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Studies on the Combining Ability for Silage Yield and Major Agronomic Characters of Corn

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飼料用 옥수수 選拔을 위한 收量 및 主要形質의 組合能力 分析

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ABSTRACT

This experiment was conducted to identify the superior corn hybrids for silage production and to determine the combining ability of their parental inbred lines. A 7-entry diallel cross was evaluated for grain and stover yields, and agronomic characters under 3 different seasons. Hybrids Hi34 x Tx601, Hi26 x Hi34, and Hi29 x Hi34 showed high total dry matter yields. In general, late maturing hybrids had higher grain and silage yields than early maturing hybrids. Leaf area index was correlated with grain and stover yields. Rust rating was negatively correlated with yields and all characters, indicating that rust (*Puccinia sorghi*) was one of the major factors affecting yields. Diallel analysis showed that inbred Hi34 which was late in maturity and resistant to rust was the best combiner for both grain and silage yields. General combining ability (GCA) and specific combining ability (SCA) effects for yields and other characters were significant, suggesting that both additive and non-additive gene effects are involved for those characters. Ratio of GCA/SCA mean squares showed that GCA effects were more important than SCA effects for yields and other characters. GCA x season and SCA x season interactions were significant for grain and stover yields, revealing that gene effects were not stable for those yields under dissimilar environments.

INTRODUCTION

Corn breeders have devoted considerable effort and expenses to the development of inbred lines of corn with superior combining ability for yields. Dhillon and Singh[7] found that GCA was more important than SCA in the expression of mean yield. Inbreds with high GCA for kernel depth and kernel rows per ear had high GCA for yield[6]. He found significant interactions of GCA with environments for yield, ear length, and kernel rows. It was indicated that the absence of environmental interactions with GCA or SCA for ear traits might be important for development of high yielding hybrids from these inbreds.

Corn silage is widely used for ruminant livestock feeding. In area where early maturity is a major consideration, it is suggested that corn hybrids for silage should be fully as early as the best adapted

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grain hybrids for that region. Thompson[14] reported that late maturing tropical corn grown in North Carolina produced 13 to 41% more dry matter and 4 to 28% more estimated total digestible nutrients than check hybrids. Genter and Camper[9] in Virginia reported that the early maturing hybrids tended to be lower in grain yield and total dry matter than the late maturing hybrids. In general, late maturing corn hybrids have been reported to produce the higher grain and silage yields [1, 5, 12, 13]. High silage yield from late maturing hybrids than early and medium maturing hybrids may be attributed to the longer period of time available for the corn to grow. Giesbrecht[10] reported that the late maturing and taller hybrids were better adapted to competition in high populations than were the early maturing hybrids. However, increased production alone is not necessarily a convincing criterion for practical aspects. Tall growth is a major cause of the lodging problem. Harvest index, the ratio of the grain dry weight to the total above ground dry weight of a crop at maturity, is an index similar to grain/stover ratios used to evaluate a crop partitioning efficiency. Early maturing hybrids had higher harvest index than late maturing hybrids[2, 3]. A high grain/stover ratio in corn silage may be as important as total dry matter production. Many feeders grow productive hybrids to produce a silage with high grain yield and low stover ratios.

Yield components have not been used extensively as selection criteria by plant breeders for improvement of yield. However, selection for the components may be effective during corn inbred development. If such inbreds had greater GCA for yield, the yield components would be useful selection criteria. El-Lankany and Russell[8] observed relatively high phenotypic correlations between yield and yield components. Hartfield et al. [11] in Kenturky observed that the correlation between ear components and grain yield was drastically affected by the environment, suggesting that the genetic yield potential of varieties can not be evaluated by component correlations except as these varieties react to a specific environment. Chase and Nanda[4] observed that there was a significant positive correlation between the number of leaves and number of days to flowering. The objectives of this experiment were to identify superior corn hybrids for silage production and to determine the combining abilities of their parent inbreds for yields and major agronomic characters.

MATERIALS AND METHODS

Twenty one corn hybrids from a 7-entry diallel cross were used in this trial. Parent inbreds used were Hi26, Hi28, Hi29, Hi31, Hi34, and Tx601. Hi26, Hi31, and Hi33 were U.S. Corn Belt inbreds, while Hi28, Hi29, Hi34, and Tx601 were tropical inbreds. All parental inbreds were converted for resistance to virus and other diseases in Hawaii. This experiment was conducted at the Waimanalo Research Station of the University of Hawaii under 3 different seasons. Plantings were made on November 16, 1981, February 2, 1982, and May 5, 1982. These are treated as different seasons, as differences in incident light are very great in these trials. A randomized complete block design with four replications was used in each trials. Plot size was 3.5m x 2 rows of 30 plants with 76cm between rows. Two seeds were planted per hill and thinned to a stand 60,000 plants per hectare after 4 weeks. A preplant fertilizer application equivalent to N-P_2O_5-K_2O= 130-130-100 kg/ha was made and corn plants were side-dressed with 70 kg/ha of nitrogen as urea after thinning. The herbicide was incorporated to control weeds. Overhead sprinkler irrigation was used on a 5-day interval.

Data were recorded for days to tassel emergence, plant height, filled ear length, number of kernel rows, number of kernels per row, 100 kernel weight, and rust rating. Data on barren stalks were collected in the November planting and leaf area index (LAI) was observed in the May planting. Ten plants per plot were recorded for each plant character, and 6 to 7 ears were sampled after harvesting for yield component measurement. Ears were harvested by hand picking, and then stover was cut with sickle. After weighing the stover, 2 to 3 corn stalks were sampled and shredded at field. These shredded stalk samples were dried in a forced air dryer (temp. 60-65°C) to determine moisture content. Grain yields were adjusted to 15.5% moisture and stover yields (including aboveground parts except cobs) were given as dry matter. Total dry matter yield was estimated by summing grain yield and stover yield.

RESULTS AND DISCUSSION

Average total dry matter (TDM), grain and stover yields over 3 plantings are presented in Table 1. The highest TDM yield was observed in Hi34 x Tx601 (12.78T/ha). Hi26 x Hi34 and Hi29 x Hi34 also had high TDM yields, while Hi31 x Hi33 showed the lowest TDM yield. The highest grain yield was observed in Hi26 x Hi34, but the highest stover yield was observed in Hi34 x Tx601 which had the highest TDM yield. The grain/stover ratio ranged from 0.78 (Hi29 x Tx601) to 1.23 (Hi26 x Hi28). This indicated that hybrid Hi26 x Hi28 had the highest quality for silage production. Hybrid Hi34 x Tx601 which showed the highest TDM yield had a little lower grain/stover ratio than average ratio. Among 3 high yielding hybrids for TDM yield, Hi26 x Hi34 would be the best hybrid for silage production as it showed high grain/stover ratio indicating good quality of silage for feeding. In general, hybrids which were high in grain yield had longer filled ear length, more kernel rows perear and kernels per row (Table 2). Correlation coefficients among yields, plant haracters, and yield components are presented in Table 3. There were significant correlations between grain yield and yield components. Stover yield was highly significantly

Table 1. Average total dry matter (TDM), grain and stover yields, grain/stover (G/S) ratio, days to tasseling, plant height, leaf area index (LAI) and rust rating of corn hybrids from a 7-entry diallel evaluated over 3 seasens.

Hybrid	TMD yield	Grain yield	Stover yield	G/S ratio	Days to tassel	Plant height	LAI[1/]	Rust [2/] rating
	T/ha				(day)	(cm)		(1-7)
Hi26 x Hi28	10.98	6.05	4.93	1.23	56.4	233	3.97	2.6
Hi26 x Hi29	9.41	4.90	4.51	1.09	57.2	228	4.00	3.1
Hi26 x Hi31	8.48	4.26	4.22	1.01	56.8	219	3.98	4.5
Hi26 x Hi33	9.22	4.75	4.47	1.06	55.8	225	4.10	4.0
Hi26 x Hi34	12.49	6.70	5.79	1.16	59.3	232	4.40	2.3
Hi26 x Tx601	10.42	5.40	5.02	1.08	58.3	241	4.01	3.3
Hi28 x Hi29	10.61	5.30	5.31	1.00	56.4	227	4.07	3.3
Hi28 x Hi31	10.52	5.61	4.91	1.14	55.8	230	3.95	3.6
Hi28 x Hi33	8.43	4.44	3.99	1.11	54.3	213	3.59	3.8
Hi28 x Hi34	11.02	5.67	5.35	1.06	57.7	222	4.38	2.7
Hi28 x Tx601	10.48	4.94	5.54	0.86	58.3	239	3.97	3.3
Hi29 x Hi31	9.22	4.78	4.44	1.08	56.3	230	3.92	4.8
Hi29 x Hi33	8.96	4.76	4.20	1.13	55.3	217	3.54	4.0
Hi29 x Hi34	12.26	6.10	6.16	0.99	57.9	224	4.52	2.8
Hi29 x Tx601	10.40	4.57	5.83	0.78	58.9	251	3.80	3.4
Hi31 x Hi33	7.70	3.99	3.71	1.08	55.2	216	3.48	5.3
Hi31 x Hi34	9.26	4.71	4.55	1.04	57.8	222	4.16	4.1
Hi31 x Tx601	9.26	4.82	4.44	1.09	58.7	238	3.82	4.1
Hi33 x Hi34	9.60	5.15	4.45	1.16	55.5	209	4.01	3.8
Hi33 x Tx601	9.66	4.65	5.01	0.93	57.2	234	3.94	3.8
Hi34 x Tx601	12.78	5.97	6.81	0.88	60.2	238	4.48	2.6
Mean	10.06	5.12	4.94	1.04	57.1	228	4.00	3.6

1/ : Data in May planting. 2/ : 1-highly resistant, 7-highly susceptible.

Table 2. Average yield components of corn hybrids over 3 seasons and barrenness in November planting.

Hybrid	Filled ear length	Kernel rows per ear	Kernels per row	Kernel weight	Barren-ness
	(cm)			(mg)	(%)
Hi26 x Hi28	12.8	14.1	26.9	27.1	18
Hi26 x Hi29	12.7	12.0	26.4	24.0	24
Hi26 x Hi31	11.7	11.2	21.8	27.9	56
Hi26 x Hi33	13.3	10.7	29.1	25.1	57
Hi26 x Hi34	13.4	12.7	30.4	25.9	15
Hi26 x Tx601	12.9	13.0	27.4	24.5	38
Hi28 x Hi29	13.0	13.9	27.0	25.3	31
Hi28 x Hi31	12.9	13.0	26.2	28.6	45
Hi28 x Hi33	13.3	11.9	27.0	25.3	46
Hi28 x Hi34	13.2	12.7	29.7	25.4	15
Hi28 x Tx601	13.2	13.8	28.8	24.5	39
Hi29 x Hi31	11.4	11.4	21.5	27.1	58
Hi29 x Hi33	12.6	12.5	26.6	23.4	55
Hi29 x Hi34	13.3	12.7	28.3	26.5	15
Hi29 x Tx601	13.0	12.5	26.7	23.7	31
Hi31 x Hi33	11.7	11.1	24.6	23.5	91
Hi31 x Hi34	10.4	11.5	23.0	26.7	31
Hi31 x Tx601	12.1	11.2	23.0	25.2	67
Hi33 x Hi34	12.5	11.7	27.0	25.6	38
Hi33 x Tx601	13.4	12.0	29.0	22.5	42
Hi34 x Tx701	14.1	12.0	30.9	28.6	30
Mean	12.7	12.3	26.7	25.5	40

correlated with all plant characters, such as days to tasseling, plant height, and rust rating. This result shows that late maturing and vigorous taller hybrids had higher silage yield.

In the November planting, severe barrenness was observed due to concentrated heavy rainfall and strong wind. Barrenness ranged from 15 to 91%. Hi26 x Hi34, Hi28 x Hi34, and Hi29 x Hi34 showed relatively lower barrenness (15%), while high barrenness (60-90%) was generally observed in poor yielding hybrids. Hybrid Hi34 x Tx601 which was the highest TDM yield showed a little higher barrenness (30%). Days to tasseling ranged from 54 to 60 days with average 57 days. Hybrid Hi31 x Hi33, the poorest hybrid for TDM yield, was 55 days, while the high yielding hybrid Hi34 x Tx601 was 60 days for days to tasseling. This indicated that the late maturing hybrids produced high silage yields. The result from this trial was consistent with those of other researchs [1, 5, 12, 13, 14]. Plant heights ranged from 209 cm to 251 cm. Generally hybrids which had high TDM yield were tall in plant height. There was a highly significant correlation between days to tasseling and plant height, indicating late flowering hybrids were tall in plant height. Leaf area index was measured only in May planting. The range of LAI was 3.54 (Hi29 x Hi33) to 4.48 (Hi34 x Tx601). Highly significant correlations were observed between LAI and grain and stover yields. Correlation coefficient for stover yield ($r=0.72^{**}$) was higher than grain yield ($r=0.56^{**}$). Hybrids Hi26 x Hi34, Hi29 x Hi34, and Hi34 x Tx601 which were good for silage production showed the highest LAI values. This shows that LAI is an important character to be considered for development of high yielding hybrid for silage production.

Common rust (*Puccinia sorghi*) was unexpectedly severe on these trials. The rust strains in Hawaii in 1981 and 1982 were virulent on all resistant monogenes and notably on the Rp-d allele presented in Hi31. Inbred Hi31 and related B19-derived inbreds have the Rp-d fleck type resistance, but have low level of general resistance. Yields of Hi31 hybrids in this trials were thus reduced inordinately, and relevant GCA values must be interpreted accordingly. Rust ratings were evaluated in 3 planting. The rating scale was from 1 to 7 with a rating of 1 being highly resistant and 7 being highly susceptible. The average rust rating in November, February, and May plantings were 5.2, 2.7, and 2.9, respectively. This indicated that rust *(Puccinia sorghi)* was more severe in cool winter season than spring and summer. The overall average rating over 3 seasons showed that Hi26 x Hi28, Hi26 x Hi34, and Hi34 x Tx601 were relatively resistant, while Hi29 x Hi31 and Hi31 x Hi33 were susceptible to rust. Significant negative correlations were observed between rust rating and grain and stover yields (Table 3). Also, rust rating was negatively correlated to all yield components except kernel weight. These results suggested that rust might be one of the factors reducing corn yield in this

Table 3. Correlation coefficients among yields, plant characters, and yield components over 3 seasons.

Character	Stover yield	Days to tassel	Plant height	Filled ear length	Kenrnel rows per ear	Kernels per row	Kernel weight	Rust rating
Grain yield	0.69**	0.45*	0.22	0.53*	0.57**	0.59**	0.44*	-0.86**
Stover yield		0.78**	0.59**	0.62**	0.49*	0.64**	0.26	-0.77**
Days to tasseling			0.73**	0.26	0.18	0.31	0.15	-0.55*
Plant height				0.29	0.34	0.20	-0.05	-0.36
Filled ear length					0.43	0.89**	-0.09	-0.69**
Kernel rows per ear						0.41	0.05	-0.67**
Kernels per row							-0.16	-0.74**
Kernel weight								-0.19

*,**: Significant at 5% and 1% probability levels, respectively.

trial.

Maturity was recorded on a scale from 1 to 5 in May planting, with 1 being very early and 5 being very late in maturity. Highly significant correlations were observed between maturity rating and grain and stover yields. These relationship also revealed that late maturing hybrids had high grain and stover yields. Combined analysis of variance of grain yield, stover yield, plant characters, and yield components showed that hybrid x season interactions for all characters were highly significant. This indicated that hybrids were different in response of yields, plant characters, and yield components under different seasons.

Estimates of general combining ability (GCA) and specific combining ability (SCA) for grain yield and stover yield are presented in Table 4. GCA effects of 7 parent inbreds indicated that Hi34 was the best combiner for both grain and stover yields, while Hi31 and Hi33 were poor combiners for those yields. The hybrid with the highest SCA effects for grain and stover yields was Hi28 x Hi31 followed by Hi26 x Hi34 and Hi34 x Tx601. GCA effects for yield components showed that Hi26 and Hi28 had positive effects for all of the components, and Hi34 which was the best combiner for yields had the largest effects for number of kernels per row, and kernel weight. GCA effects for plant height showed that T x 601 had positive effects, indicating hybrids from inbred T x 601 were taller in plant height, while inbred Hi 33 had negative value. Combined analysis of combining ability revealed that GCA and SCA effects were highly significant for grain and stover yields, indicating that both additive and non-additive gene effects are involved. Although both GCA and SCA effects were highly significant, GCA effects were more important than SCA effect for both characters when the two mean squares were compared. Ratio of GCA/SCA mean squares for grain and stover yields were 5 and 10, respectively. GCA x season,

Table 4. Estimates of SCA and GCA effects for grain and stover yields over 3 different seasons.

Inbred	SCA effects						GCA effects
	Hi28	Hi29	Hi31	Hi33	Hi34	Tx601	
Hi26	0.38	-0.41	-0.60	-0.07	-0.61	0.10	0.26
	0.04	-0.47	0.09	0.42	0.29	-0.37	-0.13
Hi28		-0.04	0.72	-0.21	-0.45	-0.39	0.29
		0.13	0.56	-0.27	-0.37	-0.09	0.08
Hi29			0.24	0.27	0.34	-0.40	-0.08
			0.01	-0.14	0.36	0.11	0.17
Hi31				-0.05	-0.60	-0.30	-0.52
				0.20	-0.42	-0.44	-0.67
Hi33					-0.12	0.18	-0.57
					-0.43	0.22	-0.76
Hi34						0.22	0.71
						0.57	0.70
Tx601							-0.90
							0.61

Upper and lower values are grain and stover yields, respectively.

Table 5. Combined analysis of combining ability for grain and stover yields, days to tasseling, and plant height.

Source	df	Mean squares			
		Grain yield	Stover yield	Days to tasseling	Plant height
GCA	6	3.14**	4.86**	22.02**	900.17**
SCA	14	0.63**	0.49**	0.59**	68.64**
Season (S)	2	266.79**	113.60**	1021.53**	131589.50**
GCA x S	12	0.26**	0.21**	0.47**	123.08**
SCA x S	28	0.13*	0.30**	0.31*	44.46**
Error	180	0.07	0.08	0.15	22.72

*,**: Significant at 5% and 1% probability levels, respectively.

and SCA x season interactions were significant for both yields. These results revealed that GCA and SCA effects were different in response to different environmental conditions. Plant height and days to tasseling were highly significant for GCA and SCA effect. Also, GCA x season and SCA x season interactions were significant. GCA/SCA ratios for plant height and days to tasseling were 13 and 37, respectively, suggesting that importance of GCA effects for plant characters was greater than for grain and stover yields.

In summary, the highest silage yield of corn was observed in late maturing hybrids, while the early maturing hybrids were very low for silage yield. These results could be explained by the significant correlations between yields and days to tasseling and relative maturity. Most of the plant characters studied were significantly correlated to stover yield. Rust rating was negatively correlated to grain and stover yields, and other characters, indicating that rust disease is one of the major factors reducing silage yield. Diallel analysis revealed that inbred Hi34 which is late in maturity and of high rust resistance was the best combiner for both grain and silage yields. Inbred Hi31 and Hi33, early maturing genotypes of high rust susceptibility, were poor combiners for both yields. Combining ability analysis suggested that GCA and SCA effects were both significant in contributing to the genetic variations of grain and stover yields of corn. The GCA/SCA ratio showed that additive genes effects were more important in the genetic variations. GCA x season and SCA x season interactions were significant for grain and stover yields, indicating that the responses of GCA and SCA effects were different under different environmental conditions.

摘　　要

옥수수 自殖系統의 收量 및 主要形質에 對한 組合能力을 調査하고, 飼料用 單交雜種 옥수수의 選拔을 위하여 7個 自殖系統의 二面交配에서 生産된 21個의 F_1 을 供試하여 3個 環境條件에서 圃場試驗을 實施하였으며 그 結果를 要約하면 다음과 같다.

1. 總乾物重에 있어서는 交雜種 Hi 34×Tx 601이 가장 높았으며, Hi 26×Hi 34와 Hi 29×Hi 34도 比較的 높은 收量을 보였다. 一般的으로 開花期와 熟期가 늦은 交雜種들이 收量이 높은 傾向이었다.

2. 草長은 稈葉重과 正의 相關을 보였으며, 收量構成要素는 種實收量과 正의 相關을 나타냈다. 葉面積指數는 種實收量 및 稈葉重과 高度의 相關을 보였으며 飼料用 交雜種 옥수수의 選拔에 葉面積指數가 考慮되어야 할 하나의 要因으로 생각된다.

3. 供試된 7個의 自殖系統 중에 種實收量 및 稈葉重에 있어서 自殖系統 Hi 34가 一般組合能力이 가장 높았으며, Hi 31과 Hi 33은 낮았다. 自殖系統 Hi 34는 收量構成要素에 대한 一般組合能力도 높은 편이었다. 銹病(*Puccinia sorghi*)은 收量 및 모든 形質과 負의 相關을 보여 銹病이 收量減少에 크게 影響을 주는 것으로 思料된다.

4. 收量 및 主要形質의 一般組合能力은 環境과 有意性 있는 相互作用을 보였으며, 이는 組合能力의 反應이 環境에 따라 相異함을 나타냈다.

5. 種實收量 및 稈葉重의 一般 및 特定組合能力은

모두 高度의 有意性을 보여 相加的 및 非相加的 因子가 關與하나, 一般組合能力의 값이 特定組合能力의 값보다 顯著히 크기 때문에 相加的 因子의 作用이 더 큰 것으로 思料된다.

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