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GENETIC VARIATION FOR COMBINING ABILITY IN THE SHORT-DAY ONION CULTIVAR PIRA-OURO IN TOPCROSSES WITH BAIA PETROLINI

W.R. Maluf[1,2], R.D. Corte[1] and M. Toma-Braghini[1]

ABSTRACT

Six onion cultivars [Granex Ouro (G.O.) F_1, Granex 33 (G-33) F_1, Brownsville (BV) F_1, Pira-Ouro (P.O.) o.p., Baia Petrolini (B.P.) o.p. and Baia Periforme Superprecoce (B.P.S.P.) o.p.] were tested in a trial along with 40 different experimental hybrids, obtained by topcrossing male-sterile S_0 clones from P.O. to B.P. Significant differences among treatments were found for yield, cycle, percent bolting and average bulb weight. The highest yielding checks were P.O. (43.2 t/ha) and B.P. (38.9 t/ha), followed by G-33 (30.2 t/ha), BV (28.2 t/ha), G.O. (27.0 t/ha) and B.P.S.P. (24.7 t/ha). Variance among topcrosses was significantly larger than zero for all traits under consideration, indicating the existence of ample genetic variation for combining ability within the cultivar Pira-Ouro in topcrosses with open-pollinated Baia Petrolini. The average yield of the topcrosses was similar to that of the lowest yielding parental cultivar (B.P.), but some topcrosses outyielded the highest yielding parent (P.O.) by as much as 25.9%. The average cycle of the topcrosses was comparable to that of the earliest parent (P.O. = 181 days), but some topcrosses were considerably earlier, comparable to the earliest of the check cultivars in the trial (G-33 = 170 days). Genotypic and phenotypic correlations among all traits were low, except that between yield and average bulb weight, indicating the possibility of selection of topcrosses that are simultaneously higher yielding, earlier and less prone to bolting than Pira-Ouro.

INTRODUCTION

The onion *Allium cepa* L. is a self-compatible, allogamous species subject to inbreeding depression (Jones and Davis, 1944; Guimarães and Torres, 1953; Erick-

[1] Bioplanta Tecnologia de Plantas S.A., Caixa Postal 1141, 13100 Campinas, SP, Brasil.

[2] Present address: Departamento de Agricultura/Escola Superior de Agricultura de Lavras, Caixa Postal 37, 37200 Lavras, MG.

son and Gabelman, 1954). It has been greatly improved in characteristics such as quality, yield, uniformity, disease resistance, adaptability to different latitudes and growing practices (Jones and Mann, 1963; Costa, 1978; Pike, 1986).

Breeders in the United States of America developed the crop during the years 1925-1940 to the point that it might be considered a classic example of crop improvement (Pike, 1986). The work of Henry Jones and his co-workers during that period provided the bulk of the information available to date on genetics and breeding methods. The most notable achievement in onion breeding began in 1925 with the discovery by Jones and Emsweller (1936) of a male sterile plant in a breeding nursery at the University of California at Davis. The inheritance of the male sterility trait was elucidated years later (Jones and Clark, 1943): male sterility results from the interaction of a nuclear recessive gene *ms* with a cytoplasmic factor *S*, and fertility is restored with the presence of either the dominant allele *Ms* or the normal cytoplasmic factor *N*. From the plant breeding standpoint, that mean that a male-sterile A line (S msms) could be maintained through pollination with a complementary B (fertile) line with genotype N msms. The development of A/B line pairs allowed for the production of F_1 onion hybrids in commercial scale, starting around 1952 (Costa, 1978). By 1973, ca. 30% of the total amount of onion seed produced in the U.S.A. was from hybrids (McCollum, 1976). The growing demand for onion F_1 hybrids in the U.S. and in Europe is due to their reported advantages over the open-pollinated cultivars, namely higher yields and higher uniformity, allowing for a single once-over harvest (Pike, 1986).

A remarkable achievement of the short-day onion breeding was the development of the Granex F_1 hybrid by the U.S.D.A. in the 1950's. According to Jones *et al.* (1956), Granex was obtained from the combination of an A line from cultivar Excel with Texas Grano as pollinator. Granex and its related hybrids have predominated since the 1950's, and are presently grown in many tropical and subtropical areas of the world, including Southeastern Brazil. Bred for the arid conditions of the winter crop in Texas, Granex and its parents are highly susceptible to foliage diseases. Together with their low keeping quality, this fact limits their usage in wetter seasons in the tropics. Therefore, it is clear that development of new hybrids from short-day cultivars that are more resistant to diseases and longer keeping should be emphasized in tropical areas (Costa, 1978).

In Brazil, after the identification by Costa (1967) of A/B line pairs in the population Baia Periforme Precoce Piracicaba, Costa and Dias (1967) exploited the possibility of producing F_1 hybrids from locally adapted materials. Two local cultivars from Brazil, Baia Periforme (yellow bulbs) and Barreiro (red bulbs), produced a highly heterotic combination which on one hand demonstrated the importance of using locally adapted material for the development of good F_1 hybrid combinations, but on the other hand had little immediate economic interest due to the undesirable bulb color (pink/red). The cross was later utilized in the development of the open-pollinated cultivar Pira-Ouro, which associates the yellow bulb color of Baia Periforme to the resistance to *Colletotrichum gleosporioides* of Barreiro (Paiva, 1980).

During the past 30 years, a large number of open-pollinated onion cultivars and selections were developed by Brazilian breeders, especially in the states of São Paulo (Escola Superior de Agricultura "Luiz de Queiroz"/Universidade de São Paulo), Rio Grande do Sul (IPAGRO/State Agricultural Experiment Station; EMBRAPA), Pernambuco (IPA/Empresa Pernambucana de Pesquisa Agropecuária) and Santa Catarina (EMPASC/Empresa de Pesquisa Agropecuária de Santa Catarina). A broad range of open pollinated materials is now available, ranging in adaptation from the Equator to the southernmost parts of Brazil (ca. 32° South). The potential for development of inter and intravarietal hybrids appears to be great, but actual critical evaluations of this potential are not available.

This paper reports on the evaluation of the potential of the intervarietal cross between two open-pollinated Brazilian cultivars (Pira-Ouro and Baia Petrolini) for the production of superior F_1 hybrids. The extent of the variation within Pira-Ouro for combining ability with Baia Petrolini will also be estimated.

MATERIALS AND METHODS

Experimental treatments

Six short-day onion commercial cultivars [Granex Ouro (G.O.) F_1, Granex 33 (G-33) F_1, Brownsville (BV) F_1, Pira-Ouro (P.O.) o.p., Baia Petrolini (B.P.) o.p. and Baia Periforme Superprecoce (B.P.S.P.) o.p.] were chosen as checks. G.O., G-33 and BV are F_1 hybrids of American origin, whereas P.O., B.P. and B.P.S.P. are open-pollinated cultivars developed for the Southeastern and Southern parts of Brazil. Four of these checks (G.O., G-33, P.O. and B.P.S.P.) are often grown commercially in the state of São Paulo.

Pira-Ouro and Baia Petrolini were used to obtain topcrosses to be included in the trial. Pira-Ouro was released by the Instituto de Genética of the "Luiz de Queiroz" School of Agriculture of the University of São Paulo at Piracicaba; it was developed from a cross between populations Baia Periforme and Barreiro, and is widely adapted to growing conditions in the state of São Paulo (ca. 22 - 24°C). Baia Petrolini is a selection of Baia Periforme bred by the Rio Grande do Sul Agricultural Research Station (IPAGRO) for the conditions of the southernmost parts of Brazil. In 1987, ca. 500 male-sterile non-inbred (S_0) plants were sampled from the open-pollinated Pira-Ouro. In 1988, clones of these male-sterile plants were interplanted with open-pollinated Baia Petrolini to obtain topcrosses. A random sample of 40 topcrosses were chosen for inclusion in the 1989 trial, along with the checks. Except for the male sterility trait, the Pira-Ouro clones were unselected, and can therefore be assumed to adequately represent the genetic variation within Pira-Ouro.

Field trial

The 46 treatments (6 checks and 40 P.O. x B.P. topcrosses) were grown in a randomized complete block design with 3 replications at the Bioplanta Tecnologia de Plantas Research Station in Paulínia-SP. Plots were allocated to 8 m rows spaced 0.60 m from each other, with an ideal stand of 80 plants per plot. Sowing date was April 25, 1989, and transplanting date was June 17, 1989. Plots were harvested in October through November, the harvest date for each plot being that which corresponded to a minimum of 90% maturity.

Traits evaluated

The following traits were evaluated and are reported on this paper: total yield, cycle (= number of days from sowing date), percent early bolting and average weight per bulb. Other traits were evaluated, including final plot stand, degree of leaf waxiness and *Alternaria* incidence, but they are not reported here because of lack of any significant difference among topcrosses (in fact, the only significant differences for these traits can be accounted for by the check cultivars G.O., G-33 and BV, which have less wax and are more susceptible to *Alternaria* leaf spot than the other treatments).

Statistical and genetic analyses

Analyses of variance were performed for yield, cycle, percent bolting and average weight per bulb. The "Among treatments" sum of squares was splitted into its components "Among checks", "Contrast checks vs. topcrosses" and "Among topcrosses" sum of squares. Estimates of environmental (V_E) and among topcrosses (V_C) variance components were obtained by equating the respective mean squares to the expressions of the expected means squares, as described by Becker (1984).

The estimates of V_C and V_E were used in the estimation of broad sense heritabilities for combining ability both at the single plot [$H^2 = V_C/(V_C + V_E)$] and treatment mean [$H^2 = V_C/(V_C + V_E/3)$] levels. The standard errors associated with estimates of variance components and heritabilities were calculated as indicated by Hallauer and Miranda Filho (1981).

Average heterosis of the topcrosses was calculated relatively to the parental mean and to each of the parental cultivars.

In order to identify Pira-Ouro clones with superior combining ability, estimates of combining ability deviations for all male-sterile P.O. clones were obtained, according to the following model:

$$Y_i = u + g_i + e_i$$

where:

Y_i = mean of the topcross whose seed parent is the P.O. male sterile clone i.

u = mean of all topcrosses.

g_i = deviation of the topcross whose seed parent is the P.O. male sterile clone i relative to the mean of all topcrosses. (The sum of the g_i's is zero over all i's).

e_i = error associated with the ith topcross, averaged over three replications.

It follows that $g_i = Y_i - Y.$, where Y, is an estimate of u.

RESULTS AND DISCUSSION

The analyses of variance (Table I) for yield, cycle, percent bolting and average bulb weight indicate significant effects for checks, for the contrast checks vs. topcrosses and for topcrosses for all traits, with the exception of the differences in the percent bolting among checks.

Table I - Analyses of variance for a 1989 onion trial with 46 treatments (six commercial checks, and 40 topcrosses between Pira-Ouro male-sterile clones and Baia Petrolini o.p.).

Source	DF	Mean squares			
		Yield	Cycle	% Bolting	Avg. bulb wt.
Blocks	2	41.516ns	0.9638ns	12.383ns	2473.6081ns
Treatments:	45	90.452**	79.1749**	117.727**	2890.7571**
Among checks	5	161.400**	181.9222**	15.062ns	5141.2844**
Checks vs. Topcrosses	1	729.604**	112.4668*	163.384**	10548.3533**
Among topcrosses	39	64.967**	65.1485**	129.718**	2405.8793**
Error	90	31.292	17.9415	20.126	1185.1156

Pira-Ouro and Baia Petrolini, the cultivars used as parentals in the topcrosses, were the highest yielding cultivars among the checks (Table II). Granex-33 and Granex Ouro were the earliest cultivars, even though their cycle length may have been underestimated, because the heavy *Alternaria* incidence required harvesting before signs of full maturity. Pira-Ouro had a greater tendency to bolt prematurely than the other check cultivars, even though the difference among them was not significant (Table II).

Table II - Treatment means of the six commercial checks, and range of the topcross means in a 1989 onion trial in Paulinia-SP, Brazil.

Treatment	Yield[a]	Cycle[a]	% Bolting[a]	Avg. bulb wt.[a]
Pira-Ouro	43.20	180.67	5.56	263.87
Baia Petrolini	38.89	190.00	0.42	235.27
Granex 33	30.21	170.00	0	198.12
Brownsville	28.20	185.33	0	260.27
Granex Ouro	26.95	171.33	0	172.47
Baia Superprecoce	24.72	180.33	0	174.26
Tukey's M.S.D. (5%)[b]	18.71	14.16	15.00	115.11

[a] Yield = total yield (ton/ha); Cycle = # days from seeding to harvest'; % Bolting = percent early bolting, measured at harvest; Avg. bulb wt. = average weight per bulb (g/bulb).

[b] Tukey's minimum significant difference between any two treatment means (alpha = 0.05).

Overall topcross averages indicate that dominance deviations are in the direction of lower yields, shorter cycles, higher percent bolting and lower bulb weights (Table III), i.e., topcrosses on average resemble Pira-Ouro in cycle and percent bolting, and Baia Petrolini in yield and bulb weight (Table III). Average heterosis, whether relative to midparent or to any of the two parental cultivars, is modest in magnitude, and, with the exception of that for cycle, in the undesirable direction. Yields of topcrosses were similar to the lower yielding parent B.P., and 10% lower than the higher yielding one (P.O.). Nevertheless, the topcross average compares favorably with that of the commercial check Granex-33 in yield and in average bulb weight, although not in cycle and percent bolting.

Table III - Heterosis, variance components, broad sense heritabilities and genetic coefficients of variation for topcrosses of male-sterile Pira-Ouro clones with Baia Petrolini o.p.

Parameter	Estimates				
	Yield		Cycle	% Bolting	Avg. bulb wt.
Parental averages:					
- Pira-Ouro (o.p.)	43.2		180.7	5.6	263.9
- Baia Petrolini (o.p.)	38.9		190.0	0.4	235.3
Topcross average	38.9		182.3	4.2	243.3
Topcross range	29.0-54.3		169.3-190.0	0.0-33.5	175.7-334.7
Heterosis:					
- Relative to midparent	-2.2	(-5.3%)	-3.1	+ 1.2	-6.3
- Relative to Pira-Ouro	-4.3	(-10.0%)	+ 1.6	-1.4	-20.6
- Relative to Baia Petrolini	0.0	(0.0%)	-7.7	+ 3.8	+ 8.0
Average deviation					
- Relative to Granex 33	+ 8.7	(+ 28.8%)	+ 12.3	+ 4.2	+ 45.2
Variance components: (+ std. error)					
- Among topcrosses (V_C)	11.23 (+5.02)		15.74 (+4.88)	36.53 (+9.60)	406.92 (+186.45)
- Error (V_E)	31.29 (+4.61)		17.94 (+2.65)	20.13 (+2.97)	1185.12 (+174.74)
Broad-sense heritability: (+ std. error)					
- Single-plot level	0.264 (+0.118)		0.467 (+0.145)	0.645 (+0.169)	0.256 (+0.117)
- Treatment mean level	0.518 (+0.232)		0.725 (+0.225)	0.845 (+0.222)	0.507 (+0.232)
Genetic coefficient of variation (%)	8.6		2.2	143.9	8.3

[a] Yield = total yield (ton/ha); Cycle + # days from seeding to harvest; % Bolting = percent early bolting, measured at harvest; Avg. bulb wt. = average weight per bulb (g/bulb).

There was considerable variation among the topcrosses for all traits (Tables I and III). The range of variation among topcrosses (Table III) is considerably larger than Tukey's minimum significant difference at alpha = 0.05 (Table II) for all traits. This fact is reflected in estimates of variance among topcrosses (V_C) that are significantly different from zero. Because V_C reflects the genetic variation within Pira-Ouro for combining ability with Baia Petrolini, we conclude that it should be possible to select specific clonal topcrosses that are superior to the topcross average for all traits. Furthermore, the magnitude of the genetic coefficients of variation and of the broad-sense heritability estimates (especially at the treatment mean level) indicate that genetic gains for these traits should be fairly easy to achieve through selection among topcrosses. This can be demonstrated in Table IV: topcrosses of Pira-Ouro clones #21 and #374 outyield the average of topcrosses by 8.4 and 15.5 t/ha respectively, representing a 4.2 t/ha (10.0%) and 11.3 t/ha (25.9%) superiority over the higher yielding parent. Similarly, topcrosses of clones #385, #086 and #481 are respectively 9, 11 and 13 days shorter in cycle than the topcross average, being therefore considerable earlier than Pira-Ouro, and similar in cycle to the standard non-parental check Granex-33. Early bolting can be considerably reduced or even entirely eliminated by selecting topcrosses of clones #252, #284, #469, #481, #564 or #589.

Table IV - Combining ability estimates of male-sterile Pira-Ouro clones topcrossed to Baia Petrolini o.p.

Parameter[b]	Least-squares estimates			
	Yield[a]	Cycle[a]	% Bolting[a]	Avg. bulb wt.[a]
u	38.9	182.3	4.2	243.3
g-001	0.5	-2.0	9.0	15.1
g-021	8.4	0.0	1.8	46.8
g-043	5.2	7.0	-0.6	36.4
g-047	-0.3	0.4	29.3	6.2
g-069	3.4	-2.3	-2.5	22.1
g-086	1.4	-11.0	4.4	10.4
g-091	2.7	0.4	13.0	9.2
g-104	3.6	5.4	-0.5	15.5
g-114	1.4	2.7	-2.1	6.9
g-155	0.7	-1.3	0.4	2.1
g-178	-8.1	-1.3	-3.8	-33.6
g-199	-2.0	1.7	-3.2	-2.8

Continued

Table IV - Continued.

Parameter[b]	Least-squares estimates			
	Yield[a]	Cycle[a]	% Bolting[a]	Avg. bulb wt.[a]
g-227	1.4	3.0	-0.8	8.1
g-237	4.4	-2.0	-2.5	23.3
g-252	2.5	-1.0	-4.2	10.1
g-278	-1.4	-5.3	-3.8	-2.8
g-284	-5.4	-0.3	-4.2	-38.9
g-290	-5.0	5.4	-3.3	-24.4
g-311	-8.0	2.7	-3.0	-55.0
g-326	-2.7	2.0	3.0	-20.0
g-348	-0.2	-0.3	-3.8	-8.4
g-364	3.9	2.7	-0.3	24.4
g-374	15.5	7.7	-3.0	91.4
g-385	-2.3	-9.0	-0.8	-20.0
g-406	3.2	0.4	-3.4	13.6
g-416	-0.2	3.7	15.0	2.8
g-440	-9.0	-4.3	0.8	-53.0
g-450	0.0	1.4	-3.8	-5.4
g-469	0.2	1.4	-4.2	10.3
g-481	-9.8	-13.0	-4.2	-67.6
g-490	-1.6	-4.0	-1.0	-4.4
g-501	-0.6	4.7	-2.5	-10.2
g-517	-1.7	-3.0	-3.8	-8.3
g-535	2.6	6.0	-2.3	21.0
g-550	1.0	4.7	-1.7	1.0
g-562	-2.9	0.0	-2.1	-22.8
g-564	-3.6	-4.3	-4.2	-22.6
g-578	0.6	-5.6	6.5	11.7
g-584	1.4	6.0	-3.3	14.3
g-589	0.7	0.0	-4.2	-2.5
Std. error (u)	0.6	0.4	0.4	3.3
Std. error (gi)	3.2	2.4	2.6	20.1

a Yield = total yield (ton/ha); Cycle = # days from seeding to harvest; % Bolting = percent early bolting, measured at harvest; Avg. bulb wt. = average weight per bulb (g/bulb).

b The indices following g- designate the male sterile seed parent Pira-Ouro clone.

Not only can genetic gains be obtained, but they can also be achieved simultaneously for all traits: the modest magnitudes of the genotypic coefficients of correlation (Table V) among all traits (except between yield and average bulb weight, which are essentially measures of the same trait) are low enough to allow for the selection of topcrosses that are simultaneously higher yielding, earlier and less prone to bolting than the cultivar Pira-Ouro. In our limited sample of 40 topcrosses, there are indications that this can indeed be achieved (Table IV): the topcrosses P.O. clone #69 x B.P. and P.OI. clone #237 x B.P. are good compromises towards the ideal situation.

Table V - Genotypic (below diagonal) and phenotypic (above diagonal) coefficients of correlation among traits in topcrosses of male-sterile onion clones of Pira-Ouro with Baia Petrolini (o.p.).

	Yield	Cycle	% Bolting	Avg. bulb wt.
Yield	-	0.34912	0.11180	0.95526
Cycle	0.42499	-	0.05244	0.35188
% Bolting	0.08876	-0.02403	-	0.16573
Avg. bulb wt.	0.97570	0.42773	0.14297	-

[a] Yield = total yield (ton/ha); Cycle = # days from seeding to harvest; % Bolting = percent early bolting, measured at harvest; Avg. bulb wt. = average weight per bulb (g/bulb).

In spite of the widespread use of F_1 hybrid onions in many countries (Jones and Mann, 1956; Pike, 1986; Melo and Ribeiro, 1990), published data on the extent of heterosis in intervarietal crosses is scarce. In Brazil, Costa and Dias (1986) reported heterosis in the intervarietal hybrids F_1 (Excel x Barreiro) and F_1 (Baia Periforme Precoce de Piracicaba x Barreiro) in trials under different growing system (transplants and sets) in two different years (1966 and 1967); there were indications of additive gene action for earliness, resistance to *Alternaria* leaf blotch and post-harvest shelf life. In later trials, heterosis in the F_1 (Baia x Barreiro) was not as evident (Costa, 1978).

Our results indicate that, whereas there may appear to be no significant advantage in the use of intervarietal hybrids between Pira-Ouro and Baia Petrolini, from an examination of average heterosis alone, careful selection for combining ability within Pira-Ouro can lead to the identification of hybrids that are heterotic, earlier and less prone to bolting than the best parent.

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RESUMO

Seis cultivares de cebola [Granex Ouro (G.O.) F_1, Granex 33 (G-33) F_1, Brownsville (BV) F_1, Pira-Ouro (P.O.) o.p., Baia Petrolini (B.P.) o.p. e Baia Periforme Superprecoce (B.P.S.P.) o.p] foram testadas num ensaio, juntamente com 40 diferentes híbridos experimentais ("topcrosses"), obtidos pela polinização de diferentes clones S_0 de P.O. com a população B.P. Foram encontradas diferenças significativas entre tratamentos para produção, ciclo, percentagem de florescimento prematuro e peso médio de bulbo. As testemunhas mais produtivas foram P.O. (43.2 t/ha) e B.P. (38.9 t/ha), seguidas de G-33 (30.2 t/ha), BV (28.2 t/ha), G.O. (27 t/ha) e B.P.S.P. (24.7 t/ha). O componente de variância entre "topcrosses" foi significativamente maior do que zero para todas as características consideradas, indicando a existência de ampla variabilidade genética para capacidade combinatória da cultivar Pira-Ouro para cruzamentos com Baia Petrolini. A produtividade média dos "topcrosses" foi semelhante à da cultivar parental menos produtiva (B.P.), mas alguns "topcrosses" superaram a cultivar mais produtiva (P.O.) em até 25.9%. O ciclo médio dos "topcrosses" foi comparável ao da cultivar parental mais precoce (P.O. = 181 dias), mas alguns "topcrosses" foram consideravelmente mais precoces, comparáveis à mais precoce das cultivares incluídas no ensaio (G-33 = 170 dias). As correlações genotípicas e fenotípicas entre todas as características analisadas foram baixas (com exceção da correlação entre produtividade e peso médio de bulbo), indicando a possibilidade de se selecionar "topcrosses" que sejam simultaneamente mais produtivos, mais precoces e menos sujeitos ao florescimento prematuro do que a cultivar Pira-Ouro.

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