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Correlations Between Various Characters of Inbred Strains of Corn and the Relationship Between Inbred Strains and their Hybrids Tested at Three Different Ecological Locations

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Summary. 1. The different reactions of inbred strains and hybrids often influence yield performance under different ecological conditions. Because of the negative correlation between length of vegetation period and yield of the hybrids (r = –0.473) it was possible in some cases to obtain higher yields in a shorter vegetation period up to tasseling and silking. In kernel yield, the relationship between inbred strains and their hybrids was small. Here, specific combining ability is much more important, and length of vegetation period did not show any apparent direct influence.

Only in cases of a combination of both high-yielding performance and appropriate day length and temperature could high yields be obtained under corresponding climatic conditions.

2. Dry matter content in kernels at harvest time was distinctly influenced by length of vegetation period (r = 0.639 for inbred strains and r = 0.767 for hybrids). Correlation between strains and hybrids in dry matter content of kernels was not very close (r = 0.335).

3. Grain yield was much more influenced by the number of kernels per plant in inbred strains (r = 0.572) than in hybrids (r = 0.338), but there was no dependence of the number of kernels per plant on length of vegetation period. The number of kernels was much more influenced by the number of rows per ear (r = 0.761 for inbred strains and 0.531 for hybrids), by diameter of ear (r = 0.672 and r = 0.414) and by length of ear (r = 0.684 and 0.657) respectively. For these characteristics the correlation between inbred strains and hybrids was distinct for length of ear (r = 0.537) and number of kernels per plant (r = 0.384) only. Some strains, however, did show a closer correlation in these characteristics.

4. Yield is influenced quite clearly by TKW as well (r = 0.546 for inbred strains and 0.703 hybrids). There was no relationship between the other tested characters and TKW. The inheritance of these characters between inbred strains and hybrids was quite clear, especially for Cr Mi (r = 0.808).

5. Cob percentage (in % d.m. of the whole ear) was only weakly inherited by some of the lines, for example, F 2. Between kernel yield and cob percentage, a negative correlation with r = –0.542 for the inbred strains and r = –0.307 for the hybrids could be found.

Key words: *Zea mays* – Correlations of various characteristics – Regressions

Introduction

Inbred lines of corn from various parts of the world have been studied for their physiological reaction to growth and development and their influence on the performance of both inbred strains and hybrids (Hejazi 1974; Schuster et al. 1976; Schuster and Hejazi 1977; Černjul 1977; Schuster et al. 1978). These investigations have been continued with further inbred lines and the results are given in this paper. Strains from the USA could be included. Francis et al. (1969) considered them to be neutral in photoperiod and showing partial long-day reaction until the determination of the flower ('D'-stage). Such types may be of special interest for hybrid selection under long-day conditions as in Central and Northern Europe. According to Francis (1970) lines with neutral photoperiod are the basis of a good adaption to different climatic conditions. A number of papers exist on different reactions of inbred strains and hybrids to photoperiod and temperature as well as on cold resistance of corn. These have been reviewed by Hejazi (1974) and Černjul (1977).

In this study, the inbred strains and their related hybrids have been grown in climatic chambers, 12 and 18 h of daylength, each with low (8°C night and 18°C day =

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13°C average temperature) and high temperature (15°C night and 25°C day = 20°C average temperature). Schuster et al. (1978) already reported on growth and development of this material under controlled conditions in comparison to the field experiments carried out at three different ecological locations. The results of the trials of both inbred strains and hybrids from Trauen (Northern Germany), Groß-Gerau (near Frankfurt) and Zagreb (Yugoslavia) are given elsewhere (Černjul 1977).

In this paper, the correlations between several traits and the dependence of hybrid performance on that of their parental strains are presented.

Material and Methods

The field experiments were carried out in 1973 and 1974 at the following sites:

1. Trauen in the Lüneburger Heide, near Münster, at 10°6′ longitude, 52°56′ latitude, 76 m altitude; humus sand (podsolized heath soil), average temperature of the year 7.6°C and average rainfall 800 mm.
2. Groß-Gerau (Institute of Agronomy and Plant Breeding, University of Gießen) in the Rhine-Main area near Frankfurt. 8°29′ longitude, 49°56′ latitude, 90 m altitude, light humus sand, average temperature 9.5°C, average rainfall 590 mm.
3. Zagreb-Bodinez (Institute of Plant Breeding, Zagreb, Yugoslavia) 15°39′ longitude, 45°49′ latitude, and 122 m altitude; loam soil, average temperature 16.3°C, average rainfall 880 mm.

A fourth location, Stara Susica in Yugoslavia in the mountains of Gorshi-Kotar at 740 m altitude, 120 km southwest from Zagreb, long-range average 7.3°C and 1922 mm rainfall, had to be excluded in both years because the kernels did not attain full maturity.

The following strains were tested:

No.	Line	Country of origin	Maturity groep
1	F7	France	Early
2	F2	France	Early
3	L1	Yugoslavia (Zagreb)	Very early
4	116 (= Co 106)	Canada	Medium early
5	CV3	Canada	Medium early
6	Me 16	USA	Early
7	Ms 206	USA (Michigan)	Medium early
8	MeF 56-66-7	USA	Medium early
9	Gi 471/69 (= Ima)	Germany (Gießen)	Medium late
10	Gi 509	Germany (Gießen)	Medium late
11	Bc 28	Yugoslavia (Zagreb)	Medium early
12	Bc 29 A	Yugoslavia (Zagreb)	Medium early
13	Cr Mi	USA	Medium early
14	Bc 5	Yugoslavia (Zagreb)	Medium late
15	Bc 5B	Yugoslavia (Zagreb)	Medium late
16	Bc 153	Yugoslavia (Zagreb)	Late
17	W 153 R	USA (Wisconsin)	Late
18	Ia 153	USA (Iowa)	Late
19	Fc 33	France	Late
20	C 153	USA (Connecticut)	Late

These 20 lines were grown in both years, whereas the single hybrids of the diallel crossing, which were produced in Zagreb in 1973, were only grown at the four locations in 1974.

All field trials were carried out in two plantings, the first at optimal sowing time and the second three weeks later. In Zagreb the second planting had to be resown in 1974, which made a difference of 6 weeks relative to the first planting.

The plot size was 7.0 qm and consisted of 40 plants, 20 plants in each of the two rows, which were 5 m long. The spacing was 0.7 × 0.25 m. The experiments were carried out in blocks with two replications.

All records during vegetation period and after harvest were done on 10 plants per plot = 20 plants per trial.

The data of the 66 single hybrids and their parental strains, which were grown in 1974 in the same locations side by side (Černjul, 1977) were used for correlation and regression analyses.

Results

1 Correlations Between Different Characters

Simple correlation coefficients between 19 characters, using the data of the inbred strains, are given in Table 1 and those of the hybrids are given in Table 2. For each of the correlations the same set of data was not always available because results of the field trials in Trauen in 1974 could not be fully used. There was, however, sufficient data available for the statistical test.

In both tables, the closest relationship was found between kernel yield in dt/ha and kernel yield per plant. The thousand kernel weight has a greater influence on the yield of hybrids (with $r = 0.703$ and 0.690) than on the inbred strains (with $r = 0.546$ and with $r = 0.521$). The number of kernels per plant is of greater importance for the yield of the inbred strains ($r = 0.572$ and $r = 0.686$) than it is for the hybrids. For both, inbreds and hybrids, the relationship between TKW and number of kernels per plant is not very close. The correlation between TKW and number of kernels per ear was even less and not significant for the inbreds whereas for the hybrids the expected negative correlation, with $r = -0.424$, could be found.

The number of kernels per ear did not directly influence the kernel yield. The number of rows per ear is also of less importance for the yield. Between number of kernels per plant and number of rows per ear a distinct correlation, with $r = 0.761$ for the inbreds and $r = 0.531$ for the hybrids, could be observed. No clear relationship between number of kernels per plant and kernel number per ear could be found for the hybrids.

The grain number per plant was greatly influenced by the number of kernels per row ($r = 0.966$ and $r = 0.931$ for the inbred strains and the hybrids, respectively). Only for the inbreds is there a clear relationship with the yield per ha ($r = 0.622$) and the yield per plant ($r = 0.738$), whereas for the hybrids a medium high correlation with $r = 0.550$ could be found as far as the yield per plant was concerned. Ear length correlation coefficients of $r = 0.683$ for the inbred strains and of $r = 0.694$ for the hybrids could be calculated. From the data of the breds, the correlation between kernel number per row and row number per ear, r = 0.621, and between kernel number per row and ear diameter, r = 0.621, are of some interest.

Ear diameter is clearly correlated, especially for the inbreds but less for the hybrids, with kernel number per plant (r = 0.672) and with the number of rows per ear (r = 0.640) but not with kernel number per ear.

Kernel yield is influenced by ear length more in the inbreds, r = 0.542 and r = 0.602, but less in the hybrids (r = 0.474 and 0.589). A distinct correlation exists with the kernel number per plant. In the inbreds, correlations between ear length and row number per ear as well as ear diameter, could be stated, whereas, and this is not quite understandable, no correlation could be found between ear length and kernel number per plant.

The negative relationship of cob percentage on yield is particularly clear for the inbreds, with r = –0.542 and r = –0.491. The vegetation period from emergence until silking is negatively correlated to yield for the hybrids only, hence, similar relationships for the individual sections of the vegetation period with a correlation from r = –0.459 to r = –0.557 could be observed.

The interdependence of the individual sections of the vegetation period is especially clear for the hybrids where r = 0.947 and r = 0.887 could be found. For the inbreds, however, the correlations were much less, except between emergence and determination (D-stage) and between emergence and B-stage, with r = 0.958. The time from tasseling to silking is only slightly negatively correlated to the yield for the inbreds as well as for the hybrids. Only for this time does a closer correlation exist with the other sections of the vegetation period (r = 0.607 and 0.684, respectively), while the association between the other sections of the vegetation period and yield is less consistent (r = 0.318 to r = 0.590).

Dry matter content of the grains is associated with kernel yield only for the hybrids (r = 0.762 and 0.707). There are clear negative correlations, especially for the hybrids, between dry matter content of the grains and the duration of the individual sections of the vegetation period, even to the very early stages from emergence until D- and B-stage. For the period from emergence until B, correlations of r = 0.420 and r = 0.849 for the inbreds and the hybrids, respectively, could be calculated.

Plant height and ear length are positively correlated for both hybrids (r = –0.639) and inbred strains (r = 0.503). Plant height and kernel number per row showed an association of r = 0.690 for the hybrids only. In the hybrids, a positive relationship with yield (r = 0.507) could be found, which is probably due to heterosis. The time from emergence until tasseling and silking is – as was found for kernel yield – negatively correlated with plant height, r = –0.512 and r = –0.462 for the inbred strains and r = –0.449 and r = 0.473 for the hybrids.

Ear position is closely correlated with plant height, with r = 0.826 and r = 0.837 for the inbreds and the hybrids, respectively. For the hybrids, a connection between ear position and number of grains per row with r = 0.559 could be found, which might be due to the correlation between plant height and ear length. No relationship between number of ears per plant and any of the other characters could be found.

2 *Relationship Between Inbred Strains and Their Hybrids*

As various investigations have shown, the value of an inbred line has to be evaluated through test-crosses (review of literature is given by Haile 1976). Obviously some of the characters of the strains are inherited in different manners. In this study, diallel crossing was carried out with a set of 12 strains. The hybrids and their corresponding strains have been tested in 1974 in field trials at two planting times at three locations. By means of correlation- and regression analyses the inheritance of several characters of the strains has been studied.

The mean values of 14 characters from both inbred strains and hybrids are given in Table 3. As expected, hybrids surpass line performance in all cases. Heterosis (difference between mean value of the parental lines and the hybrid mean) is highest for kernel yield per plant, showing an increase from 29.8 to 102.2 g. Kernel yield per hectar also showed great hybrid vigor. There was in increase from 19.5 dt/ha to 69.1 dt/ha (average of all 12 lines) for the hybrids. The largest increase could be observed for MeF 56-55-7, CV 3, and Gi 417/69.

The hybrids did not show such an increase in TKW (186.7 g and 232.4 g for the inbred strains and the hybrids, respectively). Here differences between the strains could be observed as well. The hybrids of Me 16 had the smallest, and those of Gi 509 the highest increase in TKW.

The number of kernels per plant must have had a stronger influence on the yield as shown by the increase from 145.3 (inbreds) to 392.1 (hybrids) kernels per plant. For this character the greatest difference between inbred strains and hybrids could be found for strains MeF 56-55-7 and Cr Mi, while L 1 had the smallest difference.

For a number of rows per ear only slight heterosis could be observed (11.1 to 13.9). The greatest increases were again found for those two strains which had shown the highest increase in number of kernels per plant, whereas Gi 471/69 showed the least difference from the hybrids.

Ear diameter for the hybrids was 1 cm larger than for the inbred strains. Here, the relationship between number of kernels, number of rows per ear and ear diameter is also apparent since the hybrids of Cr Mi and Me F 56-55-7,

Table 1. Correlations between different characters in inbred strains of corn. Data from field trials in 1973 and 1974 at Trauen, Groß Gerau and Zagreb (n = 160-240)

	Kernel yield dt/ha d.m. 1	Kernel yield g/plant 2	TKW 3	Kernel number per plant 4	Row number per ear 5	Ear diameter 6	Ear length cm 7	Cob percentage in % d.m. 8	Sprouting – 'D' – days 9
Kernel yield dt/ha d.m.									
Kernel yield g/plant	0.944[b]	–							
TKW	0.546[b]	0.521[b]	–						
Kernel number per plant	0.572[b]	0.686[b]	0.260[b]	–					
Row number per ear	0.317[b]	0.372[b]	0.086	0.761[b]	–				
Ear diameter	0.432[b]	0.478[b]	0.253[b]	0.672[b]	0.640[b]	–			
Ear length cm	0.550[b]	0.602[b]	0.497[b]	0.684[b]	0.517[b]	0.647[b]	–		
Con percentage in % d.m.	−0.542[b]	−0.491[b]	−0.209[b]	−0.391[b]	−0.290[b]	−0.359[b]	−0.200[a]	–	
Sprouting – 'D' – days	−0.168[a]	−0.181[a]	−0.161	0.033	0.036	−0.047	−0.014	−0.005	–
Sprouting – 'B' – days	−0.145[a]	−0.171[a]	−0.192[a]	−0.041	−0.028	−0.108	−0.052	0.030	0.958[b]
Sprouting – tasseling – days	−0.041	−0.114	−0.200	−0.283	−0.226[b]	−0.221[b]	−0.220[b]	0.004	0.488[b]
Sprouting – silking – days	−0.168[a]	−0.250[b]	−0.277[b]	−0.300[b]	−0.192[b]	−0.233[b]	−0.276[b]	0.025	0.586[b]
Tasseling – silking – days	−0.288[b]	−0.336[b]	−0.243[b]	−0.191[b]	−0.040	−0.137[a]	−0.215[b]	0.109	0.561[b]
% d.m. of the kernels	0.232[b]	0.213[b]	0.352[b]	0.034	−0.060	−0.207[b]	0.030	−0.045	−0.455[b]
Kernel number per row	0.622[b]	0.738[b]	0.306[b]	0.966[b]	0.621[b]	0.634[b]	0.683[b]	−0.418[b]	0.003
Plant height cm	0.131	0.183[b]	0.301[b]	0.428[b]	0.395[b]	0.443[b]	0.503[b]	−0.025	0.108
Height of ear cm	0.078	0.078	0.241[b]	0.318[b]	0.226[b]	0.284[b]	0.349[b]	−0.021	0.238[b]
Ear number per plant	0.057	0.019	−0.148	0.026	0.014	0.065	0.006	−0.142	0.071
Kernel number per ear	0.072	0.128	0.022	0.097	0.054	0.020	−0.038	−0.169[a]	0.369[b]

[a]significantly different from 0 at P 0.05
[b]significantly different from 0 at P 0.01

which showed the highest heterosis effect, are again highest in heterosis.

Ear length increased from 11.8 to 18.0 cm. The differences between the strains was less distinct. CV 3 increased in ear length from 9.5 to 17.9 cm for the hybrids, while Bc 28 and Bc 29 A with 24.5 had a smaller difference from their hybrids (18.9 and 18.7 cm respectively).

Cob percentage decreased from 29.7% (inbreds) to 18.7% (hybrids). For this character too, clear differences between the strains could be observed. While strain Gi 509 only reduced cob percentage from 24.8% to 20.1%, MeF 56-55-7 with 41.0% decreased to 16.8% for the hybrids.

All sections of the vegetation period were shorter for the hybrids than for the inbred strains. In particular, faster development of the hybrids could be observed for the period from sprouting to silking where, on an average, the hybrids were 10 days earlier than the inbreds. For this character strain differences could also be observed. Me 16 did not substantially reduce the vegetation period of its hybrids whereas the hybrids of Bc 29 A developed much faster than the strain itself. The time from tasseling until silking was reduced from 10.6 days for the inbred strains to 7.9 days for the hybrids. The hybrids of F 2 were even 1 day later than the strain itself.

In dry matter content of the grains, heterosis could also be observed. On the average, d.m. content increased from 65.1% to 69.3%. The greatest increase could be found for the hybrids of the late strains Bc 28 and Bc 29 A, while in the hybrids of the early F 2 only a slight increase of the dry matter content could be observed.

The correlation coefficients in Table 4, show even more clearly the relation between inbred strains and their hybrids. The influence of every single strain may be seen from the regression coefficients of Table 5. A high correlation coefficient means a close relation between inbred and hybrid performance, without saying anything about the increase of the performance. Only the coefficient of regression explains how mych hybrid performance increases when the regarded character of the line is increased by one unit. High correlation plus high regression coefficients

Table 1. (Continued)

	Sprouting – 'B' – days	Sprouting – tasseling days	Sprouting – silking – days	Tasseling – silking – days	% d.m. of the kernels	Kernel number per row	Plant height cm	Height of ear cm	Ear number per plant	Kernel number per ear
	10	11	12	13	14	15	16	17	18	19
Kernel yield dt/ha d.m.										
Kernel yield g/plant										
TKW										
Kernel number per plant										
Row number per ear										
Ear diameter										
Ear length cm										
Con percentage in % d.m.										
Sprouting – 'D' – days										
Sprouting – 'B' – days	–									
Sprouting – tasseling – days	0.600[b]	–								
Sprouting – silking – days	0.679[b]	0.935[b]	–							
Tasseling – silking – days	0.563[b]	0.318[b]	0.607[b]	–						
% d.m. of the kernels	–0.420[b]	–0.638[b]	–0.632[b]	–0.152	–					
Kernel number per row	–0.065	–0.267[b]	–0.299[b]	–0.221[b]	0.059	–				
Plant height cm	0.016	–0.512[b]	–0.462[b]	–0.109	0.181[a]	0.382[b]	–			
Height of ear cm	0.157[a]	–0.426[b]	–0.371[b]	–0.034	0.181[a]	0.312[b]	0.816[b]	–		
Ear number per plant	0.080	0.130	0.114	0.041	–0.061	0.030	–0.002	–0.147[a]	–	
Kernel number per ear	0.345[b]	0.145[a]	0.187[b]	0.214[b]	–0.190[a]	0.096	–0.067	0.018	–0.082	–

imply high inheritance of the line for the character under study. Correlation and regression over all 12 inbred lines were r = 0.243 and b = 0.478 for kernel yield in dt/ha and r = 0.461 and b = 0.942 for single plant yield in g. For the individual strains distinct statements can be made.

For kernel yield in dt/ha the highest correlation between inbred strains and hybrids could be found for F 2, where a regression coefficient of b = 2.07 could be calculated. Ms 206 also showed a close correlation of r = 0.587 and a b value of 1.99. On the contrary, for line MeF 56-55-7, correlation and regression were negative. This implies that with an increase of inbred performance the yield of the hybrids will decrease. The strains CV 3, Gi 471/69, L 1 and Cr Mi had small correlations; the b values showed an increase in the related hybrids of 2.2 for Gi 471/69 and 1.3 for L 1. High correlations for yield per plant with r = 0.7 were found for F 2, Ms 206, Be 29 A and Cr Mi. Here, high regressions of 3.4 g for Gi 471/69 to 2.6 g for Cr Mi could be found. This means that with an increase in plant yield of the lines by 1 g, the hybrids increased in plant yield by 3.4 and 2.6 g, respectively.

Correlation and regression between all 12 inbred strains and their hybrids were r = 0.263 and b = 0.336 for TKW. Cr Mi had the closest correlation and the highest b value with r = 0.808 and b = 1.58. For F 2, negative values (r = –0.402 and b = –1.43) were calculated. This means that this line has a negative influence on the TKW of its hybrids, even if, on an average, the TKW increased from 245 to 275 g from the inbreds to the hybrids, respectively.

The overall correlation between inbred strains and hybrids for number of kernels per plant with r = 0.384 was not very high, and the b value was only 0.525. The closest correlation was found to be r = 0.700 for the strains 116, CV 3, and Bc 29 A. The highest increases could be found in their related hybrids of CV 3 with b = 2.0, Gi 471/69 with b = 1.8, MeF 56-55-7 with b = 1.6 and F 2 with b = 1.5. For dry matter content, overall relation was also small (r = 0.335, b = 0.197). Highest correlations for this character were Bc 29 A with r =

Table 2. Correlations between different characters in corn hybrids. Data from field trials in 1973 and 1974 at Trauen, Groß-Gerau and Zagreb (n = 792)

	Kernel yield dt/ha d.m. 1	Kernel yield g/plant 2	TKW 3	Kernel number per plant 4	Row number per ear 5	Ear diameter 6	Ear length cm 7	Cob percentage in % d.m. 8	Sprouting – 'D' – days 9
Kernel yield dt/ha d.m.									
Kernel yield g/plant	0.937[b]	–							
TKW	0.703[b]	0.690[b]	–						
Kernel number per plant	0.338[b]	0.541[b]	0.188[b]	–					
Row number per ear	0.145[b]	0.166[b]	–0.024	0.531[b]	–				
Ear diameter	0.369[b]	0.395[b]	0.119	0.414[b]	0.474[b]	–			
Ear length cm	0.474[b]	0.589[b]	0.356[b]	0.657[b]	0.207[b]	0.392[b]	–		
Cob percentage in % d.m.	–0.307[b]	–0.191[b]	–0.331[b]	0.159[b]	0.094	0.280[b]	0.289[b]	–	
Sprouting – 'D' – days	–0.524[b]	–0.517[b]	0.249[b]	–0.120[a]	0.058	–0.152[b]	–0.168[b]	–0.244[b]	–
Sprouting – 'B' – days	–0.535[b]	–0.557[b]	0.193[b]	–0.186[b]	0.054	–0.163[b]	–0.204[b]	–0.219[b]	0.926[b]
Sprouting – tasseling – days	–0.473[b]	–0.535[b]	0.147[a]	–0.282[b]	0.021	–0.187[b]	–0.279[b]	–0.249[b]	0.895[b]
Sprouting – silking – days	–0.459[b]	–0.544[b]	0.089	–0.287[b]	0.056	–0.163[b]	–0.256[b]	–0.157[a]	0.887[b]
Tasseling – silking – days	–0.242[b]	–0.357[b]	–0.058	–0.173[b]	0.142[b]	–0.015	–0.066	0.119	0.519[b]
% d.m. of the kernels	0.762[b]	0.707[b]	0.420[b]	0.121[a]	–0.051	0.151[b]	0.172[b]	–0.457[b]	0.815[b]
Kernel number per row	0.323[b]	0.550[b]	0.240[b]	0.931[b]	0.210[b]	0.270[b]	0.694[b]	0.158[a]	–0.148[b]
Plant height cm	0.304[b]	0.507[b]	0.117	0.645[b]	0.174[b]	0.363[b]	0.639[b]	0.303[b]	–0.295[b]
Height of ear cm	0.067	0.264[b]	0.049	0.492[b]	0.076	0.229[b]	0.450[b]	0.214[b]	–0.007
Ear number per plant	–0.102[a]	–0.103[a]	0.060	–0.064	0.007	–0.026	–0.087	–0.013	0.174[b]
Kernel number per ear	–0.121[a]	–0.049	–0.424[b]	0.188[b]	0.030	0.036	–0.025	0.350[b]	–0.228[b]

[a]significant different from 0 at 0.05;
[b]significant different from 0 at 0.01

0.540 and Gi 509 with r = 0.450. In all cases, the b values were below 1. The change of 1% d.m. in the line means a smaller increase or decrease in the hybrids, depending on the environmental conditions.

For row number per ear an overall correlation of only r = 0.154 and a b value of 0.117 could be found. The individual strains did not show much difference for this character. The relation to ear diameter (r = 0.259, b = 0.246) was not much closer. In none of the combinations was the b value above 1. Almost the same situation could be seen for ear length though the overall correlation between inbred strains and hybrids with r = 0.537 was somewhat higher.

Overall correlations and regressions for cob percentage gave low values, r = 0.044 and b = 0.018, respectively. In some of the cases negative b values were found for some strains, which is quite understandable, because cob percentage of the hybrids decreases, as could already be seen in Table 3.

Highest r- and b values could be calculated for the duration of the particular sections of the vegetation period. This implies that the length of the vegetation period of the hybrids depends to a great extent on that of their respective inbred strains. For all inbreds the b values were above or close to 1 and not negative. (Within all sections the b values of line Gi 471/69 were greater than 1). For the time from sprouting to tasseling b = 1.6, which means that this strain tends to prolong the vegetation period of its respective hybrids. Correlations and regressions for the time from tasseling to silking were fewer and the differences between the lines were greater. The closest relations were found for CV 3 (r = 0.774), Gi 509 (r = 0.716) and Bc 29 A (r = 0.690). Within the period from tasseling to silking the hybrids of these lines are determined by their parental lines up to 50%. The strains F 2, 116 and Me 16 had b values close to 1. The hybrids of these lines prolong this part of the vegetation period, as could already be seen from the mean values in Table 3.

To show the influence of the different reactions of the inbred strains on their hybrids as well as the relationship between climatic reaction and performance, the development of the strains and their hybrids in climatic chambers and at the three sites, as well as the performance of both inbreds and hybrids, are combined in Figure 1. In addition to the most important yield components, number of kernels per plant, TKW, and dry matter content of the

Table 2. (Continued)

	Sprouting – 'B' – days 10	Sprouting – tasseling – days 11	Sprouting – silking – days 12	Tasseling – silking – days 13	% d.m. of the kernels 14	Kernel number per row 15	Plant height cm 16	Height of ear cm 17	Ear number per plant 18	Kernel number per ear 19
Kernel yield dt/ha d.m.										
Kernel yield g/plant										
TKW										
Kernel number per plant										
Row number per ear										
Ear diameter										
Ear length cm										
Cob percentage in % d.m.										
Sprouting – 'D' – days										
Sprouting – 'B' – days										
Sprouting – tasseling – days	0.944[b]	–								
Sprouting – silking – days	0.947[b]	0.975[b]	–							
Tasseling – silking – days	0.590[b]	0.510[b]	0.684[b]	–						
% d.m. of the kernels	–0.859[b]	–0.767[b]	–0.763[b]	–0.451[b]	–					
Kernel number per row	–0.223[b]	–0.325[b]	–0.344[b]	–0.249[b]	0.140[b]	–				
Plant height cm	–0.358[b]	–0.449[b]	–0.473[b]	–0.352[b]	0.170[b]	0.690[b]	–			
Height of ear cm	–0.075	–0.166[b]	–0.206[b]	–0.246[b]	–0.092	0.559[b]	0.837[b]	–		
Ear number per plant	0.168[b]	0.175[b]	0.153[b]	0.030	–0.138[b]	–0.075	–0.061	–0.165[b]	–	
Kernel number per ear	–0.326[b]	–0.297[b]	–0.321[b]	–0.286[b]	0.164[b]	–0.202[b]	0.257[b]	0.228[b]	–0.012	–

kernels from the field trials at Trauen, Groß-Gerau, and Zagreb in 1974 are given in this Figure.

On the whole, high kernel yields of the hybrids of Bc 29 A and Bc 28 could be realized at each of the three locations. As can be seen from Figure 1, these lines were late in their development under long-day and low-temperature conditions. In the field experiment at Trauen these two strains were also especially late. At Zagreb, both, these strains and their hybrids were relatively early.

Gi 471/69, whose hybrids almost reached the kernel yields of Bc 29 A, even showed a clear reaction to temperature under long day, while the vegetation period was clearly reduced under high temperature. The photoperiod reaction of this line, even under high temperature, was not very distinct. Due to this reaction at Trauen, the vegetation period until silking was shorter than for the two strains mentioned above. The dependence of the hybrids on their respective strains is much greater for the number of kernels per plant than for TKW.

Number of kernels per plant were high for Bc 29 A and Gi 471/69 for both inbreds and hybrids. TKW was higher for BC 29 than for the other two lines. Number of kernels per plant is inherited to a greater extent by Bc 29 A than it is for the other two lines. At Trauen in 1974 the hybrids of these three strains had a low yielding capacity. Because of their stronger day-length and temperature reaction, they are too late for this location.

The strains Me 16 and Cv 3, which were the lowest in day-length reaction, or Me 16, which had low-temperature reaction, were earlier in all three locations, and had only poor yields at Groß-Gerau and Zagreb. The hybrids of CV 3, however, were rich in yield and the differences between Groß-Gerau and Zagreb were quite small. At Trauen, the most unfavorable site, the hybrids of Me 16 had the best yield. Thousand kernel weight was relatively high for Me 16 and low for CV 3. Both lines did not show a correlation to the TKW of their hybrids. The number of kernels per plant was low for both strains, and only between CV 3 and its hybrids could a correlation be found. The strains Me 16 and CV 3 as well as their respective hybrids developed fast, which resulted in high dry matter content.

Strain MeF 56-55-7, which Francis (1970) observed to have a long-day tendency, was not grown in the greenhouse, so only data from its hybrids are available. The hybrids throughout show only slight reactions to day

Table 3. Mean values of different characters of inbred strains and their F_1-hybrids. Data from field trials in 1974 at Groß-Gerau and Zagreb (n = 66)

Characteristics \ Line		F2	L1	116	CV3	Me 16	Ms 206	Gi 471	Bc 28	Bc 29A	Cr Mi	MeF 56	Gi 509	Mean
Kernel yield dt/ha d.m.	S	30.7	11.9	25.1	10.1	11.5	16.8	21.9	33.0	24.2	13.0	9.5	26.1	19.5
	H	70.3	55.0	65.2	70.8	66.3	66.6	75.6	73.6	76.0	68.4	68.0	72.8	69.1
Kernel yield g/plant	S	43.7	17.7	40.8	14.6	17.7	26.5	32.2	52.3	39.1	20.5	13.1	39.6	29.8
	H	100.6	81.9	97.7	104.4	98.2	110.4	110.8	108.3	112.7	101.8	103.2	107.3	102.2
% d.m. of the kernels	S	68.3	68.5	57.3	75.3	75.8	62.3	63.5	55.8	54.0	68.0	66.0	66.3	65.1
	H	68.5	72.1	69.0	71.1	74.5	69.3	65.6	67.9	65.5	68.5	71.2	68.7	69.3
TKW	S	244.8	171.8	198.5	161.3	200.5	197.5	179.0	200.3	176.8	195.8	161.5	152.0	186.7
	H	274.5	234.3	215.3	219.4	220.9	235.4	229.9	243.8	221.4	230.7	225.6	238.0	232.4
Kernel number per plant	S	178.3	119.2	193.5	118.3	113.3	105.3	192.2	192.8	171.3	73.5	64.5	221.2	145.3
	H	340.8	326.9	402.8	432.3	393.0	382.6	418.4	397.8	434.7	400.0	404.2	371.3	392.1
Row number per ear	S	11.2	10.2	12.3	11.3	10.2	10.5	13.7	12.2	11.7	8.7	8.5	12.5	11.1
	H	12.9	13.4	14.0	15.3	12.9	13.3	14.5	14.2	14.5	14.1	13.9	13.4	13.9
Ear diameter	S	3.7	–	3.3	3.5	3.3	3.2	3.8	3.8	3.7	2.8	2.8	3.7	3.4
	H	4.3	–	4.5	4.6	3.9	4.3	4.8	4.5	4.5	4.4	4.4	4.5	4.4
Ear length cm	S	12.7	8.5	10.2	9.5	11.0	11.8	13.3	14.5	14.5	11.7	10.3	13.7	11.8
	H	17.9	15.6	17.0	17.9	18.6	17.4	19.1	18.9	18.7	18.9	17.2	19.0	18.0
Cob percentage in % d.m.	S	23.6	27.8	20.7	30.0	40.0	24.0	34.0	27.9	30.5	31.9	41.0	24.8	29.7
	H	17.7	16.3	19.8	18.2	18.5	17.0	21.3	20.3	18.4	20.3	16.8	20.1	18.7
Sprouting – D – days	S	23.7	21.8	26.2	28.2	20.8	27.2	30.2	32.0	33.2	28.8	28.0	33.7	27.8
	H	22.3	20.4	24.5	24.3	23.1	25.5	24.7	24.0	26.1	24.3	24.9	25.3	24.1
Sprouting – B – days	S	31.2	30.5	34.2	36.7	28.1	36.5	41.0	40.5	43.8	36.7	38.7	41.8	36.6
	H	28.2	26.4	31.2	30.4	28.0	31.8	31.9	30.4	32.8	30.5	30.8	32.1	30.4
Sprouting – tasseling	S	67.7	68.8	74.3	67.2	68.5	75.0	76.3	73.5	79.5	75.2	75.2	77.3	73.2
– days	H	64.3	63.2	66.8	64.5	63.5	67.3	68.9	64.9	68.1	67.2	65.5	68.3	66.1
Sprouting – silking	S	71.7	74.5	88.7	84.0	113.3	82.8	86.0	88.5	92.3	85.5	80.7	88.8	86.4
– days	H	69.4	67.7	75.0	73.2	113.3	73.2	76.3	73.8	75.8	73.8	72.0	75.9	76.6
Tasseling – silking	S	5.0	6.6	10.3	18.0	8.7	8.8	10.8	15.8	13.8	11.3	6.3	12.2	10.6
– days	H	6.1	5.3	9.2	9.5	8.1	6.8	8.4	9.9	8.5	7.5	7.3	8.6	7.9

S = inbred strain H = hybrid.

Table 4. Correlations of different characters between inbred strains and their F_1-hybrids. Data from field trials in 1974 at Groß-Gerau and Zagreb (n = 66).

Characteristics \ Strain	F2	L1	116	CV3	Me 16	Ms 206	Gi 471	Bc 28	Bc 29A	Cr Mi	MeF 56	Gi 509	Total
Kernel yield dt/ha d.m.	0.471[c]	0.306[a]	0.274[a]	0.393[b]	–0.147	0.587[c]	0.303[a]	0.119	0.434[c]	0.443[c]	–0.448[c]	0.253[a]	0.243[a]
Kernel yield g/plant	0.726[c]	0.595[c]	0.600[c]	0.537[c]	0.144	0.792[c]	0.544[c]	0.602[c]	0.750[c]	0.785[c]	0.151	0.587[c]	0.461[c]
% d.m. of the kernels	–0.142	0.210	0.244[a]	–0.177	0.119	0.233	–0.073	0.332[b]	0.540[c]	0.272[a]	0.004	0.450[c]	0.335[b]
TKW	–0.402[b]	0.284[a]	0.214	–0.078	–0.088	0.471[c]	0.172	0.393[c]	0.383[c]	0.808[c]	0.164	–0.310[b]	0.263[a]
Kernel number per plant	0.340[b]	0.140	0.702[c]	0.738[c]	–0.258[a]	0.648[c]	0.652[c]	0.681[c]	0.795[c]	0.428[c]	0.447[c]	0.527[c]	0.384[b]
Row number per ear	–0.070	–0.083	0.205	0.189	0.043	0.208	0.236[a]	0.014	0.155	0.100	0.094	–0.122	0.154
Ear diameter	–0.126	–	0.364[b]	0.156	–0.071	0.271[a]	0.290[a]	0.502[c]	0.405[c]	0.273[a]	0.000	0.289[a]	0.259[a]
Ear length cm	0.186	0.492[c]	0.618[c]	0.401[b]	0.057	0.634[c]	0.690[c]	0.608[c]	0.440[c]	0.585[c]	0.593[c]	0.470[c]	0.537[c]
Cob percentage in % d.m.	0.436[c]	0.243[a]	–0.026	0.387[b]	–0.053	–0.425[c]	0.470[c]	–0.235[a]	0.169	0.199	–0.067	0.251[a]	0.044
Sprouting – D – days	0.867[c]	0.893[c]	0.860[c]	0.942[c]	0.851[c]	0.896[c]	0.901[c]	0.932[c]	0.909[c]	0.885[c]	0.835[c]	0.927[c]	0.828[c]
Sprouting – B – days	0.898[c]	0.879[c]	0.918[c]	0.938[c]	0.851[c]	0.926[c]	0.909[c]	0.937[c]	0.866[c]	0.875[c]	0.879[c]	0.890[c]	0.853[c]
Sprouting – tasseling – days	0.947[c]	0.976[c]	0.828[c]	0.941[c]	0.902[c]	0.942[c]	0.931[c]	0.900[c]	0.961[c]	0.903[c]	0.951[c]	0.968[c]	0.899[c]
Sprouting – silking – days	0.954[c]	0.978[c]	0.641[c]	0.945[c]	0.941[c]	0.952[c]	0.933[c]	0.953[c]	0.959[c]	0.931[c]	0.920[c]	0.963[c]	0.884[c]
Tasseling – silking – days	0.411[c]	0.497[c]	0.535[c]	0.774[c]	–0.218	0.646[c]	0.527[c]	0.607[c]	0.690[c]	0.612[c]	0.258[a]	0.716[c]	0.571[c]

[a]significant different from 0 at P 5%
[b]significant different from 0 at P 1%
[c]significant different from 0 at P 0,1%

Table 5. Regressions (b values) of different characters between inbred strains and their F_1-hybrids. Data from field trials in 1974 at Groß-Gerau and Zagreb (n = 66).

Characteristics \ Line	F2	L1	116	CV3	Me 16	Ms 206	Gi 471	Bc 28	Bc 29A	Cr Mi	MeF 56	Gi 509	Total
Kernel yield dt/ha d.m.	2.066	1.299	0.442	1.593	–0.809	1.991	2.244	0.182	0.757	1.550	–1.217	1.288	0.478
Kernel yield g/plant	2.598	3.082	0.953	2.999	0.737	2.552	3.402	0.807	1.298	2.602	0.725	1.822	0.942
% d.m. of the kernels	–0.167	0.057	0.114	–0.359	0.118	0.159	–0.079	0.230	0.549	0.275	0.003	0.470	0.197
TKW	–1.430	0.374	0.198	–0.277	–0.097	0.655	0.283	0.540	0.544	1.579	0.241	–0.568	0.336
Kernel number per plant	1.499	0.273	0.796	2.044	–0.572	1.577	1.811	0.759	0.834	1.347	1.599	1.050	0.525
Row number per ear	–0.107	–0.084	0.290	0.198	0.040	0.255	0.545	0.019	0.169	0.091	0.091	–0.212	0.117
Ear diameter	–0.136	–	0.386	0.152	–0.068	0.400	0.309	0.385	0.455	0.382	0.000	0.341	0.246
Ear length cm	0.527	0.595	0.538	0.303	0.104	0.736	0.869	0.885	0.418	0.488	0.749	0.706	0.479
Cob percentage in % d.m.	0.340	0.134	–0.048	0.256	–0.016	–0.222	0.540	–0.140	0.061	0.090	–0.013	0.265	0.018
Sprouting – D – days	1.057	1.042	1.118	1.213	1.598	1.210	1.109	0.719	0.743	0.914	1.026	0.808	0.844
Sprouting – B – days	1.090	0.893	1.141	1.018	1.072	1.439	1.337	0.869	0.897	0.819	0.847	0.818	0.861
Sprouting – tasseling – days	1.172	1.032	0.848	1.124	0.852	1.327	1.606	1.039	1.068	0.969	1.061	1.096	0.977
Sprouting – silking – days	1.271	1.070	0.497	0.952	1.069	1.078	1.116	0.872	0.831	0.922	1.018	0.835	0.824
Tasseling – silking – days	1.258	0.697	1.072	0.576	–0.272	0.510	0.352	0.359	0.409	0.565	0.477	0.428	0.375

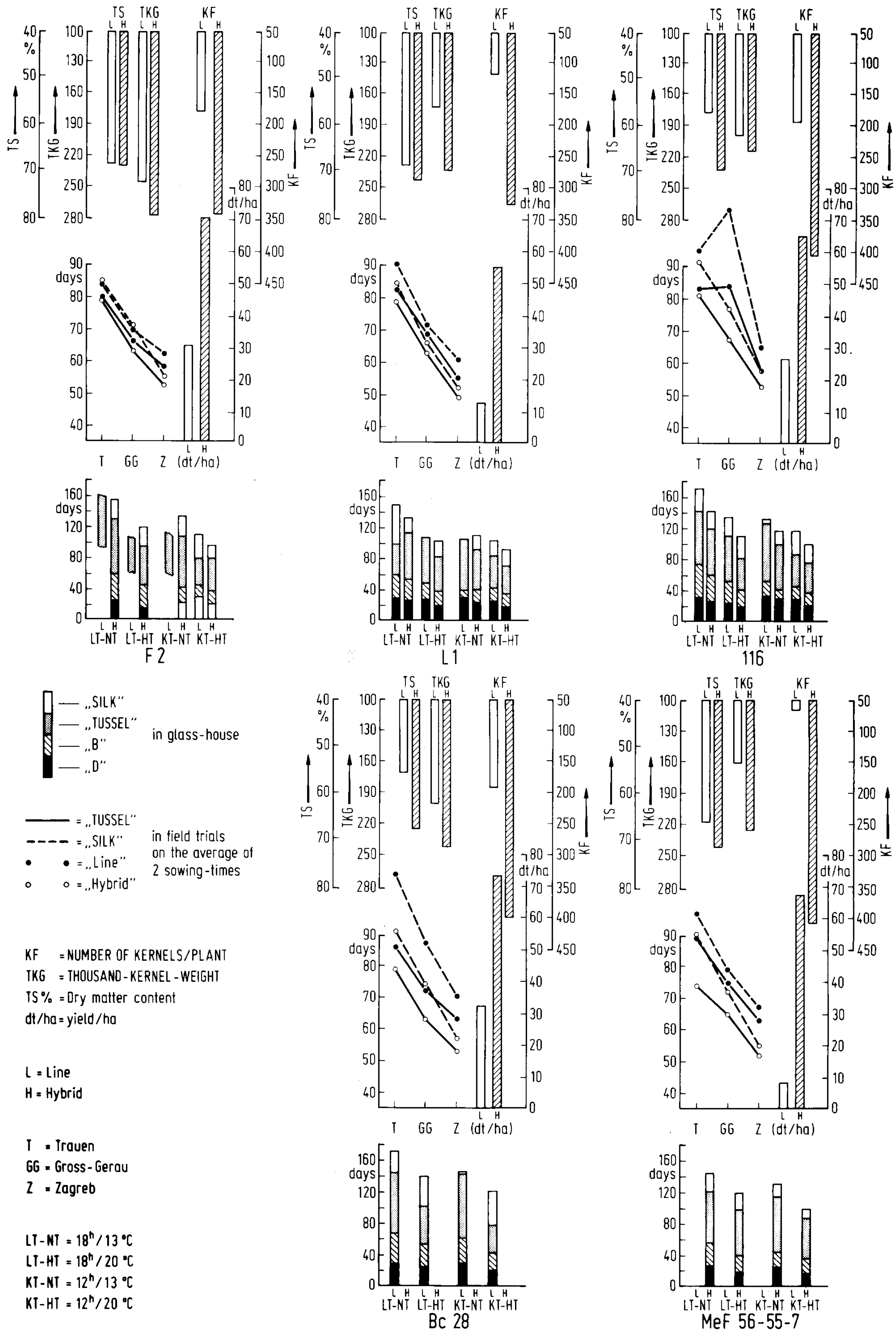
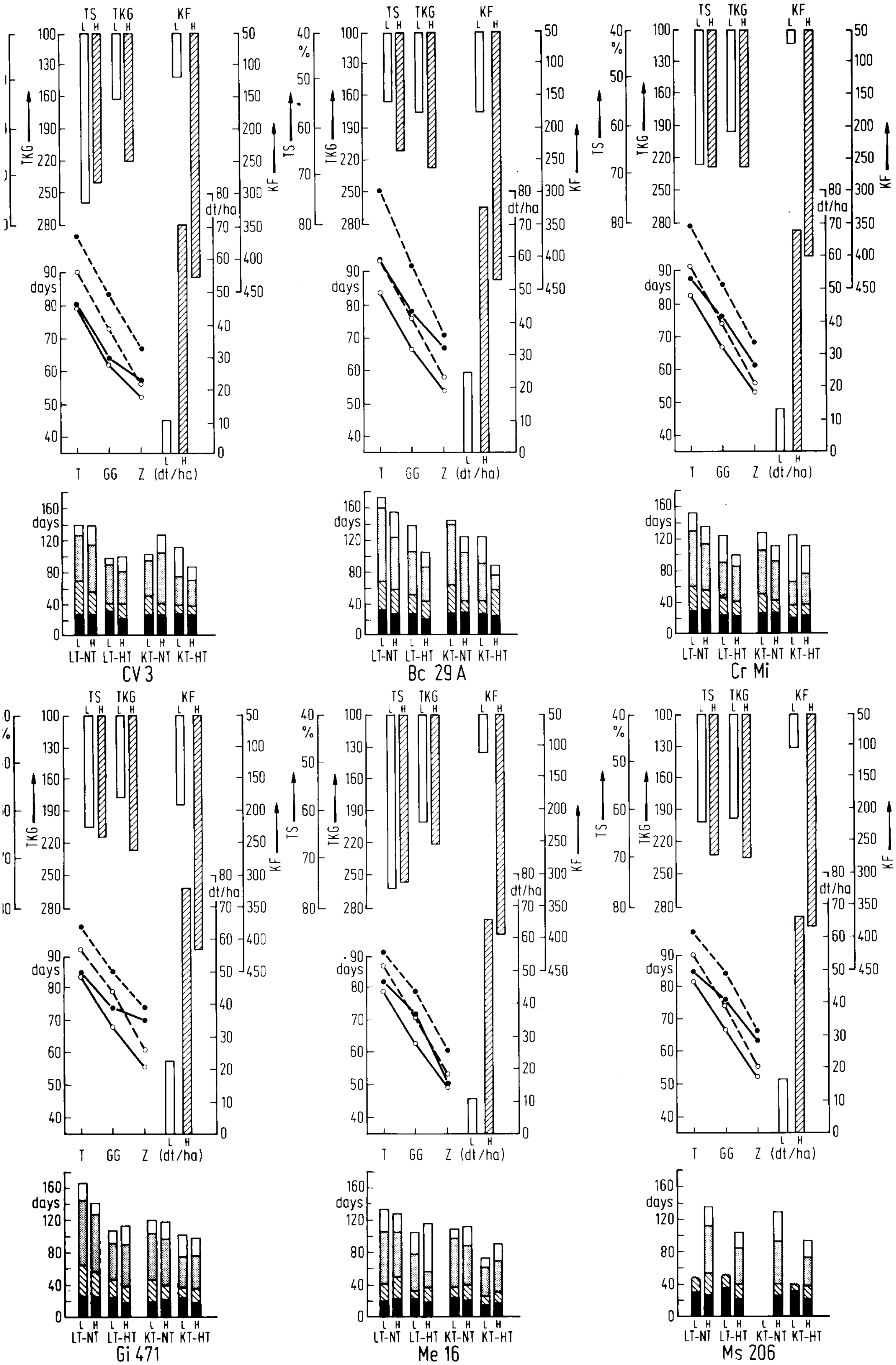


Fig. 1. Relationships between lines and their hybrids in grain yield (dt/ha), dry matter (%), TKW (g), number of kernels per plant an



gth of vegetation period in days under controlled climatical conditions and different locations in 1974 length and temperature. Due to this, the vegetation period was relatively short at Trauen and Groß-Gerau, while in Zagreb, the vegetation period was longer than that for Me 16. Kernel yield of the line with 9.5 dt/ha ranged last. However, heterosis was quite high, and even negative correlation and regression between inbreds and their hybrids could be calculated. This means that corresponding to a decrease in inbred yield, hybrid yield increases. For this strain too, kernel number plant was the most important yield component, while TKW was quite low. For both characters, the hybrids of MeF 56-55-7 showed average values, whereas dry matter content was relatively high.

As also observed by Hejazi (1974) F 2, which was often used in Europe, shows low day-length reaction. Both, the inbred strain and the hybrids had a short vegetation period which could be observed very well at Groß-Gerau and Trauen. Compared to the short vegetation period, kernel yield was quite high for the inbred strain and the hybrids. Though TKW and number of kernels per plant were high, the hybrids increased only minimally. Even if the inbred strain and the hybrids developed fast, dry matter content was quite low.

Strain L 1, which is also early, showed stronger day-length reactions. While for both inbreds and hybrids vegetation period increased under long day and especially under low temperature, a particular short vegetation period due to a short day and high temperature could be observed. On the average of the locations, yield performance of the strain and the hybrids was poor in 1974. This may depend on a small number of kernels per plant and a low TKW of the hybrids. However, dry matter content of the hybrids was high.

Strain Ms 206 which Francis (1970) denoted neutral in day-length reaction, died early in the greenhouse. Regarding the early stages of development of the strain and the whole vegetation period of the hybrids, day-length neutrality could be proved, as could be done for Me 16. For all three locations the vegetation period of the inbred strain and the hybrids was medium. Kernel yield, also, was not very high. Though TKW was quite high and number of kernels per plant low, a distinct correlation between inbreds and hybrids for these characters could be found.

Line 116, widely used in Europe, showed only low reactions to temperature, especially in short-day conditions, which had already been observed by Hejazi (1974). Compared to Groß-Gerau, this strain was tasseling quite early at Trauen. In 1974, under cooler growing conditions, the yield of the strain was quite high, while the respective hybrids did not yield best. The number of kernels per plant of the 116 hybrids was high and a distinct correlation between inbred strains and hybrids could be found. TKW was medium and no correlation could be established. Dry matter content of the strain was low, which might be due to the long vegetation period at Groß-Gerau. No other strains showed anything of particular interest; therefore no details will be given here.

Discussion and Conclusions

The present paper continues and extends the investigations of Hejazi (1974). The reaction of inbred lines of corn and their respective hybrids to day length and temperature in relation to development and performance have been studied (Schuster et al. 1978). Besides these facts, an interpretation of the inheritance of the physiological reaction, yield, and other important characters between inbred strains and their hybrids should be discovered. The data of the strains and the hybrids were used separately to compute correlations between the various characters. Summarizing the results, it can be seen that in most cases one can conclude from the length of the vegetation period of the inbred strains on that of the hybrids. High correlation coefficients between inbred strains and hybrids for all sections of the vegetation period could be found. Only time from tasseling to silking between inbreds and hybrids was less correlated. The observed quantitative graduation in photoperiodic reaction, as could be seen in the strains Me 16 and CV 3, could also be recognized in their hybrids. In the case of Me 16, this is related to better suitability to the unfavorable site at Trauen. In the hybrids of CV 3, however, only certain combinations were rich in yield under unfavorable climatic conditions. Regarding the results of all lines, it can be seen that a favorable reaction in day length and temperature under North European conditions does not always lead to a higher yielding capacity. Besides favorable climatic reactions, a specific combination of yield-determining factors is needed to realize high yields.

For the obtained data, however, a negative correlation between length of vegetation period and kernel yield was calculated. This means that in many cases early hybrids yielded better than the later ones.

The different inheritance of the characters from the individual lines to their hybrids could be shown quite clearly by means of correlation analyses. This renders strain selection for combining ability more difficult.

Particular strains inherited their yield as well as other important characters quite strongly, while others showed no great inheritance factor for this or that character. Finally, only test crosses can answer the question as to the value and the combining ability of a strain. The employment of strains neutral in day length or having even long-day tendency and a short vegetation period is not sufficient, as the examples of Me 16 and F 2 may show. To realize high yields under appropriate climatic conditions, these characteristics have to be combined with other factors.

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