in Swadzim (52°26'N; 16°45'E) in 2009, 2010 and 2011. It was conducted in a split-plot´split-block design with three research factors in four field replications. The experiment studied the effect of four doses of urea $CO(NH_2)_2$ – (0, 50, 100, 150 kg N ha^{-1}) and two doses of magnesium (0, 25 kg MgO ha^{-1} in the form of kieserite [25% MgO, 50%SO_3 – 20% S, sulfur and sulfate]) on the analysis of active organ growth in the process of photosynthesis in both types of maize varieties.

Previous studies showed the effect of years, cultivars, years×cultivars interactions and a lack of the effect of nitrogen or magnesium doses on values of individual traits (Szulc et al. 2013). Thus in this study an interdependence of observed traits was analysed for individual cultivars in successive years of observations when eliminating the effect of nitrogen and magnesium doses. Phosphorus at a dose of 80 kg P_2O_5 ha^{-1} was used in the form of granular triple superphosphate 46% P_2O_5, and potassium at a dose of 120 kg K_2O ha^{-1} as potassium salt 60% K_2O. Nitrogen was applied according to the scheme of the experiment. Nitrogen, phosphorus and potassium fertilizers as well as kieserite were applied before sowing of maize.

Tillage and other elements of agricultural technology were implemented according to maize cultivation recommendations in seed technology.

Soil under study according to the FAO classification was an Albic Luvisol, originated from loam sands, lying on sandy loam. According to the Polish agronomic evaluation, this soil represents a good rye complex.

Morphological measurements were taken in 2009, 2010 and 2011. The following parameters were analysed: assimilation surface area, ASA [cm^2]; ear weight, EW [g]; ear weight fraction, EWF [%]; leaf area index, LAI; leaf area ratio, LAR [SLA×LWF]; leaf weight, LW [g]; leaf weight fraction, LWF [%]; number of leaves, NL [pcs]; plant weight, PW [g]; specific leaf area, SLA [cm^2 g^{-1}]; stem weight, SW [g]; and stem weight fraction, SWF [%]. Detailes were described in a study by Szulc et al. (2013).

Firstly, the normality of distribution of the traits was tested using Shapiro-Wilk's normality test (Shapiro, Wilk, 1965). The minimum, mean and maximum values as well as the standard error, coefficient of variation, kurtosis and skewness coefficients were calculated for each trait and for both types of maize cultivars. The relationships between the traits were estimated using the correlation coefficients and tested by the *t*-test for both cultivar types and for three years independently. Data analyses were performed using the GenStat v. 17 statistical package.

RESULTS

All observed traits were characterised by a normal distribution (Table 1). Both measures of kurtosis and coefficients of asymmetry (skewness) in all the investigated cases were slight (Table 1). In turn, statistically significant correlation coefficients for traits in 2009, 2010 and 2011 are presented in Tables 2, 3 and 4, respectively. The largest number of statistically significantly correlated pairs of traits was observed in 2009 (Table 2), and the lowest in 2010 (Table 4). In all the three years of the study and for both maize cultivars significant positive correlations were observed between LW–SW, LW–PW, EW–SW, PW–SW, EW–PW, EW–EWF, SLA–LAR, SW–SWF, SLA–SW, EW–LAR; while the negative correlations were for LW–SLA, LAR–SW, PW–SLA, PW–LAR, SWF–EWF (Tables 2, 3, 4).

Moreover, for ES Palazzo statistically significant correlations were observed for the following pairs of traits in all the three years of the study: SW–SWF (a positive correlation) as well as EW–LWF, EW–SWF (negative correlations) (Tables 2, 3, 4). In the case of cv. ES Paroli SG in

Table 1. Summary statistics for phenotypic values of the studied traits in 2009–2011.

Trait	Cultivar	Mean ± standard error	Range	Coefficient of variation [%]	Kurtosis	Skewness
NL	ES Palazzo	10.745±0.07	9.25–12.50	6.62	0.187	-0.541
	ES Paroli SG	10.422±0.06	9.00–12.00	5.97	0.348	-0.431
LW	ES Palazzo	99.89±1.62	67.80–138.05	15.9	0.182	-0.832
	ES Paroli SG	105.83±1.73	65.10–145.88	15.99	0.187	-0.352
SW	ES Palazzo	339.8±7.7	195.4–575.4	22.3	0.782	0.290
	ES Paroli SG	316.9±7.8	215.2–555.9	24.1	0.994	0.422
EW	ES Palazzo	235.8±7.6	115.0–407.2	31.6	0.217	-1.064
	ES Paroli SG	209.8±6.2	108.0–371.5	29.1	0.417	-0.568
PW	ES Palazzo	675.5±13.3	396.4–1030.0	19.4	0.227	-0.487
	ES Paroli SG	632.5±12.5	388.3–930.0	19.3	0.400	-0.529
ASA	ES Palazzo	3614±70	2436–4855	19.0	0.370	-1.199
	ES Paroli SG	3895±57	2532–4915	14.1	0.179	-0.649
SLA	ES Palazzo	36.7±0.74	22.53–54.88	19.7	0.413	-0.021
	ES Paroli SG	37.5±0.70	26.24–56.67	18.36	0.595	-0.177
LWF	ES Palazzo	14.97±0.17	12.38–19.52	10.97	0.883	0.162
	ES Paroli SG	16.9±0.17	13.84–20.89	9.55	0.330	-0.538
LAR	ES Palazzo	547.7±11.5	327.2–794.7	20.7	0.049	-0.624
	ES Paroli SG	632.2±12.2	389.5–911.4	19.0	0.187	-0.835
SWF	ES Palazzo	50.5±0.68	37.07–66.73	13.14	0.284	-0.378
	ES Paroli SG	50.07±0.62	37.15–60.78	12.12	-0.279	-1.118
EWF	ES Palazzo	34.54±0.72	16.05–48.92	20.45	-0.067	-0.522
	ES Paroli SG	33.03±0.68	21.84–46.11	20.03	0.505	-0.987
LAI	ES Palazzo	2.517±0.059	1.677–3.657	22.83	0.582	-0.888
	ES Paroli SG	2.885±0.048	1.809–3.782	16.27	0.381	-0.644

NL – number of leaves, LW – leaf weight, SW – stem weight, EW – ear weight, PW – plant weight, ASA – assimilation surface area, SLA – specific leaf area, LWF – leaf weight fraction, LAR – leaf area ratio, SWF – stem weight fraction, EWF – ear weight fraction, LAI – leaf area index

Table 2. The correlation matrix for the traits# studied for ES Paroli SG (above diagonal) and ES Palazzo (below diagonal) in 2009.

	NL	LW	SW	EW	PW	ASA	SLA	LWF	LAR	SWF	EWF	LAI
NL	1	ns	ns	ns	ns	ns	-0.36 *	ns	ns	ns	ns	ns
LW	0.60 ***	1	0.88 ***	0.75 ***	0.93 ***	0.81 ***	-0.78 ***	ns	-0.66 ***	ns	ns	0.740 ***
SW	0.52 **	0.82 ***	1	0.67 ***	0.96 ***	0.81 ***	-0.59 ***	ns	-0.68 ***	0.45 **	ns	0.71 ***
EW	0.42 *	0.73 ***	0.45 **	1	0.84 ***	0.49 **	-0.73 ***	ns	-0.83 ***	ns	0.45 *	0.48 **
PW	0.60 ***	0.93 ***	0.89 ***	0.81 ***	1	0.78 ***	-0.71 ***	ns	-0.78 ***	ns	ns	0.70 ***
ASA	ns	0.64 ***	0.54 **	0.39 *	0.57 ***	1	ns	ns	ns	0.40 *	-0.41 *	0.97 ***
SLA	-0.53 **	-0.53 **	-0.45 *	-0.45 **	-0.53 **	ns	1	ns	0.86 ***	ns	ns	ns
LWF	ns	ns	-0.48 **	-0.42 *	-0.49 **	ns	ns	1	0.41 *	ns	ns	ns
LAR	-0.51 **	-0.51 **	-0.59 ***	-0.56 ***	-0.66 ***	ns	0.89 ***	0.62 ***	1	ns	ns	ns
SWF	ns	ns	0.37 *	-0.64 ***	ns	ns	ns	ns	ns	1	-0.98 ***	ns
EWF	ns	ns	ns	0.73 ***	ns	ns	ns	ns	ns	-0.98 ***	1	ns
LAI	ns	0.60 ***	80.45 **	0.39 *	0.53 **	0.97 ***	ns	ns	ns	ns	ns	1

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; ns – non-significant
# see Table 1

Table 3. The correlation matrix for the traits# studied for ES Paroli SG (above diagonal) and ES Palazzo (below diagonal) in 2010.

	NL	LW	SW	EW	PW	ASA	SLA	LWF	LAR	SWF	EWF	LAI
NL	1	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
LW	ns	1	0.73 ***	0.45 **	0.83 ***	ns	-0.87 ***	0.40 *	-0.65 ***	ns	ns	-0.46 **
SW	ns	0.65 ***	1	0.35 *	0.90 ***	ns	-0.73 ***	ns	-0.84 ***	0.53 **	-0.43 *	-0.37 *
EW	ns	ns	0.35 *	1	0.71 ***	ns	-0.40 *	ns	-0.59 ***	-0.56 ***	0.69 ***	ns
PW	ns	0.70 ***	0.89 ***	0.72 ***	1	ns	-0.78 ***	ns	-0.88 ***	ns	ns	-0.44 *
ASA	ns	0.52 **	ns	ns	ns	1	0.37 *	ns	0.51 **	ns	ns	-0.38 *
SLA	ns	-0.74 ***	-0.59 ***	ns	-0.64 ***	ns	1	ns	0.84 ***	ns	ns	ns
LWF	ns	0.46 **	ns	-0.53 **	ns	0.48 **	ns	1	ns	ns	ns	ns
LAR	ns	ns	-0.67 ***	-0.66 ***	-0.76 ***	0.49 **	0.65 ***	0.63 ***	1	ns	ns	ns
SWF	ns	ns	0.51 **	-0.58 ***	ns	ns	ns	ns	ns	1	-0.92 ***	ns
EWF	ns	ns	ns	0.75 ***	ns	ns	ns	-0.45 **	ns	-0.90 ***	1	ns
LAI	0.35 *	ns	ns	-0.49 **	-0.46 **	ns	0.44 *	ns	0.59 ***	ns	ns	1

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; ns–non-significant
# see Table 1

Table 4. The correlation matrix for the traits# studied for ES Paroli SG (above diagonal) and ES Palazzo (below diagonal) in 2011.

	NL	LW	SW	EW	PW	ASA	SLA	LWF	LAR	SWF	EWF	LAI
NL	1	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
LW	0.59 ***	1	0.90 ***	0.52 **	0.84 ***	ns	-0.72 ***	ns	-0.66 ***	0.40 *	-0.36 *	ns
SW	0.43 *	0.86 ***	1	0.62 ***	0.92 ***	ns	-0.57 ***	ns	-0.66 ***	0.45 **	ns	ns
EW	ns	0.51 **	0.53 **	1	0.87 ***	ns	ns	-0.72 ***	-0.54 **	-0.40 *	0.56 ***	ns
PW	0.45 **	0.83 ***	0.89 ***	0.86 ***	1	ns	-0.47 **	-0.41 *	-0.68 ***	ns	ns	ns
ASA	ns	ns	ns	ns	ns	1	0.67 ***	ns	0.59 ***	ns	ns	0.95 ***
SLA	-0.40 *	-0.73 ***	-0.54 **	ns	-0.50 **	0.85 ***	1	ns	0.89 ***	-0.39 *	0.41 *	0.72 ***
LWF	ns	0.41 *	ns	-0.51 **	ns	ns	-0.47 **	1	ns	0.54 **	-0.77 ***	ns
LAR	ns	-0.65 ***	-0.57 ***	-0.44 *	-0.60 ***	0.84 ***	0.95 ***	ns	1	ns	ns	0.62 ***
SWF	ns	ns	0.41 *	-0.54 **	ns	ns	ns	0.49 **	ns	1	-0.96 ***	ns
EWF	ns	ns	-0.36 *	0.60 ***	ns	ns	ns	-0.70 ***	ns	-0.96 ***	1	ns
LAI	ns	ns	ns	ns	ns	0.93 ***	0.79 ***	ns	0.79 ***	ns	ns	1

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; ns–non significant
# see Table 1

all the three years of the observations LW–EW were positively correlated, while negative correlations were found for LAR–LW (Tables 2, 3, 4). LAI and ASA for cv. ES Paroli SG were positively correlated in 2009 and 2011, and negatively correlated in 2010 (Tables 2, 3, 4). This may indicate a strong effect of years on the expression of leaf area index and assimilation surface area. The other significant correlation coefficients were observed for no more than two years of observations.

DISCUSSION

A larger variation in traits was found for cv. ES Palazzo than for ES Paroli SG, except for LW and SW (Table 1). This means that the stay-green cultivar is more equalized than the traditional form. A greater smoothing in the stay-green hybrid shows that values of individual morphological traits do not fluctuate within an extensive range (are more stable) under the influence of changing weather conditions (e.g. excessive precipitation, or atmospheric drought). In turn, the hybrid ES Palazzo responded more strongly to changing weather conditions than did ES Paroli SG. This proves, for example, that plant morphological traits are decided both by weather conditions and hybrid type. Genetic variability of varieties derived from the process of heterosis cultivation of F1 hybrids. Currently cultivated maize varieties are F1 hybrids, characterized by an identical genotype and varietal differences arise from genotype of the hybrid parental components (paternal and maternal lines).

Analysis of trait interdependencies is an important stage in research. Results of this analysis determine the decisions taken at further stages of research as well as those made when realising successive experiments. Gas exchange between environment and plant takes place mainly through the leaf surface. Intensity of development and maintaining active assimilation area for a long time significantly affect also the amount of effectively captured solar radiation and therefore dry matter accumulation (Muchow, Davies, 1988). Pandey et al. (2000) stated that maize genotypes differ in the number of developed leaves, growth rate and biomass production under the conditions of different amounts of water and nitrogen. Appearance of subsequent leaves results from several biochemical reactions, usually controlled by temperature, which determines the rate of leaf appearance and time of leaf development (Bonhomme, 2000). The use of nitrogen and plant nutrition with this nutrient has no influence on the rate of leaf blade appearance in maize (Vos et al., 2005).

Also the volume of generative yield of the stay-green hybrid was more stable, compared to that of the traditional cultivar. In an earlier study by Szulc and Bocianowski (2011b) a greater positive effect was shown for total precipitation in the period from 15.07 to 15.08 on the yield volume of maize than the effect of air temperature. The relationship between the volume of grain yield and precipitation total of the 15.07–15.08 period under the adopted experimental conditions was stronger in the stay-green cultivar than in the traditional hybrid. This indicates a greater productivity of such cultivars at increased amounts of precipitation. In contrast, in the case of water deficit the stay-green hybrid should also yield more consistently as longer lifespan and period of assimilation capacity contribute to more effective photosynthesis.

CONCLUSIONS

1. The stay-green maize hybrid was characterized by a greater smoothing of analyzed traits than the traditional form.
2. The observation of correlations for several traits in the traditional maize cultivar ES Palazzo and the stay-green hybrid ES Paroli in all the three years of the experiments provides accurate inference in future experiments with no need to conduct observations of all traits.
3. Variable temperature and humidity conditions prevailing in the growing season of maize and the profile of a maize hybrid (variety) markedly affect the morphological traits of the plant.

REFERENCES

Bekavac G., Stojaković M., Ivanović D., Jacković N., Vasić B., Purar J., Boćanski J., Nastasić N., 2002. Relationships of stay green trait in maize. Genetika, 34(1): 33-40.

Bocianowski J., Kozak M., Liersch A., Bartkowiak-Broda I., 2011. A heuristic method of searching for interesting markers in terms of quantitative traits. Euphytica, 181: 89-100.

Bocianowski J., Seidler-Łożykowska K., 2012. The relationship between RAPD markers and quantitative traits of caraway (*Carum carvi* L.). Industrial Crops and Products, 36: 135-139.

Bonhomme R., 2000. Bases and limits to using 'degree.day' units. European Journal of Agronomy, 13: 1-10.

Muchow R.C., Davies R., 1988. Effect of nitrogen supply on the comparative productivity of maize and sorghum in a semi-arid tropical environment II. Radiation interception and biomass accumulation. Field Crops Research, 18: 17-30.

Pandey R.K., Maranville J.W., Chetima M.M., 2000. Deficit irrigation and nitrogen effects on maize in a Sahelian environment. II. Shoot growth, nitrogen uptake and water extraction. Agriculture and Water Management, 46: 15-27.

Seidler-Łożykowska K., Bocianowski J., Król D., 2013. The evaluation of the variability of morphological and chemical traits of the selected lemon balm (*Melissa officinalis* L.) genotypes. Industrial Crops and Products, 49: 515-520.

Shapiro S.S,. Wilk M.B. 1965. An analysis of variance test for normality (complete samples). Biometrika, 52: 591-611.

Skuza L., Rogalska S.M., Dyba S.M., Bocianowski J., 2013. RAPD polymorphism in the prebreeding material for cultivation of synthetic variations of lucerne (*Medicago sativa* L.). Central European Journal of Biology, 8(1): 38-47.

Szulc P., 2009. Effect of nitrogen fertilization and methods of magnesium application on chlorophyll content, accumulation of mineral components, and morphology of two maize hybrid types in the initial growth period. Part III. Morphological features of plants. Acta Scientiarum Polonorum, 8(2): 63-75.

Szulc P., 2010. Effect of differentiated levels of nitrogen fertilization and the method of magnesium application on the utilization of nitrogen by two different maize cultivars for grain. Polish Journal of Environmental Studies, 19(2): 407-412.

Szulc P,. Bocianowski J., 2011a. Hierarchy of mineral uptake in the creation of generative yield. Fresenius Environmental Bulletin, 20(8a): 2135-2140.

Szulc P., Bocianowski J., 2011b. Variability and correlation of components of grain yield structure of two different types of maize cultivars (*Zea mays* L.). Fresenius Environmental Bulletin, 20(10a): 2684-2692.

Szulc P., Bocianowski J., Rybus-Zając M., 2013. Influence of soil supplementation with nitrogen and magnesium on the size of assimilation area of maize cultivars (*Zea mays* L.) differing in genetic profile. Electronic Journal of Polish Agricultural Universities, 16(2), #01.

Thomas H., Howarth J.C., 2000. Five ways to stay green. Journal of Experimental Botany, 51: 329-337.

Thomas H., Smart C.M., 1993. Crops that stay green. Annals of Applied Biology, 123: 193-219.

Vos J., Putten P.E.L., Birch C.J., 2005. Effect of nitrogen supply on leaf appearance, leaf growth, leaf nitrogen economy and photosynthesis capacity in maize (*Zea mays* L.). Field Crops Research, 93: 64-73.

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