Yield evaluation of fourteen populations of climbing bean (*Phaseolus vulgaris* L.) segregating lines with anthracnose (*Colletotrichum lindemuthianum*) resistance genes

Evaluación del rendimiento de catorce poblaciones de líneas segregantes de fríjol voluble (*Phaseolus vulgaris* L.) con genes de resistencia a antracnosis (*Colletotrichum lindemuthianum*)

Nelson A. Pachón[1], Diego F. Gracia[1] and Gustavo A. Ligarreto[1, 2]

ABSTRACT

Common bean is an important low cost and easy access protein source for the Andean region population. Fourteen 'Bola roja' and 'Cargamanto' climbing bean populations resulting from hybridizing six different regional varieties with anthracnose resistant genotype G2333, were evaluated under greenhouse conditions. With the aim of assessing yield of these hybrids, a completely randomized design was applied for the comparison of the following parameters: 100-seeed weight, number of grains per pod, and number of pods per plant. The latter was found to be the most important yield indicator. The study also allowed determining the best evaluated genotypes, which are currently still segregating. Therefore, it is recommended to continue developing line RC_1F_3.

Key words: yield variables, legume, greenhouse, Colombia.

RESUMEN

El fríjol común es de importancia en la dieta de la población de la región Andina por ser una fuente accesible de proteína a bajo costo. Bajo cubierta plástica se evaluaron 14 poblaciones de fríjol voluble 'Bola roja' y 'Cargamanto' provenientes de hibridaciones de seis genotipos distintos por G2333 resistente a Antracnosis. El objetivo principal fue evaluar el rendimiento de los híbridos de fríjol. Se utilizó un diseño completo al azar. Se compararon las variables de rendimiento, teniendo como resultado la diferencia entre variables como número de vainas por planta, número de granos por vainas y peso de 100 granos. El análisis de rendimiento por planta, las variables de rendimiento y sus componentes, mostraron que el carácter vainas por planta fue el de mayor importancia sobre la determinación del rendimiento. El estudio también permitió determinar las mejores de entre las catorce poblaciones evaluadas. Se recomienda continuar con el avance de RC_1F_3.

Palabras clave: variables de rendimiento, leguminosa, invernadero, Colombia.

Introduction

A very important and nutritious leguminous crop, beans are cultivated worldwide on 26,9 million ha that produced 19.2 million t in 2007 (FAO, 2009). This crop is well appreciated by all social groups as an important ingredient of numerous highly consumed typical dishes, and constitutes one of the most outstanding Latin American foods. In consequence, beans are highly valuated within local cultures, as in the case of Colombia, where they are consumed in all regions.

According to Ligarreto (2001), within the traditional Andean culture bean cultivation is associated to smallholdings usually lower than 5 ha in size. In Colombia, the number of families currently growing this crop is estimated around 65,000, and the number of direct day's wages around 12.5 million per year (CIAT, 2001; Ríos and Quirós, 2002; Proexport, 2003). In 1988, the country produced 0.7% of the total world dry bean production, which is equivalent to 114,503 t, and implies a 1.9% annual average growth rate during the period comprised from 1991 to 1998. The main factor explaining this behavior is yield increase, which went from 808 kg ha^{-1} in 1992, to 945 kg ha^{-1} in 1998 (Corporación Colombia Internacional, 2000).

Regarding anthracnose, five improved climbing bean varieties have been obtained in Colombia so far. Three of

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1 Departamento de Agronomía, Facultad de Agronomía, Universidad Nacional de Colombia, Bogotá.
2 Corresponding author: galigarretom@unal.edu.co

them have been developed for the department of Antioquia, and correspond to the 'Cargamanto' type. However, due to their lack of commercial quality when compared to the regional varieties (which are anthracnose susceptible), they have not been well accepted. Meanwhile, no anthracnose resistant 'Bola roja' varieties have been developed in the country (Ligarreto, 1997).

Seeking for bean protection, which has become a challenge for plant breeders and phytopathologists, the present work searched for better anthracnose resistant genotypes. Monogenic resistance genes are appreciated for their easy manipulation, as they can be introduced in susceptible genotypes by means of simple cross breeding (Vallejo and Estrada, 2002; Garzón, 2006). These should ideally be combined with desirable yield features, among which the most outstanding ones are number of pods per plant (p/pl), number of seeds per pod (s/p) and grain weight, also known as primary yield components. According to Ligarreto (2003) yield, p/pl, and 100-seed weight are the most frequently used characters in describing bean collections.

Thus, by means of a completely randomized statistical analysis, the present work was aimed at evaluating yield performance on 14 `Bola roja' and `Cargamanto' promissory climbing bean populations previously hybridized with anthracnose resistance genes, and comprising 42 segregating lines. As part of the assessment of the obtention of BC1F3, the study evaluated the following parameters: p/pl, s/p, 100-seed weight, plant yield and precocity.

Materials and methods

The present experiment was carried out under greenhouse conditions at the Faculty of Agronomy of Universidad Nacional de Colombia - Bogota campus. Located at 2,556 m a.s.l., the cultivation area presents respective average, average minimum, and average maximum temperatures of 14.7, 4.0 and 20.5°C. Relative humidity is 80%, and solar brightness is 4.5 h d^{-1} (Vargas, 2001).

The mentioned 14 populations of 'Bola roja' and 'Cargamanto' climbing beans had been obtained by hybridizing six different regional varieties with CIAT's anthracnose resistant genotype G2333. This accession is characterized by yielding small grains (100-seed weight is 25 g) and having type IV intermediate growth habit (Pastor-Corrales *et al*., 1994). The studied materials were BC_1F_2 populations previously obtained by Garzón (2006). Control experiments were set with cultivars Cabrera, Agrario, Cargamanto, Pesca, Simijaca and D. Moreno (Fig. 1). The agronomic management was conducted according to Ríos and Quirós (2002) and Escobar (2002).

The evaluated treatments corresponded to the 42 bean genotypes under study, plus their six progenitor cultivars, making up a total of 48 treatments with 10 repetitions each, arrayed in a completely randomized design (Melo, 2006). The experimental unit was a 4 m long row allowing 40 seeds (plants) at a 0.1 m planting distance. Each of the variables in study was subject to analysis of variance, and the minimum significant differences for the criteria under evaluation were determined by means of a Tukey test.

The performance of the different lines was assessed by means of the following variables: a) time to flower (d); b) number of pods per plant; c) number of seeds per pod; d) 100-seed weight (grams); e) plant yield (grams per plant) and f) growth habit. Variables b, c and d correspond to bean yield components.

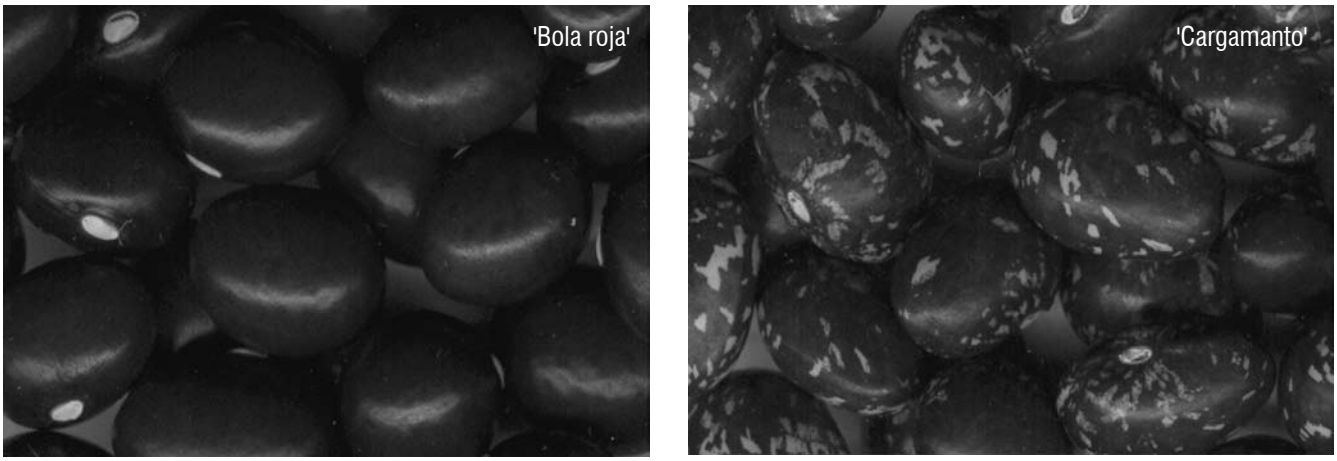

FIGURE 1. Climbing bean genotypes Bola roja and Cargamanto, used as controls.

In assessing variable "a", the planting day was that of actually sowing the seeds; and the flowering day was defined as that on which 50% of the row presented at least one flower per plant. As to variable "b", p/pl was counted on ten plants chosen randomly out of each row, then calculating the average per plant, and extrapolating it to the row. Variable "c" was assessed by counting all the grains produced by ten plants out of each row, and dividing the result by the number of pods tallied on those same plants. Variable "d" was measured by weighing 100 dry seeds from each row, and the growing habit was evaluated according to Van Shoonhoven and Pastor-Corrales (1987).

Results and Discussion

Number of pods per plant

When analyzed through the Tukey test, the means of this variable showed a series of groupings, among which the highest performance was exhibited by genotypes UN1045 and UN1046, both with the same hybridization profile ((G2333 x Cargamanto) x Cargamanto), and showing no significant difference among them (Tab. 1 and 2). Genotype UN1113, obtained from Pesca x (Pesca x G2333), had a good performance regarding this variable too, and showed no significant difference with the former genotypes. Meanwhile, when compared to the other tested lines, it did score significant differences.

Although genotypes UN1045 and UN1046 scored the least s/p counts, their plant yield score was significantly better than those of controls 'Agrario', 'D. Moreno', 'Pesca' and 'Simijaca'; but not significant with respect to the best controls, which were 'Cargamanto' and 'Cabrera'.

High p/pl records can be considered a phenotypic expression of Mesoamerican races, which are the origins of accession G2333 (Ligarreto, 2003; Garzón, 2006). This could contribute to explain the situation mentioned above, given that both UN1045 and UN1046 come directly from a G2333 x Cargamanto hybrid female whose progenitors include another G2333 female (Tab. 1 and 2).

According to a climbing bean yield study carried out by López (2006), high p/pl values failed to prove any relation with higher productive behaviors in the studied genotypes. Indeed, the lines exhibiting such values presented higher empty seed records, or scored low s/p values. However, this behavior might be related to low pollen viability caused by exposition to high temperatures. In effect, this condition determines early tissue degeneration, thus limiting early pollen nutrition and affecting proline translocation to the anther wall, which in turn plays an important role in defining viability or fertility of pollen grains (Prasad *et al*., 2002). In consequence, p/pl may still be considered an interesting character.

Number of seeds per pod

According to the Tukey test, genotypes UN1103 and UN1104, both obtained from cross D. Moreno x (G2333 x D. Moreno), presented the highest average values for this feature, showing significant differences with the other tested genotypes, but not among each other (Tab. 2).

These same genotypes exhibited significant 100-seed weight differences with 'D. Moreno', and significant plant yield differences with the other tested genotypes, as well as with controls 'Agrario', 'Pesca', 'D. Moreno' and 'Simijaca', but not with controls 'Cabrera' and 'Cargamanto', which attained good production. P/pl values, particularly those of genotype UN1103, showed no significant differences when compared to the control materials.

Garzón (2006) has mentioned that in direct and reciprocal crossings in Darien, municipality of Calima, department of Valle del Cauca, the highest s/p scores were obtained when using G2333 as female. However, in the present work, those genotypes more directly related to G2333 produced the least scores for this variable. The mentioned author also indicates that, as a Mesoamerican material, G2333 is well adapted to low altitudes such as Darien, where it presents less number of abortions. On the other hand, at the altitude of the Bogota Plateau, this phenomenon may have been more abundant in the (G2333 x n) x n genotypes, as it could be inferred from Tab. 1 and 2, specifically regarding genotypes UN1045 and UN1046, which exhibited the highest p/pl and least s/p numbers.

The previous analysis excluded genotypes as UN1109, obtained from cross Pesca x (G2333 x Pesca), and UN1113, obtained from Pesca x (Pesca x G2333), which presented high p/pl and low s/p records as well.

100-seed weight, plant yield and growth habit

The highest 100-seed weight scores were reached by genotypes UN1085, obtained from cross Cabrera x (Cabrera x G2333); followed by UN1091, obtained from cross Cargamanto x (Cargamanto x G2333). These genotypes exhibited significant differences when compared to controls 'Agrario', 'Cabrera' and 'Cargamanto'; and highly significant dif-

TABLE 1. Means of the 14 hybrid and 6 control populations of climbing bean.

Populations	100-seed weight (g)	P/PL[1]	S/P[2]	P/Y[3] (g)	DTF[4]
Hybrids					
1. (Cabrera x G2333) x Cabrera	74.63	31.35	2.24	45.16	75
2. (G2333 x Cargamanto) x Cargamanto	70.23	75.57**	1.38	58.01	77
3. (G2333 x D. Moreno) x D. Moreno	64.56	48.42*	3.68	99.53	72**
4. (G2333 x Pesca) x Pesca	70.21	57.01*	3.46	138.70**	86
5. Agrario x (G2333 x Agrario)	62.95	26.26	4.26	71.22	68**
6. Cabrera x (Cabrera x G2333)	81.46*	21.03	3.22	57.13	80
7. Cabrera x (G2333 x Cabrera)	72.80	23.71	4.43	78.73	77
8. Cargamanto x (Cargamanto xG2333)	72.35	33.98	3.35	86.37	79
9. D. Moreno x (D. Moreno x G2333)	79.29	17.08	4.07	56.22	81
10. D. Moreno x (G2333 x D. Moreno)	74.72	17.80	5.60**	78.47	78
11. Pesca x G2333) x Pesca	67.46	30.16	3.28	66.88	77
12. Pesca x (G2333 x Pesca)	73.15	40.03	3.02	86.10	83
13. Pesca x (Pesca x G2333)	72.38	59.52**	2.70	101.46	78
14. Simijaca x (Simijaca x G2333)	65.31	50.60	3.93	126.87	86
Controls					
Agrario	59.20	30.10	4.90	87.31	-
Cabrera	86.90	21.30	5.90	109.20	-
Cargamanto	87.00	21.30	5.90	109.33	-
D. Moreno	65.30	30.20	5.60	110.44	-
Pesca	64.20	28.40	5.10	92.99	-
Simijaca	60.30	29.20	5.90	103.88	-

[1] P/PI, number of pods per plant; [2] S/P, number of seeds per pod; [3] P/Y, plant yield; [4] DTF, Days to flower.

* Significant differences ($P \leq 0.05$); ** significant differences ($P \leq 0.01$), for the Tukey test applied to the treatment means.

ferences with respect to controls 'D. Moreno', 'Pesca' and 'Simijaca' (Tab. 2).

This was so because UN1085 and UN1091 had received this feature from their Andean female progenitors. According to Ligarreto (2003), Andean cultivars are characterized by having heavier grains than Mesoamerican ones. This is confirmed by the higher 100-seed-weight values exhibited by controls 'Cabrera' and 'Cargamanto'. Although the latter are in turn lower than those of genotypes UN1085 and UN1091, this apparent contradiction can be explained as a case of transgressive inheritance.

The genotypes that reached the best yield results were those that achieved the best compensation among yield components, that is, good p/pl, s/p and 100-seed-weight scores (the latter above 65 g). These were genotype UN1114, obtained from cross Pesca x (Pesca x G2333); followed by genotypes UN1091, from cross Cargamanto x (Cargamanto x G2333); and UN1122, from Simijaca x (Simijaca x G2333). These not only reached significant differences with the other tested genotypes, but also with the regional controls. It must be highlighted that both Pesca and Simijaca are Bola roja cultivars, and that in these crosses they (as well as cultivar Cargamanto in UN1091) were acting as female progenitors.

Out of the 42 evaluated genotypes, 21 were classified as having type IVa growth habit, whose pods are distributed all over the plant. Fifteen genotypes were classified as type IVb, and 6 as IIIb. In these two last categories pods are mainly distributed on the upper third of the plant. Type IV includes undetermined growth climbing plants with weak, long and twisted stem and branches. Type III includes undetermined and prostrate growth plants (Van Shoonhoven and Pastor-Corrales, 1987). Tab. 2 specifies the growth habits of the different genotypes. Due to their small p/pl, which ranged between 8 and 31, type III genotypes attained low yield scores when compared to type IV ones, whose p/pl ranged from 5 to 93. In disregard of wether type IV genotypes are a or b, they should ideally have high p/pl, more than three s/p, and higher than 70 g 100-seed-weight records.

Precocity (days to flower)

This parameter was assessed by measuring time to flower, which showed the tested genotypes to be clustered in groups

TABLE 2. Average values of the studied variables for each climbing bean genotype.

Code number	Population[1]	Growth habit[2]	DTF[3]	100-seed weight (g)	P/PI[4]	S/P[5]	P/Y[6] (g)
UN1023	1	IV a	77	77.53	22.000	2.9399	50,14
UN1025	1	IV a	67	71.03	48.473	1.0619	36,50
UN1026	1	IV a	84	75.34	23.600	2.7479	48,85
UN1045	2	IV a	77	72.19	92.255**	0.7371	49,09
UN1046	2	IV a	77	64.25	93.418**	0.7121	42,74
UN1047	2	IV a	79	74.26	41.055	2.6965	82,20
UN1048	3	IV b	77	64.54	62.782	1.9979	80,95
UN1050	3	IV b	77	64.58	34.073	5.3674	118,11
UN1052	4	IV b	81	70.21	57.018	3.4649	138,70
UN1072	5	III b	68	63.26	23.000	3.8966	56,69
UN1075	5	IV a	68	62.64	29.527	4.6363	85,75
UN1083	6	III b	88	76.28	8.855	3.3164	22,40
UN1085	6	IV a	71	91.420**	20.709	2.1359	40,44
UN1086	6	IV a	81	76.70	33.545	4.219	108,55
UN1087	7	IV a	81	81.27	29.818	3.9059	94,65
UN1088	7	IV a	71	80.35	30.855	5.5369	137,27
UN1089	7	III b	77	44.16	21.109	5.1601	48,10
UN1090	7	III b	77	85.42	13.073	3.1257	34,90
UN1091	8	IV a	81	89.600**	30.200 NS	5.7369 NS	155,23*
UN1091	8	IV a	81	72.48	37.327	2.0808	56,30
UN1091	8	IV a	81	74.23	31.436	2.7435	64,02
UN1092	8	IV a	81	73.64	53.945	3.6583	145,32
UN1093	8	IV a	81	71.35	34.909	4.824	120,15
UN1093	8	IV a	81	56.08	15.018	4.7797	40,25
UN1094	8	III b	71	75.96	31.927	1.3877	33,65
UN1094	8	IV a	77	64.47	38.018	3.1024	76,04
UN1099	9	IV b	81	78.26	19.091	4.8848	72,98
UN1101	9	III b	81	80.33	15.073	3.2649	39,47
UN1103	10	IV b	77	76.18	22.055	6.0923*	102,34
UN1104	10	IV b	77	81.27	17.818	6.5441*	94,76
UN1105	10	IV b	81	79.60	25.473	4.8754	98,86
UN1106	10	IV b	81	61.84	5.891	4.9206	17,93
UN1107	11	IV b	81	67.46	30.164	3.2871	66,88
UN1108	12	IV b	88	73.70	31.145	4.0474	92,90
UN1109	12	IV b	84	71.24	44.527	0.9714	30,80
UN1110	12	IV b	77	74.52	44.418	4.0672	134,62
UN1111	13	IV b	77	71.34	36.873	3.3908	89,20
UN1113	13	IV b	77	75.56	80.018**	0.5841	35,31
UN1114	13	IV b	81	70.26	61.673	4.1512	179,88**
UN1119	14	IV a	81	66.32	43.509	4.3535	125,62
UN1120	14	IV a	94	65.10	39.418	4.0418	103,71
UN1122	14	IV a	84	64.51	68.873	3.4050	151,28*
Agrario	-	---	-	59.20	30.100	4.9000	87,31
Cabrera	-	---	-	86.90	21.300	5.9000	109,20
Cargamanto	-	---	-	87.00	21.300	5.9000	109,33
D. Moreno	-	---	-	65.30	30.200	5.6000	110,44
Pesca	-	---	-	64.20	28.400	5.1000	92,99
Simijaca	-	---	-	60.30	29.200	5.9000	103,88

[1] Hybrid populations mentioned in Tab. 1; [2] Type III growth habit: prostrate undetermined – training, IV: climbing undetermined; [3] DTF, Days to flower; [4] P/PI, number of pods per plant; [5] S/P, number of seeds per pod; [6] P/Y, plant yield.

* Significant differences ($P \leq 0.05$); ** significant differences ($P \leq 0.01$); NS, non significant differences; for the Tukey test applied to the treatment means.

differentiated from each other by an average difference of 10 d (Tab. 2). The most precocious material was found to be UN1025, obtained from cross Cabrera x (Cabrera x G2333), which took 67 d to flower. Similarly, and having taken 68 d to flower, genotypes UN1072 and UN1075, obtained from cross Agrario x (G2333 x Agrario), were also precocious and showed highly significant differences with the other lines. It is worth mentioning that these two genotypes were the only ones representing such cross.

These precocious genotypes presented moderate p/pl records, (ranging from 23 to 48 p/pl); an average 4.63 s/p count; and low plant yield scores (from 36.50 g y 85.75 g). Such behaviour might be due to relatively high empty seed numbers, especially in the case of genotype UN1025, which reached average values of 48.47 p/pl, and only 1 s/p.

The average time-to-flower score was 79 d. The longest records were reached by populations obtained from (G2333 x Pesca) x Pesca, and from Simijaca x (Simijaca x G2333), with 86 d; followed by those obtained from Pesca x (G2333 x Pesca), with 83 d; (Pesca x G2333) x Pesca, and D. Moreno x (D. Moreno x G2333), with 81 d; and finally Cabrera x (Cabrera x G2333), with 80 d (Tab. 1).

Genotypes related to cultivars Cargamanto, Simijaca and Cabrera presented early senescence, as it can be seen in their precocious falling of the leaves. As mentioned by Gallego (2005), resulting from genotype-environment interactions, these precocious genotypes bear small grains because it would require longer productive periods to fill bigger ones.

In sum, it can be said that the precocious genotypes UN1072 and UN1075, with a 68 d-to-flower period, clearly stand out of the background. Although they exhibited some of the lowest 100-seed-weight scores (respectively 63.26 g and 62.64 g), as well as low s/p values, and their p/pl values were just similar to those of the control materials, they (and precocity in general) should be considered within the Leguminous Breeding Program of Universidad Nacional de Colombia, aiming at medium precocity and good yield materials. The reason for this is that precocious materials usually have low yield and small grains. Tab. 2 shows how the highly productive genotypes UN114, UN1091, UN1122 and UN1052 are above 138 g per plant and took from 81 to 84 d to flower, exceeding the average (79 d) by two weeks.

Relation among variables

In the present work, the selection of the best performing genotypes was based on analysis of the variables presented in Tab. 2. This led to choosing UN1114 as the best genotype, which through yield component compensation attained the highest yield performance (179.88** g). In effect, , we can see that it reached a moderate 100-seed weight of 70.26 g, a high p/pl score of 61.67, and 4.15 s/p. Taken individually, these data may be considered as average records, as far as they are higher than many others, but also lower than some other ones. This is the case of genotype UN1085, which exhibited the highest 100-seed weight (91.42** g), but a 40.44 g plant yield; also UN1046, which produced an average of 93.42** p/pl, and a 42.74 g plant yield; or UN1104, with the highest s/p score (6.54*), a good 100-seed weight (81.27 g), but just 17.81 s/p. It can be said then, that the yield components of these three genotypes do not sufficiently compensate one another, consequently determining low or medium plant yield records.

Genotype UN1091, obtained from cross Cargamanto x (Cargamanto x G2333), was actually considered as the second best performing one, due to the significant differences that it scored regarding 100-seed weight and plant yield. Also, it showed significant s/p differences when compared to cultivars Agrario and Pesca; but non significant ones with respect to cultivars Cabrera, Simijaca and especially Cargamanto (Tab. 2).

Amongst all hybrids, Cabrera x (Cabrera x G2333) reached the highest 100-seed-weight values (81.46* g). This behavior might result from the fact that cultivar Cabrera, featured by having heavy grains, has always acted as female progenitor in the cross. However, this hybrid did not show significant differences when compared to controls 'Cabrera' and 'Cargamanto'. Regarding p/pl, hybrid (G2333 x Cargamanto) x Cargamanto scored highly significant differences (75.57** p/pl) in comparison to all other tested materials. This might be determined by the large p/pl that features both cultivar Cargamanto and accession G2333. Highly significant s/p differences were attained by hybrid D. Moreno x (G2333 x D. Moreno) when compared to the other ones, but not when compared to the control materials, except for 'Agrario'. The most precocious hybrids were Agrario x (G2333 x Agrario) and (G2333 x D. Moreno) x D. Moreno, exhibiting highly significant differences in comparison to the rest of them (Tab. 1).

Conclusions

Evaluation of yield and precocity in the different Bola roja and Cargamanto BC1F3 hybrids obtained showed strong segregation, not only among the populations, but also within them. This provides an ample genetic basis for

our breeding program to continue advancing towards the obtention of anthracnose resistant (conferred by material G2333) genotypes with similar or superior features to those exhibited by the regional cultivars, such as Cabrera, Agrario, Cargamanto, Pesca, Simijaca and D. Moreno. Such improved materials, mainly represented here by genotypes UN1114 and UN1091, could be not only highly beneficial for farmers due to reduced phytosanitary management, precocity and higher productivity, but for the consumer as well, through their sanitary and commercial quality.

Out of the evaluated yield components, the results point at p/pl as the most closely associated to crop yield itself, because the higher variation it exhibited makes it more appropriate for compensating the other components, which is what determines yield performance. This might also be the result of the easiness of accession G2333 (featured by high p/pl records) to combine with regional cultivars like Cargamanto, Pesca and Simijaca. Nevertheless, taking into account that 100-seed weight is not only less plastic than p/pl, but also the most important commercial characteristic of the product, it should also be given importance in our breeding program.

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Literature cited

Centro Internacional de Agricultura Topical (CIAT). 2001. Common bean: The nearly perfect food. In: CIAT in Focus. http://www.ciat.cgiar.org/ciatinfocus/pdf/beanfocus.pdf; consulted: February, 2009.

Corporación Colombia Internacional (CCI). 2000. Perfil del producto, fríjol. In: http://www.cci.org.co; consulted: February, 2009.

Debouck, D. 1994. Evolución de las especies cultivadas de fríjol: La opinión de un herético. pp. 99-104. In: Proc. XI Congreso Latinoamericano de Genética and XV Congreso de Citogenética, Sociedad Mejicana de Fitogenética. Monterrey, México.

Escobar, C.E. 2002. Recomendaciones técnicas para el manejo del cultivo de fríjol en el municipio de Urrao (Antioquia). Federación Nacional de Cultivadores de Cereales y Leguminosas (Fenalce); Fondo Nacional de Leguminosas; Convenio de Capacitación Fonade, SENA, SAC, Fenalce. Medellín, Colombia.

FAO. 2009. Faostat agricultural data. Agricultural production. In: http://www.fao.org; consulted: February, 2009.

Gallego, C. 2005. Avance en un programa de selección de poblaciones de fríjol voluble (*Phaseolus vulgaris* L.) variedad Bola roja por su reacción a la enfermedad Antracnosis (*Colletotrichum lindemuthianum*). Undergraduate thesis. Facultad de Agronomía, Universidad Nacional de Colombia, Bogotá.

Garzón, L.N. 2006. Selección asistida por marcadores tipo SCARs, de fríjol (*Phaseolus vulgaris* L.), con resistencia a *Antracnosis* (*Colletotrichum lindemuthianum*) proveniente de los cruzamientos entre variedades regionales tipo Bola roja y Cargamanto x G2333. M.Sc. thesis. Facultad de Agronomía, Universidad Nacional de Colombia, Bogotá.

Ligarreto, G. 1997. Variedades y mejoramiento de fríjol. Fenalco, SENA, SAC, Bogotá.

Ligarreto, G. 2001. Variabilidad genética en germoplasma de fríjol común (*Phaseolus vulgaris* L.) determinada por características morfológicas, fisiológicas, bioquímicas y moleculares. Ph.D. thesis. Facultad de Agronomía, Universidad Nacional de Colombia, Bogotá.

Ligarreto, G. 2003. Análisis de la variabilidad genética en fríjol. pp. 40-49. In: Franco L. and R. Hidalgo (eds.). Boletín Técnico IPGRI No. 8. International Plant Genetic Resources Institute (IPGRI). Rome.

López, J. 2006. Evaluación por rendimiento en genotipos promisorios de fríjol voluble (*Phaseolus vulgaris* L.) tipos Bola roja y reventones para las zonas frías de Colombia. Undergraduate thesis. Facultad de Agronomía, Universidad Nacional de Colombia, Bogotá.

Melo, O.O. 2006. Diseños completamente aleatorizados y tamaño de muestra. pp. 131-180. In: Melo, O.O., L.A. López and S.E. Melo (eds.). Diseño de experimentos: métodos y aplicaciones. Universidad Nacional de Colombia, Bogotá.

Pastor-Corrales, M.A., O.A. Erazo, E.I. Estrada and S.P. Singh. 1994. Inheritance of anthracnose resistance in common bean accession G2333. Plant Dis. 78, 958-962.

Proexport. 2003. Estudio de mercado de fríjol en Colombia. In: Proexport. http://www.proexport.gov.co; consulted: May, 2006.

Prasad, P.V.V., K.J. Botte, L. Hartwell and A.J.R. Thomas. 2002. Effects of elevated temperature and carbon dioxide on seed-set and yield of kidney bean (*Phaseolus vulgaris* L.). Global Change Biol. 8, 710-721.

Ríos, B.M. and D.J. Quirós. 2002. El fríjol (*Phaseolus vulgaris* L.): cultivo, beneficio y variedades. Ed. Produmedios, Bogotá.

Vallejo F.A. and E.I. Estrada. 2002. Mejoramiento genético de plantas: heterosis y producción de híbridos en autógamas. Universidad Nacional de Colombia, Palmira.

Van Shoonhoven, A. and M.A. Pastor-Corrales. 1987. Sistema estándar para la evaluación de germoplasma de fríjol. Centro Internacional de Agricultura Tropical (CIAT). Cali, Colombia.

Vargas, C. 2001. Estudio de las necesidades de riego del cultivo de cebollín (*Allium schoenoprasum*) bajo invernadero en la Sabana de Bogotá. Undergraduate thesis. Facultad de Agronomía, Universidad Nacional de Colombia, Bogotá.