Responses of Harvest Index and Other Agronomic Traits to Selection

for High and Low Harvest Index in Rice [1]

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Summary

Responses to selection for high and low harvest indices were studied in the rice cross of Kaohsiung sen 7 x Pai-kuo-chin-yu. Selection of F_3 plants proved effective producing effects on F_4 progenies. Lines selected for higher harvest index tended to give higher grain yield, more spikelets per panicle and higher fertility and showed a height reduction and earliness of maturity. The heritability estimate for harvest index obtained in this experiment was quite high (64.3%), suggesting that in segregating populations selection for higher harvest index could be effective in breeding programs, if parental germplasms were chosen properly.

(Key words: Rice, Harvest index, Selection)

INTRODUCTION

The productivity of a crop can be evaluated by:(a) biological yield, or total biomass, and (b) economic yield or the yield of usable part, that is grain yield in cereal and legume crops. The ratio of grain yield to biological yield (excluding root weight) is defined as harvest index.

Many studies so far reported indicated that selection for high harvest index was useful for improving grain yield of cereal crops (Chandler 1969; Donald 1968; Fischer and Kertese 1976; McEwan 1973; Nass 1973; Rossielle and Frey 1975; Singh and Stoskopf 1971; Syme 1972). Indeed, in wheat, oat, barley and rice, grain yield improvement was attributed to increased harvest index rather than increased biological yield.

Van Dobben (1962) compared old wheat (Triticum aestivum) cultivars evolved since the turn of the century with leading varieties of the 60's and found a progressive increase in harvest index from 34 to 40%. Sime (1963) claimed that the improvement in grain yields in Australian oat (Avena sativa) cultivars has been due almost entirely to an increase in harvest index but not to total dry matter production, when compared with old cultivars. Watson et al (1958, 1963) reported in England higher grain to straw ratio in new high yielding cultivars of barley (Hordeum Vulgare L.) as well as in spring and winter wheats than in old cultivars. Vogel et al. (1963) indicated that high yielding semidwarf wheat cultivars evolved at Pullman, U.S.A., had an improved grain to straw ratio over taller cultivars and showed a change in harvest index from 32% to 38%.

In general, cereal breeders have selected directly for yield to improve grain yield. In the past two decades, however, there has been renewed interest in indirect selection for yield improvement.

Breeding for yield components posed problems among component compensations, thus produced mixed results (Grafius 1978; Sidwell et al 1976; Abdelkader et al 1984). Donald and Hamblin (1976), hence, suggested the use of harvest index and total plant weight as early generation selection criterions in cereal breeding programs. In oats, indirect selection for grain yield through harvest index was 43% as efficient as direct selection (Rosielle and Frey 1975), but they concluded that selection through harvest index led to height reduction and earliness of maturity which contributed favorably to grain yield. Bhatt (1977) also reported that harvest index was a useful selection criterion for improving grain yield of two wheat crosses in segregating generations.

To investigate the effectiveness of selection for high harvest index on grain yield and examine how yield-component characters respond to selection for high and low harvest index, a rice cross Kaohsiung sen 7 x Pai-kuo-chin-yu was made for this study.

Materials and Methods

A rice cross kaohsiung sen 7 x Pai-kuo-chin yu was made in the first crop season of 1982 and the F_1 was propagated in the following season. In the first crop of 1983, 400 F_2 plants were grown and 100 plants randomly taken were harvested. F_3 lines were planted in the second crop of 1983. Each row consisted of 15 plants and at maturity 10 plants excluding 2 or 3 border plants on both sides were harvested for taking measurements. After harvest index was obtained in each line, 24 high and 24 low harvest-index lines were selected, and in the first crop of 1984, F_4 progeny rows derived from them were planted similarly as in F_3 with 15 plants per row. At the maturity, 10 plants per line were measured with respect to harvest index and other agronomic traits. Then, replicated yield trials with 17 highest and 17 lowest harvest-index lines were conducted in the second crop of 1984 (F_5) and in the first crop of 1985 (F_6). The experiment was designed as randomized complete blocks with 4 replications. For all the tests, N-P-K fertilizers were applied at ordinary rates, i. e., N: $P_2O_5:K_2O = 120:80:60$ kg/ha in the first crop and 100:80:60 kg/ha in the second crop. The spacing used was 25cm x 20cm throughout. The field was protected from diseases and insects as needed.

The paired t-test was used to compare the mean differences for harvest index, grain yield, total dry weight and other agronomic traits between lines selected for high and low harvest index. Phenotypic correlation coefficients between harvest index and various agronomic traits were calculated with the F_3 and F_4 data. Analysis of variance was conducted with the data transformed into logarithms from yield trials to examine if the selection for high and low harvest-index resulted in differences in harvest index, grain yield and total dry weight.

Results and Discussion

The F_3, F_4, F_5 and F_6 means of harvest index, grain yield and total dry weight for the high and low selection groups are given in Table 1. For harvest index, the high and low selection groups differed significantly in each generation with actual differences ranging from 9 to 14% in harvest index. The selection response of grain yield, ranging from 2.65 to 6.39 g/plant showed a highly significant difference between the high and low selection group. The total dry weight was not affected by the selection for high and low harvest index except in F_3 generation. This indicated that the selection for higher and lower

harvest index was effective in the F_3 as shown by the response of F_4 progenies. Lines selected for higher harvest index tended to give higher grain yield. Thus, selection for high and low harvest index in the F_3 generation was effective in selecting high and low grain-yielding lines in the F_4 generation, respectively. This finding supported certain earlier reports (Bhatt, 1977; Nass, 1980) where harvest index as a selection criterion was effective in identifying high grain yielding lines.

Table 1. Mean values of harvest index, grain yield and total dry weight for F_3, F_4, F_5 and F_6 line groups selected for high and low harvest index.

Characters	Selection groups	F_3	F_4	F_5	F_6
		(2nd crop)	(1st crop)	(2nd crop)	(1st crop)
Harvest index	High	0.45	0.53	0.36	0.50
	Low	0.31	0.39	0.27	0.41
	Difference	0.14**	0.14**	0.09**	0.09**
Grain yield	High	16.73	24.42	15.90	33.04
(g/plant)	Low	14.08	19.41	12.42	26.65
	Difference	2.65**	5.01**	3.48**	6.39**
Total dry weight	High	36.09	45.92	43.89	66.51
(g/plant)	Low	46.71	49.15	45.54	66.47
	Difference	−10.62**	−3.23ns	−1.65 ns	0.04ns

**:Significant at the 1% level.
ns:Non-significant.

The selection also brought about differences in fertility, grain test weight and spikelet number per panicle in the F_4 progeny. Selection for higher harvest index resulted in an increase of these characters. Further, selection for high harvest index resulted in earlier heading for an average of 3.4 (F_4) to 7.1 (F_3) days and 19.8 to 22 cm shorter plant height than selection for low harvest index (Table 2). Such correlated responses are important to rice breeders. Earliness is often considered an important trait for rice crops in Taiwan because it is necessary to grow a catch crop in addition to rice crops yearly. Also, short plants obtained from selection for high harvest index are desirable in rice breeding programs. The higher fertility, grain test weight and spikelet number observed in high harvest-index lines may contributed to higher grain yield.

The phenotypic correlation coefficients between harvest index and other agronomic characters were calculated with the F_3 and F_4 data (Table 3). In the F_3 generation, harvest index was found to be correlated with spikelet number per panicle, fertility, grain yield and total dry weight in the line group selected for high harvest index. In the line group selected for low harvest index, harvest index was negatively correlated with total dry weight. When the high and low groups were pooled, harvest index was found to be correlated with grain test weight, grain yield and total dry weight positively, and negatively with days to heading and plant height (Table 3). In the F_4 line group selected for high harvest index, days to heading showed a negative correlation with harvest index. The correlation coefficients for other traits were non-significant. In the group selected for low harvest index, harvest index was correlated

Table 2. Responses of harvest index, grain yield, total dry weight and other agronomic traits to selection for high and low harvest indices in F_3 and F_4 generations of Kaohsiung sen 7 x Pai-kuo-chin-yu.

Characters	F_3 (2nd crop, 1983)			F_4 (1st crop, 1984)		
	Selection group			Selection group		
	High	Low	Dif.	High	Low	Dif.
Days to heading(day)	63.7	70.8	-7.10^{**}	87.1	90.5	-3.4^{ns}
Plant height(cm)	105.6	125.4	-19.8^{**}	91.3	113.4	-22.0^{**}
Panicle No/Plant	11.3	11.5	-0.21^{ns}	13.4	12.3	1.09^{ns}
Spikelet No/Panicle	86.9	83.0	3.85^{ns}	75.7	66.6	9.16^{*}
Fertility(%)	74.4	64.5	9.93^{**}	76.1	62.1	14.0^{**}
1000-grain weight(g)	22.5	22.9	-0.47^{ns}	24.1	22.8	1.33^{**}
Grain yield/Plant(g)	16.7	14.1	2.65^{*}	24.4	19.4	5.02^{**}
Total dry weight/Plant(g)	36.1	46.7	-10.6^{**}	45.9	49.2	-3.24^{ns}
Harvest index	0.452	0.311	0.141^{**}	0.534	0.388	0.146^{**}

*,**:Significant at the 5% and 1% levels, respectively.
ns:Non-significant.

with spikelet number per panicle, fertility and grain yield. Similar results were obtained when the high and low groups were pooled (Table 3).

Table 3. Correlations between harvest index and other agronomic traits in F_3 (2nd crop, 1983) and F_4 (1st crop, 1984) line groups selected for high and low harvest indices.

Characters	F_3 (2nd crop, 1983)			F_4 (1st crop,1984)		
	Selection group			Selection group		
	High	Low	Pooled	High	Low	Pooled
Days to heading	0.386	-0.155	-0.365^{**}	-0.496^{*}	0.174	-0.484^{**}
Plant height	0.308	-0.080	-0.540^{**}	-0.291	0.255	-0.092
Panicle No/Plant	-0.120	-0.117	-0.208	-0.132	-0.206	-0.31
Spikelet No/Panicle	0.551^{**}	0.185	0.144	0.253	0.779^{**}	0.438^{**}
Fertility	0.614^{**}	0.180	0.190	0.319	0.861^{**}	0.490^{**}
1000-grain weight	0.344	0.136	0.562^{**}	0.039	0.265	0.244
Grain yield	0.674^{**}	0.151	0.557^{**}	0.082	0.631^{**}	0.356^{*}
Total dry weight	0.546^{**}	-0.844^{**}	0.585^{**}	-0.136	0.200	0.081

*,**:Significant at the 5%and 1% levels, respectively.
   df=22 for high and low groups.
   df=46 for pooled.

Heritabilities estimated from the regression of F_4 progeny values on F_3 values ranged from 0.119 to 0.792 for harvest index and other agronomic traits (Table 4). The value, 0.792, was obtained for harvest index. The realized heritability estimated from $\overline{\text{High-Low}}$ F_5/$\overline{\text{High-Low}}$ F_3 or $\overline{\text{High-Low}}$ F_6/$\overline{\text{High- Low}}$ F_4 was 0.643 (Figures obtained from Table 1) and it was considered intermediate in magnitude.

Rossielle and Frey (1975) reported realized heritability values between 0.35 and 0.66 in oat lines derived from a bulk population. Bhatt (1977) reported that realized heritability estimated for harvest index were 0.70 and 0.88 in two wheat crosses. Sharma and Smith (1986) estimated realized heritabilitis for harvest index ranged from 0.44 to 0.60 in three wheat populations. These results suggested that progress could be made in a breeding program emphasizing increased harvest index, assuming proper parental germplasms were utilized. Lower values were obtanied for grain yield and total dry weight, as have been reported previously by different workers.

Table 4. Regression of F_4 (1st crop, 1984) lines means on F_3 (2nd crop, 1983) means in high and low harvest-index groups

Characters	Selection group		
	High	Low	Pooled
Days to heading	0.025	0.755	0.584
Plant height	0.577	0.702	0.640
Panicle No/Plant	0.469	0.062	0.478
Spikelet No/Panicle	0.268	0.730	0.529
Fertility	0.150	-0.056	0.506
1000-grain weight	-0.031	0.851	0.580
Grain yield	-0.003	0.205	0.305
Total dry weight	0.155	0.047	0.119
Harvest index	0.054	-0.242	0.792

The results of analysis of variance showed highly significant effects of selection on harvest index, grain yield and total dry weight (Table 5). The differences between high and low harvest-index groups in these three traits were also highly significant. The highly significant season x selection interaction indicated the possibility of selecting genotypes expressing high harvest index in different seasons.

In conclusion, the results of this study indicate that selection was effective in establishing lines with high harvest index. The selection for high harvest index would contribute favorably to grain yield, higher spikelet number and fertility, height reduction and earliness of maturity. Therefore, the lines selected for high harvest index may be agronomically superior to those selected for low harvest index. The heritability estimate for harvest index reported in this study was relatively high suggesting that the high harvest-index genotypes in segregating populations could be effectively handled in a breeding program emphasizing selection of high harvest index, if proper parental germplasms were utilized.

The harvest index, like grain yield, is a complex character. Since not only grain-yield components, but also many components of biomass production are involved, harvest index is under polygenic

Table 5. Analysis of variance for harvest index, grain yield and total dry weight in F_5 and F_6 lines selected for high and low harvest indices (with log-transformed data)

Source of Variation	df	Mean squares		
		Harvest index	Grain yield	Total dry weight
Season				
(F VS F)	1	9.4896**	40.2794**	10.3533**
Replication/Season	6	0.1138	0.2141	0.0559
Selection	33	0.2185**	0.2090**	0.0451**
High	16	0.0385**	0.0654**	0.0435**
Low	16	0.1216**	0.1353**	0.0456**
H vs L	1	4.6484**	3.6843**	0.0611**
Season × Selection	33	0.0761**	0.0816**	0.0549**
S × High	16	0.0316**	0.0902**	0.0652**
S × Low	16	0.1004**	0.0762**	0.0458**
S × H vs L	1	0.4015**	0.0283^{ns}	0.0377^{ns}
Error	198	0.0196	0.0312	0.0122
Total	271			

**:Significant at the 1% level.
ns:Non-Significant

control. Nevertheless, relatively high heritability estimates have been observed in many cases of the present study, showing the predictive value of harvest index in yield improvement. Harvest index is equivalent to reproductive allocation in ecology which is considered representing adaptive strategy as a fundamental of adaptive mechanisms. In breeding, genotypes showing a high harvest index have a high efficiency of grain production, and selection for high harvest index results in improvement of various yield characters and yielding potential.

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高低收穫指數選拔對水稻收穫指數及其他農藝性狀之效應[1]

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摘 要

　　爲瞭解選拔高收穫指數對稻谷產量之效果，以及選拔高及低收穫指數對其他水稻主要農藝特性之影響，本試驗利用水稻雜交組合高雄秈7號　×　白殼清油之 F_3, F_4, F_5, 及 F_6 世代做爲試驗材料，選拔高及低收穫指數之兩個族群，以探討其選拔效果。試驗結果顯示 F_3 植株之選拔證實其對 F_4 後裔之選拔效果，選出之高收穫指數系統有較高產量，一穗粒數較多以及結實率高之傾向，同時具有株高較矮及早熟之特性。收穫指數遺傳率實際估值爲 0.64，指出從雜交後代族群中選拔高收穫指數之後代，以適當的親本做爲材料時是有效的。

（關鍵字：水稻、收穫指數、選拔）