Two cycles of recurrent selection for grain yield in bread wheat. Direct effect and correlated responses

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SUMMARY

The objective of this work was to evaluate 2 cycles of recurrent selection for grain yield in bread wheat and to determine direct and correlated responses. Sixteen Argentinean commercial bread wheat *(Triticum aestivum* L.) varieties with good agronomic performance were intercrossed randomly to obtain the initial population. Forty-five S_1 derived families (15 per.each cycle analyzed) were evaluated in 5 environments. A yield increase of 15% was observed after 2 cycles of recurrent selection. Despite the fact that harvest index was not used in the selection protocol, there was a significant increase of 11,4% in C_2 with respect to C_0. The recurrent selection scheme employed in this study modified the character under selection allowing the identification of superior genotypes.

Key words: *Triticum aestivum* L, grain yield, recurrent selection, correlated responses

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RESUMEN

El objetivo del presente trabajo fue evaluar 2 ciclos de selección recurrente para rendimiento en grano en trigo pan y determinar las respuestas directa y correlacionadas. Dieciséis variedades comerciales argentinas de trigo pan *(Triticum aestivum* L.) con buen comportamiento agronómico, fueron cruzadas al azar para formar la población base. Se evaluaron 45 familias S_1 derivadas (15 por cada ciclo analizado) en 5 ambientes. Se observó un aumento del 15% en el rendimiento al cabo de 2 ciclos de selección recurrente. Aunque el índice de cosecha no fue carácter objeto de selección, se observó un aumento significativo del 11,4% del C_2 respecto al C_0. El esquema de selección recurrente empleado en este trabajo modificó el carácter sujeto a mejora permitiendo la identificación de genotipos superiores.

Palabras clave: *Triticum aestivum* L, rendimiento en grano, selección recurrente, respuestas correlacionadas

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INTRODUCTION

The starting point of any plant-breeding program is the attainment of a segregating recombinant population, resulting from varieties or line crosses with superior agronomic characteristics. The recurrent selection, as a cyclical process of selection and recombination of superior individuals or families, keeps the genetic variability necessary to maintain a continuous progress and, at the same time, concentrates in a reduced number of individuals, the superior alleles present at random in the original population. As a result of the application of a recurrent selection scheme, the species will be involved in a microevolutive process that will allow a change in the frequencies of genetic determinants which rules the expression of the character under improvement.

In wheat, several authors have applied recurrent selection successfully for improving traits like grain proteins (Delzer *et al.,* 1995), grain weight (Busch and Kofoid, 1982) and yield (Bravant *et al.,* 1991; Olmedo-Arceaga *et al.,* 1995; Dubois *et al.,* 1998), which is obviously an important characteristic both for breeders and farmers. On the other hand, Salvagiotti and Maich's (1999) biennial results showed that grain yield didn't get any response after two cycles of recurrent selection, whereas there was an increase in harvest index, a trait positively associated to it. Retrospective studies have shown that the improvement in grain yield has caused a parallel increase in other characteristics. When different varieties released in different eras were evaluated, yield increase caused changes in the biological yield or biomass and most frequently in harvest index. Moreover, in five out of eight studies reviewed by Slafer *et al.* (1994) modern cultivars gave not only a higher number of grain per m^2 but also lower individual grain weights than older cultivars. With respect to recurrent selection, Olmedo-Arceaga *et al.* (1995) after 2 cycles of selection for yield in durum wheat *(Triticum turgidum* L, var. durum) observed a positive correlated response in test weight, plant height, grain weight and spike m^{-1}. In contrast with these recurrent selection results, Maich *et al.* (1998) reported a grain weight diminution in bread wheat after three cycles of selection.

This paper considers that morphophysiological changes occur under a cyclical process of selection and recombination. In order to test this hypothesis, the objective of this work was to evaluate the efficiency of the recurrent selection method for increasing grain yield in bread wheat after 2 cycles of selection and to determine correlated responses.

MATERIALS AND METHODS

Sixteen commercial bread wheat (*Triticum aestivum* L.) varieties of current or historic importance for wheat breeding were intercrossed randomly in 1985. The varieties utilized to begin with the closed population structured recurrent selection program for yield were: 'Leones INTA', 'Diamante INTA', 'Marcos Juárez INTA', 'Victoria INTA', 'Chasicó INTA and 'Las Rosas INTA' of public origin. The following varieties from private origin were also included: 'Klein Fortín', 'Klein Atlas', 'Buck Namuncurá', 'Buck Cencerro', 'Buck Pucará', 'Olaeta Artillero', 'Dekalb Tala', 'Cargill Trigal 700', 'Cargill Trigal 800' and 'Norking Pan 70'. All the varieties employed in the crosses were selected for their agronomic performance and according to its public and private origin. Eighty three S_0 hybrid combinations (C_0 = initial population) were obtained, which were evaluated in single row plots of 1,3 m length, with 100 grain m^{-2}, without replications and with systematic controls located every 9 experimental plots. These were used in order to compare and select the adjacent S_0 families in respect to the high yielding parent variety "Las Rosas INTA". Grain yield per spike was estimated from 5 representative spikes taken from each plot. Ten families with the highest values for grain yield per spike were selected and recombined in all combinations to conform a new population of 45 S_0 families corresponding to the first cycle of recurrent selection (C_1. The second cycle of recurrent selection (C_2) was obtained crossing diallelically the best ten C_1 families taking into account the grain yield per plot; the resulting 45 S_0 hybrid combinations were evaluated in the same experimental conditions as the C_o (figure 1). At the moment of constituting the C_1, recurrent selection cycle, grain yield per spike was considered as a representative of grain yield due to bird damage at plot level.

In 1992, samples of 100 seeds of the best 10 S_1 families of each cycle (C_0, C, and C_2) were spatially cultivated (25 plants m^{-2}) and 3 plants per family were selected on the basis of their phenotype (number of fertile culms and spikelets per spike, height). The original 30 S_1 plants selected per cycle (one generation of inbreeding) were reduced to 15 after a laboratory test, where those plants with satisfactory grain production for plot evaluation (200 seeds per plant) were retained. The families derived from each selected plant were evaluated in 5 environments.

The 45 S_1 derived families were evaluated in 2 sowing dates, middle May and June, in 1993 and 1994, and in one sowing date, middle of June, in 1996, at the experimental field of the Facultad de

Ciencias Agropecuarias (CEFCA), at Ferreyra (31° 29' SL and 64° 00' WL), situated in the central Argentine semiarid region.

In 1993 the $S_{1:2}$ families were arranged in one row plots of 1,3 m length, 0,2 m between rows and 100 grains m^{-2}, whereas ¡n 1994 ($S_{1:3}$) and 1996 ($S_{1:4}$), one row plots of 5 m long, 0,2 m between rows and 300 grains m^{-2} were utilized. The check variety 'Las Rosas INTA' was used as a systematic control every 9 plots, because it is still being cultivated in a significant area of Córdoba province and was the best parent at the time when the original population was constituted. A complete randomized design in each of the 5 environments was employed using the families of the same cycle as replications.

Plot data were recorded on grain yield (g m^{-2}), aerial biomass (g m^{-2}) and harvest index (%). In addition, from a random sample of 5 fertile culms and analyzing 1996 data, the following characters were collected: plant height (cm), peduncle length (cm), spike length (cm), internode spike length (cm), spikelets spike^{-1} (n°), grains spike^{-1} (n°), grains spikelet^{-1} (n°). Simultaneously, 1000 grain weight (g) and spikes m^{-2} (n°) were measured from each plot.

An analysis of variance was performed considering the cycles of selection and the environments as the principal causes of variation. The Duncan test was employed to test the significance among mean values.

RESULTS AND DISCUSSION

A significant progress (P<0,05) for grain yield was observed where the mean values of the families belonging to C_2 and C_1 were superior to that of C_0 (table 1). Yield increased 21,1 g m^{-2} (15%) after 2 cycles of recurrent selection. In spite of the fact that no significant differences were found with respect to the check cultivar, 12 S_1 derived families, 10 of the C_1, and C_2 and 2 of C_0 cycles showed superior values. Notwithstanding the fact that harvest index was not used in the selection protocol, there was a significant increase (P<0,05) of 11,4% in C_2 with respect to C_0 (table 1). Cycle x environment variances for each one of the three analyzed characters were not significant. Statistical analysis of grain yield, biomass and harvest index revealed significant variation among environments (table 1). The low trait expression during 1994 may be attributed to the fact that the heading and flowering phenological features coincided with a severe water stress during September.

Taking into account the 1996 additional variables analyzed, significant differences were detected among the recurrent selection cycles, C_2 respect to C_o, for number of spikes m^{-2} (P<0,01), number of spikelets spike^{-1} (P<0,10) and for number of grains spike^{-1} (P<0,05). There was an increase in the number of spikes m^{-2} (22,5%), number of spikelets spike^{-1} (7,3%) and for number of grains spike^{-1} (11,2%) (table 2). No significant differences were found among populations with different rate of microevolution with respect to plant height and 1000 grain weight.

According to Fischer (1998) the annual rate of genetic progress in yield of wheat is between 0,5% and 1,5%. In the present study an annual increase of 3,75% was obtained by dividing the total progress after 2 cycles (15%) by the number of years employed to complete 2 cycles of recurrent selection (2 per cycle). The progress reported here is similar to that obtained by Olmedo-Arceaga *et al.* (1995). The differences between retrospective and recurrent selection studies can be due to their particular characteristics and the characteristics of their extension. The genetic progress is often high in the first cycles of recurrent selection when the germplasm has shown a strong adaptation to the environment. The lack of coincidence with respect to grain yield between these results and those obtained by Salvagiotti and Maich (1999) may be due to the fact that, at least, a triannual trial is needed to obtain reliable results from this recurrent

Table 1. Observed mean grain yield, biomass and harvest index of 15 S_1 derived families from each cycle of a recurrent selection scheme in bread wheat evaluated along 5 environments.

	C_0	C_1	C_2	May 1993	June 1993	May 1994	June 1994	June 1996
Grain Yield g/m^2	140,3 b	155,0 a	161,4a	150,7 c	198,7 b	79,7 d	48,1 e	284,1 a
Biomass g/m^2	626,0 a	655,3 a	643,3 a	740,4 b	819,3 b	364,0 c	213,0 d	1070,8 a
Harvest Index %	21,9 b	23,4 ab	24,4 a	20,4 b	25,3 a	21,4b	22,3 b	26,8 a

a-e: different letters indicate significant differences (P < 0,05) according to Duncan test.

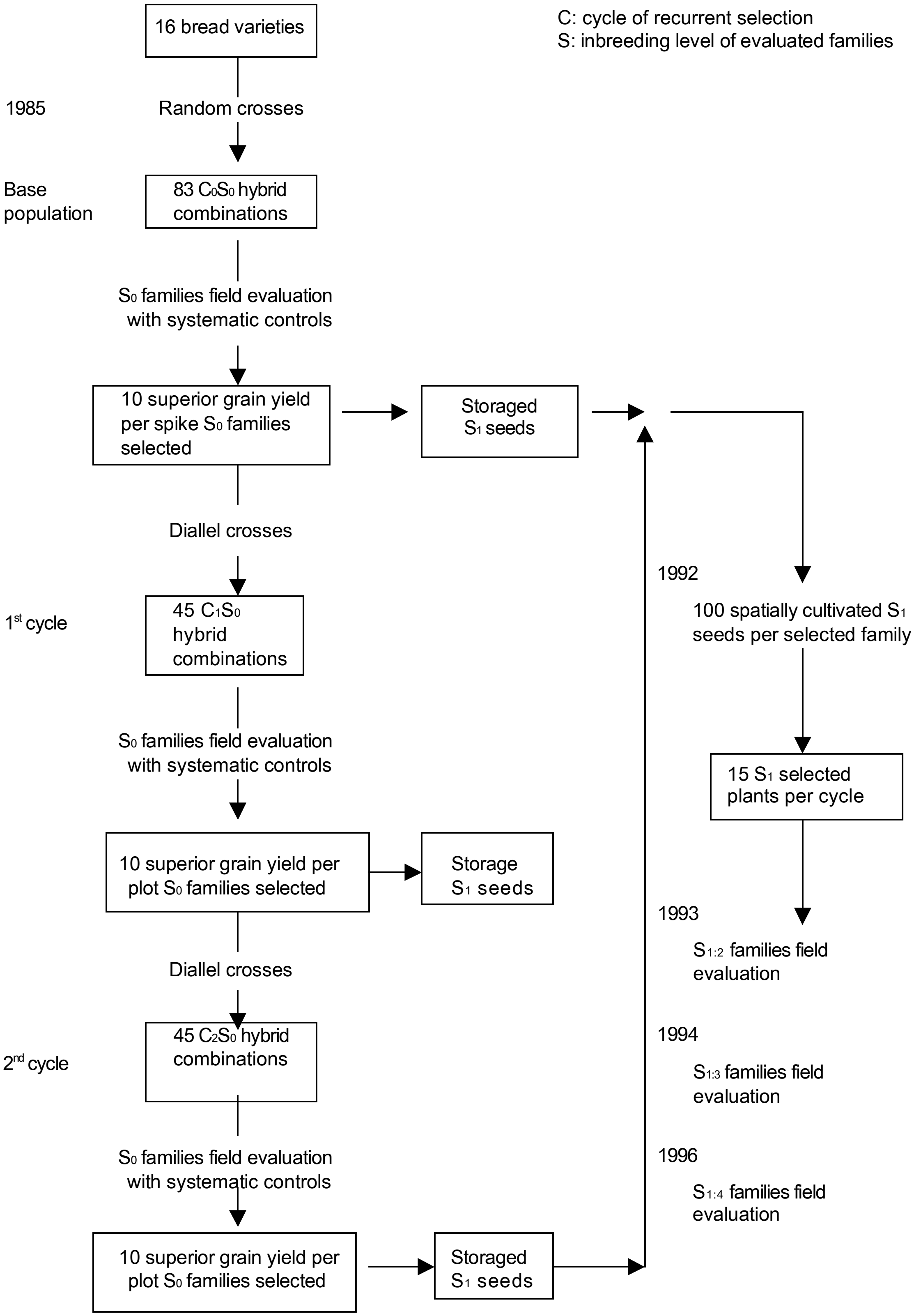

Figure 1. Phases of recurrent selection method used.

Table 2. Mean values of 9 agronomic traits of 15 S_1 derived families from each cycle of recurrent selection in wheat during 1996.

	Plant height	Peduncle length	Spikes m^{-2} ***	Spike length	Splkelets splke^{-1} *	Internode spike length	Grains spike^{-1} **	Grains spikelet^{-1}	1000 grain weight
	cm	cm	nº	cm	nº	cm	nº	nº	g
C_0	69,09 a	30,36 a	284 b	9,09 a	17,29 b	0,53 a	26,09 b	1,52 a	39,02 a
C_1	73,05 a	32,42 a	319b	9,34 a	17,98 b	0,52 a	27,55 b	1,54 a	38,74 a
C_2	70,58 a	30,63 a	348 a	9,43 a	18,55 a	0,51 a	29,01 a	1,57 a	39,59 a

a-b: different letters indicate significant differences (* P < 0,10, **P < 0,05 and *** P< 0,01) according to Duncan test.

selection program conducted under rainfed conditions of cultivation (Maich, 1998).

In agreement with several retrospective studies (Slafer *et al.,* 1994) an increase in harvest index was observed simultaneously with an increase in grain yield. In spite of that, repeated selections over the same populations under severe water stress have shown that biomass was the character with the highest correlated response associated to yield (Maich *et al.* 1998). The diversity of the climatic conditions of the selection environment allows the expression of different plant phenotypes and different relationships between yield and its related characters.

Some components of the number of grain m^{-2} evaluated (number of spikes m^{-2}, number of spikelets and grains spike^{-1}) showed a significant increase, whereas no variation was detected in grain weight. These findings are in contrast with the results of the works of Slafer *et al.* (1994) and Maich *et al.* (1998), where an increase in the grain number m^{-2} was associated with a decrease in grain weight. As in the case of biomass, for the latter results, reselections performed under different climatic conditions can lead to different correlated responses. In conclusion, the recurrent selection scheme employed in this study modified the character under selection allowing the identification of superior genotypes.

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