RESEARCH

CHILEANJAR
CHILEAN JOURNAL of AGRICULTURAL RESEARCH

INORGANIC NUTRITIONAL COMPOSITION OF COMMON BEAN (*Phaseolus vulgaris* L.) GENOTYPES RACE CHILE

Mario Paredes C.[1*], Viviana Becerra V.[1], and Juan Tay U.[1]

ABSTRACT

The current Chilean bean (*Phaseolus vulgaris* L.) collection is about 1110 accessions. To facilitate the characterization of this germplasm a core collection of 246 accessions was formed. Little information exists about the mineral content and other quality traits for those bean genotypes. This information could be useful to determine their quality and to promote its consumption. The objective of this work was to evaluate the variability for macro and micronutrients of a representative bean sample from a Chilean core collection and to compare them with representatives from other races. The results indicated the presence of a wide variability for some macro and micronutrients, such as N, Fe, and Zn. The protein content varied from 183.5 to 259.7 g kg^{-1}, Fe from 68.9 to 152.4 mg kg^{-1}, and Zn from 27.9 to 40.7 mg kg^{-1}. This situation could allow to select those genotypes with higher elements and to improve the current cultivars. The simple correlation analysis indicated that the N content was positively correlated with protein, P, Cu, Zn, and S content and negatively correlated with B content and the C/N ratio of the seed. The Fe content was positively correlated with Mn and Ca content and Zn content was positively correlated with the N, P, Cu and S content and negatively correlated with the relation C/N ratio of bean seed. There were no significant differences between the Chilean bean genotypes compared to genotypes from other races.

Key words: *Phaseolus vulgaris*, race Chile, macronutrients, micronutrients, core collection.

INTRODUCTION

The common bean (*Phaseolus vulgaris* L.) constitutes a traditional food for many people in Latin America, Africa, and Asia (Messina, 1999). Dry bean is a good source of protein, essential vitamins and minerals, soluble-fiber starch, phytochemicals, and it is a low fat food (Meiners *et al*., 1976; Messina, 1999).

Beans could serve as functional food because contain a number of bioactive compounds such as enzyme inhibitors, lectins, phytates, oligosaccharides, and phenolic substances that may play metabolic roles in humans and animals that frequently consume this food (Díaz-Batalla *et al*., 2006). The consumption of beans has been associated to several health benefits like reduction of cholesterol level (Rosa *et al*., 1998), and coronary heart diseases (Anderson *et al*., 1999; Bazzano *et al*., 2001), favorable effects against cancer (Hangen and Bennink, 2002), decrease of diabetes and obesity (Geil and Anderson, 1994), high antioxidant capacity (Heimler *et al*., 2005), antimutagenic (Azevedo *et al*., 2003), and anti-proliferative effects (Aparicio-Fernández *et al*., 2006).

[1]Instituto de Investigaciones Agropecuarias INIA, Casilla 426, Chillán, Chile. *Corresponding author (mparedes@inia.cl).
Received: 05 December 2008.
Accepted: 23 March 2009.

The genetic structure of common bean describes two main centers of diversity, one located in the Andes and another in the Mesoamerica region (Gepts and Debouck, 1991; Becerra-Velásquez and Gepts, 1994). These main centers recognize three main races, Mesoamerica, Durango, and Jalisco in the Mesoamerican gene pool, and race Chile, Nueva Granada, and Perú in the Andean gene pool (Singh *et al.,* 1991a). Besides this classification, other reports proposed the existence of secondary gene pools (Beebe *et al*., 1997) and the new race Guatemala in Mesoamerica (Beebe *et al*., 2000b) that could explain better the genetic structure of the common bean.

The common bean germplasm collected in Chile has been classified as races Chile, Nueva Granada, Peru, Durango, and Mesoamerica, with the only exception to race Jalisco. This situation could be explained by commercial reasons and by the good adaptation of bean species to Chilean agro-climatic conditions. The current bean collection in Chile consists of 1110 accessions approximately. To facilitate its characterization a core collection was formed with 246 accessions representing the genetic variability found in the general collection (Paredes and Becerra, unpublished data).

Accessions from different gene pools have been classified based on their response and adaptation to the ecological conditions, also on their reaction to races of pathogens and other traits. For instance, the Middle American gene pool had higher lectin, Ca, P, S and Zn than the Andean gene pool, but lower phaseolin and Fe (Islam *et al*., 2002).

Bean consumers of different countries and regions, even within the countries, show specific preferences for various combinations of seed size, shape and color cooking time, broth appearance, and storability (Shellie-Dessert and Bliss, 1991). For example in Chile, the most accepted and consumed dry bean market classes are Tórtola and Coscorrón (Singh *et al*., 1991a; Paredes, 1994). In addition, other minor market classes such as Manteca, Sapito, and Cuyano, are also consumed in some specific rural areas.

Little information exists about most of the mineral content, cooking quality, contents of flavonoids, phenolic acids, total phenolics, tannins, and antioxidant capacity of common beans from race Chile, therefore, there is a need to characterize this germplasm in order to promote its consumption.

The objective of this work was to characterize a representative sample of bean genotypes from the bean core collection for its chemical composition and compare them with other genotypes for future genetic improvement.

MATERIALS Y METHODS

Plant material

Fifty representative genotypes of the bean core collection were utilized in this study. This sample consisted of 40 accessions previously classified as race Chile and two accessions representing race Nueva Granada, Peru, Durango, Mesoamerica, and genotypes not classified yet. These 10 genotypes representing other races were included for comparative purposes with race Chile (Table 1).

Methods

Fifty accessions were analyzed for N, P, K, Ca, Mg, Na, Cu, Fe, Mn, Zn, B, S, and C. The C and N content was utilized to calculate the relation C/N in the bean seed. Besides, the N content of the seed was multiplied by 6.25 to obtain the protein content (Guzmán-Maldonado *et al.,* 2000).

Bean seed samples were ground to a fine powder to ensure homogeneity before analysis of macro and micronutrients. Seed bean N, S, and C were determined by the thermal conductivity procedure that included the combustion of the sample to 1040 ºC (Sadzawka *et al.,* 2007). The P and B concentrations were measured by colorimetric method using acidic vanadate molibdate, and azometrine-H, respectively (Sadzawka *et al*., 2007). Potassium, Ca, Mg, Na, Fe, Mn, and Zn were determined by flame atomic absorption spectrometry (Perkin-Elmer spectrophotometer, model 1100B, Phoenix, Arizona, USA; Sadzawka *et al*., 2007). All these macro and micronutrient determinations included calcination of the seed sample to 500 ºC and dissolution with HCl (Sadzawka *et al*., 2007).

Statistical analysis

All data were subjected to an ANOVA appropriate to a randomized complete block design in each location. A combined ANOVA was calculated in a split plot design, where locations were analyzed as main plot and the 50 genotypes as a subplot. The least significant difference (LSD) was used to compare the mean of the genotypes. The simple correlation method between macro, micronutrients and 100-seed weight was also calculated using the SAS program (SAS Institute, 2007).

RESULTS AND DISCUSSION

The quality of bean seed is determined by the protein content, amino acid composition, digestibility, and presence of anti-nutritional factors (Shellie-Dessert and Bliss, 1991), mineral content, cooking quality, concentration of phenolic compounds, like flavonoids, phenolic acids, total phenolics, tannins, which contribute to the antioxidant capacity.

Nitrogen and protein contents. Dry bean is considered a good source of N and protein. For example, a serving of bean (approximately 90 g or ½ cup cooked beans) provides approximately 7 to 8 g protein or about 15% of the recommended dietary allowance for protein for a 70 kg adult (Messina, 1999).

Genetic variability for protein concentration and for its specific seed protein components has been identified within the bean germplasm pool. The protein content in dry beans ranges between 20% and 30% (Shellie-Dessert and Bliss, 1991).

Nitrogen content of seed bean from the Chilean core collection varied between 29.4 and 41.5 g kg^{-1} and its protein from 183.5 (accession 90347) to 259.7 g kg^{-1} (accession 90395). The main market classes consumed in Chile, Tórtola presented a protein content that varied between 222.4 (accession 64) and 232.2 g kg^{-1} (accession 244) and Coscorrón ranged from 230.8 (accession 36) to 231.1 g kg^{-1} (accession 31) (Table 2). On the average, the accessions from Perú, Nueva Granada, Mesoamerica and Durango did not show a significant difference with the genotypes from race Chile.

A study carried out on bean collected in Jalisco (Mexico) showed that the protein content ranged from 222 to 330 g kg^{-1} , whereas those collected from Durango (Mexico) varied from 180 to 311 g kg^{-1} (Guzmán-

Table 1. Bean genotypes analyzed for macro and microelements.

Accession Nº	Common name	Race	100-seed weight
			g
15	Avalito	Chile	47.4
31	Coscorrón corriente	Chile	53.7
32	Hallados	Chile	51.5
33	Hallados Chico	Chile	41.0
36	Coscorrón Méndez	Chile	54.4
41	Sapito	Chile	49.8
52	Azufrado	Chile	39.4
64	Tórtola corriente	Chile	59.3
66	Manteca	Chile	46.5
76	Cara de niño	Chile	57.6
174	María	Chile	49.7
243	Juanita	Chile	59.8
244	Treile	Chile	49.9
267	Tórtola	Chile	46.5
286	Frutilla	Chile	52.9
338	Burro argentino	Chile	37.9
347	Rancagüino	Chile	60.5
354	Amarillo	Chile	44.4
476	NN	Chile	40.4
567	Peumo	Chile	56.0
90047	NN	Chile	35.9
90094	Bayo	Chile	28.9
90107	Manteca	Chile	36.8
90116	Jardín	Chile	39.7
90117	Raucalmino	Chile	40.9
90118	Azufrado	Chile	32.4
90261	Caballero	Chile	72.5
90264	Cabrito baya	Chile	50.8
90288	Gato	Chile	57.9
90290	Mono	Chile	44.6
90301	Angelito	Chile	44.9
90303	Sapito	Chile	26.6
90318	NN	Chile	43.9
90347	NN	Chile	65.3
90395	NN	Chile	60.6
90418	NN	Chile	29.1
90451	Rayado	Chile	39.6
90463	NN	Chile	60.3
90466	NN	Chile	46.4
90469	Sapo	Chile	47.7
90376	NN	Peru	44.2
573	Bayote	Peru	57.9
90212	NN	Nueva Granada	34.0
313	NN	Nueva Granada	50.2
90184	NN	Durango	32.4
225	NN	Durango	34.3
90209	NN	Mesoamerica	37.8
233	NN	Mesoamerica	37.8
90249	Cabrito	nc	63.5
262	NN	nc	48.4

NN: without common name; nc: non classified.

Maldonado *et al.*, 2000). These values agreed with those reported previously for cultivated dry common bean (Moraghan and Grafton, 1997; Guzmán-Maldonado *et al.*, 2000; 2003). On the other hand, cultivated common bean presented on average lower protein content than wild and weedy bean samples collected in Jalisco and Durango (Guzmán-Maldonado *et al.*, 2000).

Phosphorus, K, Ca, Mg, and Na contents. Genetic differences in seed mineral concentrations have been also detected among wild, weedy, and cultivated landraces and modern cultivars (Moraghan and Grafton, 1997; Graham *et al.,* 1999; Beebe *et al.*, 2000a; Guzmán-Maldonado *et al.*, 2000; House *et al.*, 2002; Gelin *et al.*, 2007) and some of this variability has been exploited for the genetic improvement of the crop (Shellie-Dessert and Bliss, 1991; Singh *et al.*, 1991b; Graham *et al.*, 1999; Beebe *et al.*, 2000a).

Calcium, Mg and K are the main cations present in common bean. Ca concentration is more variable than either Mg or K concentrations. Both environmental and genetic factors influence Ca accumulation in dry bean seed. The concentration of Na, Mg and Ca in the seed is lower than that in other parts of the plant. This may be due to the mobility of these elements. The reverse situation occurs for N and P concentrations. However, K is distributed more uniformly throughout mature plants compared with N, P, Ca, Mg, and Na (Moraghan and Grafton, 1997).

In this study, the content of P, K, Ca, Mg and Na varied slightly among genotypes. That is, the P content ranged from 4.0 to 5.6 g kg^{-1} and only one genotype (accession 90395) presented 5.6 g kg^{-1} and the rest of the genotypes were closer to 4 g kg^{-1}. Potassium content varied between 14.2 to 18.4 g kg^{-1}, Ca content were between 1.0 and 2.6 g kg^{-1} and Mg content were between 1.3 and 2.3 g kg^{-1}. Na content varied between 0.03 to 0.12 g kg^{-1} (Table 2).

The analysis of 1072 accessions from Core Collection of common bean of Centro Internacional de Agricultura Tropical (CIAT), Colombia, indicated that the mean of P content was 3.6 g kg^{-1} with a range from 2.2 to 7.1 g kg^{-1}, our data presented a lower genetic variability. In another study, carried out in a recombinant population of navy bean population the P and Ca content varied from 4.2 to 3.9 mg kg^{-1} of P and from 2.4 to 1.4 mg kg^{-1} of Ca, considering the 10% top and bottom of the population (Gelin *et al.*, 2007). Other data indicated that the mean of Ca content was 1.5 g kg^{-1} and varied from 0.5 to 3.1 g kg^{-1} (Islam *et al.*, 2002). Differences in Ca concentration were also reported in different cultivated bean market classes. For instance, the average Ca concentration in six navy bean cultivars was 90% more than the mean of three kidney and three cranberry bean cultivars. In this situation, the higher Ca concentration did not result from greater Ca absorption, but in changes of the seed-coat area/cotyledon weight ratios with increasing seed size, therefore increased growth rates of pods in a large-seeded cultivars resulted in decreased Ca concentrations due to lack of mobility of Ca from vegetative tissue to fruiting structures (Moraghan and Grafton, 1997). The wild and weedy dry bean contained more Ca than in the cultivated genotypes (Guzmán-Maldonado *et al.*, 2000).

Cupper, Fe, Mn, Zn, and B contents. Among the micronutrients Fe and Zn, vitamin A, folate, and I (Sanghvi *et al.,* 2007) have captured attention as being of public health concern, meanwhile other elements like Se and B deficiency and some vitamin like α-tocopherol, ascorbate, cobalamin, and folate, are currently of growing concern to human nutrition (Graham *et al.*, 2001).

In developing countries, cereal grains and some legumes are the primary and cheapest source of Ca, Fe and Zn, however, their intake does not satisfy the mineral requirements of the population in these countries (Guzman-Maldonado *et al.,* 2000). In the last decade, poor health, lower worker productivity, high rate of mortality and morbidity, increasing rates of chronic diseases (coronary heart disease, cancer, stroke, and diabetes) and permanent impairment of cognitive abilities of infant born from micronutrient deficient mother have been related to poor micronutrient nutrition (Welch and Graham, 2000; Graham *et al.*, 2001; Sanghvi *et al.*, 2007).

Iron deficiency is the common nutrition disorder worldwide and affects a large proportion of women and children in developing countries. Indeed, an estimated 3.5 to 5 billion people are Fe deficient in the world (Underwood, 2000; Graham *et al.*, 2001). Diets deficient in Fe are often Zn deficient (Monsen, 1988). The main symptoms of Zn deficiency include pregnancy complications, low birth weight, maternal and infant mortality and reduction of growth in infancy and childhood (Frossard *et al.*, 2000). On the other hand, Ca deficiency has also been epidemiologically linked to several chronic diseases, including osteoporosis, hypertension, and colon cancer.

The analysis of this data indicated that the bean genotypes race Chile presented significant differences between them for all micronutrients evaluated (Table 3). The mean of Cu content was 10.9 mg kg^{-1} and varied from 8.8 to 12.8 mg kg^{-1}. The mean of the Fe content was 90.2 mg kg^{-1} with a range from 68.9 and 152.4 mg kg^{-1}. On other hand, the Mn content varied from 9.6 to 18.9 mg kg^{-1}. The Zn content ranged from 27.9 to 40.7 mg kg^{-1} and B from 9.3 to 15.3 mg kg^{-1}. The S content varied from 2.2 to 2.8 g kg^{-1} and the C between 410.9 to 425.3 g kg^{-1} and the relation C/N from 10.2 to 14.4 (Table 3).

Table 2. Average macronutrient content of grain dry beans at two locations, INIA La Platina (Santiago) and INIA Quilamapu (Chillán).

Accession Nº	Common name	Race	N	Protein*	P	K	Ca	Mg	Na
					g kg^{-1}				
15	Avalito	Chile	31.5	197.5	4.0	15.0	2.1	1.5	0.05
31	Coscorrón corriente	Chile	37.0	231.1	4.9	15.9	1.7	1.7	0.11
32	Hallados	Chile	37.8	236.4	4.9	16.9	2.0	1.7	0.12
33	Hallados Chico	Chile	34.2	216.6	4.4	16.1	1.8	1.7	0.07
36	Coscorrón Méndez	Chile	36.6	230.8	4.7	16.7	2.0	1.8	0.03
41	Sapito	Chile	37.0	235.8	4.8	16.9	1.8	1.7	0.09
52	Azufrado	Chile	34.8	217.4	4.9	16.3	1.6	1.6	0.08
64	Tórtola Corriente	Chile	34.5	222.4	4.5	18.1	1.4	1.5	0.09
66	Manteca	Chile	34.6	218.8	5.0	16.9	1.6	1.6	0.12
76	Cara de niño	Chile	36.4	227.9	4.9	16.3	1.6	1.5	0.08
174	María	Chile	36.2	226.0	4.7	16.2	1.8	1.5	0.07
233	Juanita	Chile	36.4	232.4	4.9	16.5	1.8	1.4	0.07
243	Treile	Chile	38.9	243.0	5.4	16.4	1.7	1.5	0.05
244	Tórtola	Chile	37.1	232.2	5.0	17.9	1.8	1.7	0.08
262	Frutilla	Chile	36.8	232.5	4.7	17.2	2.1	1.7	0.08
267	Burro Argentino	Chile	36.6	231.3	4.9	16.8	1.0	1.5	0.10
286	Rancagüino	Chile	34.2	213.6	4.6	15.3	2.0	1.6	0.08
338	Amarillo	Chile	36.9	230.3	5.1	17.3	1.5	1.8	0.10
347	NN	Chile	34.7	219.6	4.6	17.0	1.9	1.6	0.10
354	Peumo	Chile	40.5	253.0	5.1	16.5	1.4	1.6	0.08
90047	NN	Chile	37.9	236.8	5.1	17.3	1.8	1.6	0.10
90094	Bayo	Chile	37.7	236.5	4.9	15.9	2.1	1.5	0.05
90107	Manteca	Chile	39.5	246.8	5.1	14.7	1.6	1.3	0.09
90116	Jardín	Chile	29.7	185.4	4.3	16.2	1.2	1.6	0.06
90117	Raucalmino	Chile	36.1	225.9	5.0	18.4	1.2	1.5	0.06
90118	Azufrado	Chile	40.1	250.3	5.0	15.8	1.0	1.6	0.08
90261	Caballero	Chile	37.8	236.4	4.6	16.7	1.7	1.7	0.08
90264	Cabrito baya	Chile	36.6	228.6	4.5	15.2	1.5	1.5	0.06
90288	Gato	Chile	35.3	220.8	4.3	16.1	1.5	1.7	0.04
90290	Mono	Chile	34.7	216.9	4.5	15.7	1.1	1.5	0.09
90301	Angelito	Chile	36.2	226.4	4.6	15.6	1.9	1.7	0.05
90303	Sapito	Chile	36.7	229.1	4.6	15.7	1.9	1.6	0.06
90318	NN	Chile	34.3	214.4	4.4	15.2	1.7	1.5	0.06
90347	NN	Chile	29.4	183.5	4.1	14.7	1.7	1.5	0.08
90395	NN	Chile	41.5	259.7	5.6	14.2	1.3	1.4	0.06
90418	NN	Chile	35.7	223.0	4.8	17.2	1.5	1.8	0.06
90451	Rayado	Chile	39.5	246.8	5.1	16.4	1.5	1.5	0.06
90463	NN	Chile	39.1	244.4	4.5	15.6	1.7	1.5	0.08
90466	NN	Chile	40.1	259.8	4.9	15.0	1.9	1.6	0.06
90469	Sapo	Chile	38.1	243.6	4.7	16.4	1.7	1.7	0.09
90376	NN	Peru	39.0	245.4	5.3	16.2	1.8	1.5	0.06
567	Ballote	Peru	33.5	209.2	4.6	15.6	1.7	1.5	0.08
90212	NN	N. Granada	30.5	190.6	4.6	16.9	2.6	1.9	0.10
476	NN	N. Granada	34.5	220.8	4.6	15.4	1.6	1.6	0.06
573	NN	Durango	34.2	216.1	4.3	16.6	1.4	1.6	0.05
90184	NN	Durango	37.9	237.2	4.9	16.0	1.7	1.5	0.05
90209	NN	Mesoamerica	37.6	233.0	4.9	16.1	1.6	1.5	0.04
313	NN	Mesoamerica	37.9	237.1	4.9	16.4	2.3	1.7	0.07
90249	Cabrito	nc	36.7	229.4	4.5	16.5	1.5	1.6	0.07
225	NN	nc	34.5	215.7	5.0	16.6	1.8	1.6	0.07
LSD at 5%			3.2		0.4	1.3	0.3	0.1	0.06

NN: without common name; nc: non classified; LSD: least significant difference; N: Granada: Nueva Granada.

Table 3. Average micronutrient content of dry bean grains at two locations, INIA La Platina (Santiago) and INIA Quilamapu (Chillán).

Accession Nº	Common name	Race	Cu	Fe	Mn	Zn	B	S	C	C/N
			mg kg^{-1}					g kg^{-1}		
15	Avalito	Chile	9.8	69.5	13.3	35.0	11.9	2.2	418.7	13.3
31	Coscorrón corriente	Chile	11.9	83.2	12.8	35.0	11.7	2.7	421.3	11.4
32	Hallados	Chile	12.1	90.1	13.8	38.7	13.3	2.7	420.2	11.1
33	Hallados Chico	Chile	10.4	80.8	12.4	33.3	12.6	2.6	419.1	12.3
36	Coscorrón Méndez	Chile	11.4	101.9	13.5	35.9	11.7	2.6	418.7	11.4
41	Sapito	Chile	12.4	92.0	14.5	34.6	12.4	2.7	421.2	11.4
52	Azufrado	Chile	11.1	72.3	12.7	30.9	12.0	2.7	418.7	12.0
64	Tórtola corriente	Chile	11.5	114.7	12.9	36.4	12.4	2.5	410.9	11.9
66	Manteca	Chile	11.5	86.4	12.1	37.0	13.1	2.7	418.3	12.01
76	Cara de niño	Chile	12.1	76.5	12.0	34.0	13.0	2.7	422.4	11.6
174	María	Chile	11.4	96.9	14.4	32.1	12.4	2.6	422.0	11.7
233	Juanita	Chile	9.6	81.1	12.4	31.4	10.8	2.7	418.5	11.5
243	Treile	Chile	11.4	92.2	13.0	33.1	9.3	2.6	419.7	10.8
244	Tórtola	Chile	11.8	100.2	14.7	35.9	12.1	2.7	412.9	11.1
262	Frutilla	Chile	11.5	99.8	14.4	35.9	12.3	2.6	416.3	11.3
267	Burro Argentino	Chile	10.8	80.1	11.1	33.1	11.0	2.7	414.9	11.3
286	Rancaguino	Chile	10.0	82.6	13.0	30.8	11.6	2.4	418.0	12.2
338	Amarillo	Chile	10.8	77.1	12.0	34.8	11.5	2.6	418.0	11.3
347	NN	Chile	9.9	80.2	13.2	31.0	14.0	2.4	416.5	12.0
354	Peumo	Chile	11.1	79.1	11.5	32.9	12.0	2.7	421.9	10.4
90047	NN	Chile	10.2	103.1	13.3	34.1	12.5	2.7	417.3	11.0
90094	Bayo	Chile	9.5	97.5	12.4	31.8	12.4	2.6	416.3	11.0
90107	Manteca	Chile	9.8	102.6	13.6	32.4	10.5	2.8	418.8	10.6
90116	Jardín	Chile	10.0	72.4	9.6	30.0	12.7	2.3	417.0	14.0
90117	Raucalmino	Chile	10.5	91.7	11.1	31.5	12.2	2.6	417.2	11.5
90118	Azufrado	Chile	11.6	86.3	12.7	34.3	11.3	2.7	417.1	10.4
90261	Caballero	Chile	12.0	96.6	13.3	33.8	13.3	2.7	417.1	11.0
90264	Cabrito baya	Chile	11.8	70.6	11.3	30.9	13.6	2.7	417.6	11.4
90288	Gato	Chile	9.6	83.5	12.4	32.5	12.8	2.4	413.3	11.7
90290	Mono	Chile	12.1	152.4	13.9	33.5	13.1	2.5	415.5	12.0
90301	Angelito	Chile	11.3	101.6	13.9	32.9	14.0	2.6	421.3	11.6
90303	Sapito	Chile	12.1	84.9	18.9	30.1	11.6	2.5	422.1	11.5
90318	NN	Chile	9.9	75.1	12.5	31.2	13.6	2.4	420.1	12.2
90347	NN	Chile	9.6	68.9	13.1	30.6	13.9	2.4	422.8	14.4
90395	NN	Chile	12.8	82.0	12.9	33.1	13.2	2.8	425.3	10.2
90418	NN	Chile	11.8	73.9	12.5	34.7	15.1	2.6	420.8	11.8
90451	Rayado	Chile	10.7	92.0	11.9	37.6	12.8	2.7	421.2	10.7
90463	NN	Chile	10.8	85.8	13.1	35.1	11.4	2.6	419.4	10.7
90466	NN	Chile	10.8	99.4	13.0	37.4	11.1	2.8	419.4	10.5
90469	Sapo	Chile	10.9	81.9	12.4	35.4	11.3	2.7	421.5	11.1
90376	NN	Peru	11.0	97.7	12.8	40.7	12.0	2.8	419.4	10.8
567	Ballote	Peru	9.2	104.6	15.1	29.9	10.7	2.5	415.9	12.4
90212	NN	NG	10.6	78.5	15.1	32.4	15.3	2.2	419.6	13.8
476	NN	NG	10.7	99.0	12.9	31.0	11.5	2.6	418.7	12.1
573	NN	Durango	11.6	88.5	11.3	31.1	12.7	2.6	417.3	12.2
90184	NN	Durango	8.8	100.5	12.7	27.9	12.9	2.6	420.7	11.1
90209	NN	Mesoam.	11.4	110.2	13.1	31.9	13.0	2.7	424.4	11.3
313	NN	Mesoam.	11.8	108.1	14.9	37.3	11.6	2.6	415.1	11.0
90249	Cabrito	nc	11.5	87.3	12.6	32.3	12.3	2.5	419.0	11.4
225	NN	nc	9.7	105.7	14.5	29.6	11.6	2.4	415.3	12.0
LSD			2.19	44.55	3.29	5.06	1.40	0.2	10.9	0.98

NN: without common name; nc: non classified. LSD: least significant difference; NG: Nueva Granada; Mesoam.: Mesoamerica.

Table 4. Pearson´s correlation coefficients between macro, micronutrients, protein and 100-seed weight (P100) of bean seed. (N = 50).

	N	Protein	P100	P	K	Ca	Mg	Na	Cu	Fe	Mn	Zn	B	S	C	C/N
N	1															
Protein	0.99**	1														
P100	0.01	-0.03	1													
P	0.70**	0.72**	-0.22	1												
K	0.01	-0.02	-0.06	0.16	1											
Ca	-0.18	-0.15	-0.08	-0.11	-0.04	1										
Mg	-0.18	-0.13	0.03	-0.14	0.45**	0.37**	1									
Na	-0.06	-0.05	0.05	0.11	0.23	-0.003	0.18	1								
Cu	0.37**	0.39**	0.27	0.25	0.17	-0.17	0.26	0.13	1							
Fe	0.25	0.25	-0.07	0.19	0.10	-0.02	-0.12	-0.05	0.13	1						
Mn	0.002	0.03	-0.11	-0.01	-0.09	0.55**	0.17	0.04	0.18	0.33*	1					
Zn	0.42**	0.40**	0.15	0.31*	0.25	0.12	0.27	0.18	0.45**	0.14	-0.01	1				
B	-0.36*	-0.34*	-0.02	0.29*	0.06	0.15	0.26	0.18	0.13	-0.17	-0.05	-0.08	1			
S	0.80**	0.77**	0.05	0.64**	0.09	-0.28*	-0.15	0.09	0.45**	0.14	-0.15	0.43**	-0.27	1		
C	0.19	0.17	-0.01	0.16	-0.33*	0.01	-0.20	-0.08	0.27	-0.25	0.04	0.01	0.21	0.18	1	
C/N	-0.98**	-0,97**	-0.02	-0.67**	-0.08	0.16	0.14	0.07	-0.37**	-0.31*	-0.03	-0.42**	0.39**	-0.79**	-0.07	1

* $P \leq 0.05$ ** $P \leq 0.01$

In an evaluation of more than thousand genotypes in the bean core collection of CIAT, the mean for Cu (18 mg kg^{-1}), Fe (60 mg kg^{-1}), Mn (23 mg kg^{-1}), Zn (29 mg kg^{-1}) and S (234 mg kg^{-1}) concentration were higher for wild beans (n = 119) compared with the cultivated (n = 1031) genotypes, that is, for Fe (55 mg kg^{-1}), Mn (15 mg kg^{-1}), Zn (35 mg kg^{-1}) and S (2120 mg kg^{-1}) (Beebe *et al*., 2000a). A study of recombinant inbreed navy bean population showed that the Zn content varied from 32.3 to 17.5 mg kg^{-1} and the Fe content from 86.9 to 63.5 mg kg^{-1}, calculated from the 10% top and bottom of the population (Islam *et al*., 2002).

Recent studies in bean have shown considerable variation among wild beans and modern cultivars, but domestication has not changed the mean concentration of Fe and Zn in seeds (Graham *et al*., 2001). The data collected suggest that there is sufficient genetic variability to increase about 80% and 50% of Fe and Zn content in the seed, respectively, and these genetic improvements will be stable across bean-growing environments (Welch and Graham, 2004).

The Andean and Mesoamerican gene pool differed significantly in almost all grain constituents. The Middle American gene pool presented higher concentrations for Ca, P, S, and Zn with exception of Fe. Another study carried out on genotypes collected from North Andean Gene pool (Islam *et al.,* 2002) and from introgressed genotypes (Islam *et al*., 2004) presented significantly higher Fe concentration than the two major gene pools. These studies also reported significant differences between introgressed and non introgressed common bean genotypes for protein, Ca, P, S, Fe, and Zn content (Islam *et al*., 2004). Besides, wild and weedy dry bean contain more Zn and Fe than the cultivated genotypes (Guzmán-Maldonado *et al*., 2000). This fact suggests that unique alleles might exist in this germplasm for several important nutrients.

Correlation analysis. The Pearson correlation analysis on the mean of 50 bean genotypes indicated that the protein and N content was positively correlated with the P, Cu, Zn, and S content and negatively correlated with B content and the relation C/N. The P content was positively correlated with the content of Zn, B and S in the seed and negatively correlated with the relation C/N. The K content was positively correlated with the Mg content and negatively correlated with the C content. The Cu content was positively correlated with the Zn and S content and negatively correlated with the relation C/N. The Fe content was positively correlated with Mn and negatively correlated with the relation C/N. The Zn content was positively correlated with S content and negatively correlated with the relation C/N of the seed and finally the B and C content were correlated positively and negatively with the relationship C/N of the bean seed, respectively (Table 4). One study showed that the Zn content of bean seed was positively correlated with Fe, Ca, P and yield but the highest correlation was found between Fe and P (Gelin *et al*., 2007). Similar correlations have been found between Zn and Ca (Guzmán Maldonado *et al*., 2003) and between Zn and Fe (House *et al*., 2002; Pfeiffer and McClafferty, 2007).

In the last decade, several Agricultural Research Centers started programs to explore the potential to improve the micronutrient quality of some staple food crops, including common bean (Graham *et al*., 1999; Welch and Graham, 2004; Pfeiffer and McClafferty, 2007). During 2003, the Consultative Group on International Agricultural Research (CGIAR) established HarvestPlus: The Biofortification Challenge Program. Biofortification is a new approach that relies on conventional plant breeding and modern biotechnology to increase the micronutrient density on the staple crops for improving the nutritional status and health of poor populations in both the rural and urban areas (Nestel *et al*., 2006; Pfeiffer and McClafferty, 2007).

To assess the feasibility to improve the mineral content of cultivated dry bean some studies have been carried out to identify quantitative trait *loci* (QTL) associated to Ca, Fe and Zn in crosses between cultivated and wild types (Guzmán-Maldonado *et al*., 2003). Other studies have reported the presence of bean microsatellites associated with Zn, P, and Ca (Gelin *et al*., 2007). As more information became available, breeders will be able to combine techniques of molecular genetics with conventional breeding methods through marker-assisted selection to develop cultivars with higher nutrients (Gelin *et al*., 2007) and other biotechnology tools (Bouis, 2002; Khush, 2002; Ghandilyan *et al*., 2006). Other strategy to increase the quality of bean seed could be the use of adequate methods to increase the nutritive value through the enhancement of the bioavailability of the micronutrients (Hotz and Gibson, 2007) and the reduction of the anti-nutritional substances present in the seed (Bressani, 2000; Graham *et al*., 2001; Welch and Graham, 2004; Ghandilyan *et al*., 2006).

CONCLUSIONS

The bean samples analyzed presented a wide variability for the macro and micro nutrient evaluated.

Bean genotypes of race Chile has a good level of protein, Fe and Zn and did not show significant differences with the genotypes from other races.

The simple correlation analysis indicated that N content was positively correlated with protein P, Cu, Zn, and S content and negatively correlated with B content and seed C/N relation.

The Fe content was positively correlated with Mn and Ca content, and Zn content was positively correlated with N, P, Cu and S content and negatively correlated with the C/N relation.

There were no significant differences between the Chilean bean genotypes compared to genotypes from other races

ACKNOWLEDGEMENTS

The authors thank the Chilean Science and Technology Fund, FONDECYT (Project N° 1060185) for supporting this research and to Mr. Alfonso Valenzuela (INIA Quilamapu) and Mr. Pablo Gamboa (INIA La Platina) for their support on field trials, and Mr. Hugo Flores (INIA La Platina) for his support on the statistical analysis of the data.

RESUMEN

Composición inorgánica de semillas de genotipos de poroto (*Phaseolus vulgaris* L.), raza Chile. La colección de poroto común (*Phaseolus vulgaris* L.) en Chile cuenta con 1110 accesiones. Para facilitar la caracterización de este germoplasma se formó una colección núcleo de 246 accesiones. Existe poca información acerca del contenido de minerales y otras características de calidad para estos genotipos de poroto. Esta información podría ser útil para determinar la calidad y potencialidad de esta especie y para promover su consumo. El objetivo de este trabajo fue evaluar la variabilidad de los macro y micronutrientes de una muestra representativa de la colección núcleo y compararla con genotipos representativos de las otras razas. Los resultados indicaron la presencia de una amplia variabilidad de macro y micronutrientes, tales como N, Fe, y Zn. El contenido de proteína varió entre 183,5 y 259,7 g kg^{-1}, Fe desde 68,9 hasta 152,4 mg kg^{-1}, y Zn entre 27,9 y 40,7 mg kg^{-1}. Esta situación podría permitir seleccionar genotipos con alta concentración de estos elementos para mejorar los actuales cultivares. El análisis de correlación simple indicó que el contenido de N estuvo positivamente correlacionado con el contenido de proteína, P, Cu, Zn y S y negativamente correlacionado con el contenido de B y la relación C/N de la semilla. El contenido de Fe estuvo positivamente correlacionado con el contenido de Mn y Ca. El contenido de Zn estuvo positivamente correlacionado con el contenido de N, P, Cu y S y negativamente correlacionado con la relación C/N. No hubo diferencias significativas entre genotipos chilenos con genotipos de otras razas y acervo genético.

Palabras clave: *Phaseolus vulgaris*, raza Chile, macronutrientes, micronutrientes, colección núcleo.

LITERATURE CITED

Anderson, J.W., B.M. Smith, and C.S. Washnock. 1999. Cardiovascular and renal benefits of dry bean and soybean intake. Am. J. Clin. Nutr. 70(suppl.):464S-474S.

Aparicio-Fernández, X., T. García-Gasca, G.G. Yousef, M.A. Lila, E. González de Mejía, and G. Loarca-Piña. 2006. Chemopreventive activity of polyphenolics from black Jamapa bean (*Phaseolus vulgaris* L.) on HeLa and HaCaT cells. J. Agric. Food Chem. 54:2116-2122.

Azevedo, L., J.C. Gomes, P.C. Stringheta, A.M. Gontijo, C.R. Padovani, L.R. Ribeiro, and D.M. Salvatori. 2003. Black bean (*Phaseolus vulgaris* L.) as protective agent against DNA damage in mice. Food Chem. Toxicol. 41:1671-1676.

Bazzano, L.A., J. He, L.G. Ogden, C. Loria, S. Vapputuri, L. Myers, and P.K. Whelton. 2001. Legume consumption and risk of coronary heart disease in US men and women. Arch. Int. Med. 161:2528.

Becerra-Velásquez, V., and P. Gepts. 1994. RFLP diversity of common bean (*Phaseolus vulgaris*) in its centres of origin. Genome 37:256-263.

Beebe, S., A.V. González, and J. Rengifo. 2000a. Research on trace minerals in common bean. Food Nutr. Bull. 21:387-391.

Beebe, S.E., J. Rengifo, E. Gaitán, M.C. Duque, F. Pedraza, and J. Nienhuis. 2000b. Structure of genetic diversity among common bean landraces of Middle American origin based on correspondence analysis of RAPD. Crop Sci. 40:264-273.

Beebe, S., O. Toro, A.V. González, M.I. Chacón, and D.G. Debouck. 1997. Wild-weed-crop complexes of common bean (*Phaseolus vulgaris* L., Fabaceae) in the Andes of Peru and Colombia, and their implications for conservation and breeding. Genet. Resour. Crop Evol. 44:73-91.

Bouis, H.E. 2002. Three criteria for establishing the usefulness of biotechnology for reducing micronutrient malnutrition. Food Nutr. Bull. 23:351-353.

Bressani, R. 2000. Micronutrients policies for agricultural in Latin America. Food Nutr. Bull. 21:538-541.

Díaz-Batalla, L., J.M. Widholm, G.C. Jr. Fahey, E. Castaño-Tostado, and O. Paredes-López. 2006. Chemical components with health implications in wild and cultivated Mexican common bean seeds (*Phaseolus vulgaris* L.). J. Agric. Food Chem. 54:2045-2052.

Frossard, E., M. Bucher, F. Mächler, A. Mozafar, and R. Hurrell. 2000. Potential for increasing the content and bioavailability of Fe, Zn, and Ca in plants for human nutrition. J. Sci. Food. Agric. 80:861-879.

Geil, P.B., and J.W. Anderson. 1994. Nutrition and health implications of dry beans: a review. J. Am. Coll. Nutr. 13:549-558.

Gelin, J.R., S. Forster, S.K. Grafton, P.E. McClean, and G.A. Rojas-Cifuentes. 2007. Analysis of seed zinc and other minerals in a recombinant inbred population of navy bean (*Phaseolus vulgaris* L.). Crop Sci. 47:1361-1366.

Gepts, P., and D.G. Debouck. 1991. Origin domestication and evolution of the common bean (*Phaseolus vulgaris* L.). p. 7-53. *In* van Schoonhoven, A., and O. Voyset (eds.) Common beans: research for crop improvement. Commonwealth Agricultural Bureau, Wallingford, UK.

Ghandilyan, A., D. Vreugdenhil, and M.G.M. Aarts. 2006. Progress in the genetic understanding of plant iron and zinc nutrition. Physiol. Plant. 126:407-417.

Graham, R., D. Senadhira, S. Beebe, C. Iglesias, and I. Monasterio. 1999. Breeding for micronutrientes density in edible portions of staple food crops: Conventional approaches. Field Crops Res. 60:57-80.

Graham, R.D., R.M. Welch, and H.E. Bouis. 2001. Addressing micronutrient malnutrition through enhancing the nutritional quantity of staple foods: principles, perspectives and knowledge gaps. Adv. Agron. 70:77-142.

Guzmán-Maldonado, S.H., J. Acosta-Gallegos, and O. Paredes-López. 2000. Protein and mineral content of a novel collection of wild and weedy common bean (*Phaseolus vulgaris* L.). J. Sci. Food Agric. 80:1874-1881.

Guzmán-Maldonado, S.H., O. Martínez, J.A. Acosta, F. Guevara-Lara, and O. Paredes-López. 2003. Putative quantitative trait loci for physical and chemical components of common bean. Crop Sci. 43:1029-1035.

Hangen, L., and M.R. Bennink. 2002. Consumption of black beans and navy beans (*Phaseolus vulgaris*) reduced azoxymethane-induced colon cancer in rats. Nutr. Cancer 44:60-65.

Heimler, D., P. Vignolini, M.G. Dini, and A. Romani. 2005. Rapid tests to assess the antioxidant activity of *Phaseolus vulgaris* L. dry beans. J. Agric. Chem. 53:3053-3056.

Hotz, C., and R. Gibson. 2007. Traditional food-processing and preparation practices to enhance the bioavailability of micronutrients in plant-based diets. J. Nutr. 137:1097-1100.

House, W.A., R.M. Welch, S. Beebe, and Z. Cheng. 2002. Potential for increasing the amount of bioavailable zinc in dry beans (*Phaseolus vulgaris* L.) through plant breeding. J. Sci. Food Agric. 83:1452-1457.

Islam, F.M.A., K.E. Basford, C. Jara, R.J. Redden, and S. Beebe. 2002. Seed compositional and disease resistance differences among gene pools in cultivated common bean. Genet. Resour. Crop Evol. 49:285-293.

Islam, F.M.A., S. Beebe, M. Muñoz, J. Tohme, R.J. Reeden, and K.E. Basford. 2004. Using molecular markers to asses the effect of introgression on quantitative attributes of common bean in the Andean gene pool. Theor. Appl. Genet. 108:243-252.

Khush, G.S. 2002. The promise of biotechnology in addressing current nutritional problems in developing countries. Food Nutr. Bull. 23:354-357.

Meiners, C.R., N.L. Derise, H.C. Lau, M.G. Crews, S.J. Ritchey, and E.W. Murphy. 1976. Proximate composition and yield of raw and cooked mature dry legume. J. Agric. Food. Chem. 24:1122-1126.

Messina, M.L. 1999. Legumes and soybeans: overview of their nutritional profiles and health effects. Am. J. Clin. Nutr. 70(suppl.):439S-450S.

Monsen, E.R. 1988. Iron nutrition and absorption: dietary factors with impact on iron bioavailability. J. Amer. Diet. Assoc. 88:786-791.

Moraghan, J.T., and K.F. Grafton. 1997. Accumulation of Ca in bean cultivars differing in seed size. J. Sci. Food Agric. 74:251-256.

Nestel, P., H.E. Bouis, J.V. Meenakshi, and W. Pfeiffer. 2006. Biofortification of staple food crops. J. Nutr. 136:1064-1067.

Paredes, C.M. 1994. Nuevos antecedentes a considerar en el programa de mejoramiento genético de frejol en Chile. Agric Téc. (Chile) 54:29-41.

Pfeiffer, W.H., and B. McClafferty. 2007. HarvestPlus: Breeding crops for better nutrition. Crop Sci. 47:S-88-S-105.

Rosa, C.O.B, N.M.B. Costa, R.M. Nunes, and P.F.G. Leal. 1998. The cholesterol-lowering effect of black beans (*Phaseolus vulgaris* L.) in hypocholesterolemic rats. Arch. Latinoam. Nutr. 48:306-310.

Sadzawka, A., M.A. Carrasco, R. Demanet, H. Flores, R. Grez, M.L. Mora, y A. Neaman. 2007. Métodos de análisis de tejidos vegetales. 2ª ed. Serie Actas INIA Nº 40. 140 p. Instituto de Investigaciones Agropecuarias, Santiago, Chile.

Sanghvi, T., J. Ross, and H. Heymann. 2007. Why is reducing vitamin and mineral deficiencies critical for development? Food Nutr. Bull. 28 (supl.):S167-S173.

SAS Institute. 2007. SAS/STAT users guide. SAS Institute, Cary, North Carolina, USA.

Shellie-Dessert, K., and F. Bliss. 1991. Genetic improvement of food quality factors. Common beans. p. 649-677. *In* van Schoonhoven, A., and O. Voyset (eds.) Research for crop improvement. CAB International, CIAT, Redwood Press, Melksham, Wiltshire, UK.

Singh, S.P., P. Gepts, and D.G. Debouck. 1991a. Races of common bean (*Phaseolus vulgaris*: Fabaceae) Econ. Bot. 45:379-396.

Singh, S.P., J.A. Gutiérrez, A. Molina, C. Urrea, and P. Gepts. 1991b. Genetic diversity in cultivated common bean. II. Marker-based analysis of morphological and agronomic traits. Crop Sci. 31:23-29.

Underwood, B.A. 2000. Overcoming micronutrient deficiencies in developing countries: Is there a role for agriculture? Food Nutr. Bull. 21:356-360.

Welch, R.M., and R.D. Graham. 2000. A new paradigm for world agriculture: productive, sustainable, nutritious, healthful food systems. Food Nutr. Bull. 21:361-366.

Welch, R.M., and R.D. Graham. 2004. Breeding for micronutrients in staple food crop from human nutrition perspective. J. Exp. Bot. 55:353-364.