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Contrasting accumulations of calcium and magnesium in seed coats and embryos of common bean and soybean

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Abstract

How plant genotypes affect accumulation and within-seed distribution of Ca and Mg in soybean (*Glycine max* L.) and common bean (*Phaseolus vulgaris* L.) seed is important because of concerns in regards to human nutrition. Accumulation of seed Ca and Mg in separate experiments, each with 12 genotypes, was studied. Genotype affected seed Mg concentration [Mg] and especially seed Ca concentration [Ca] in the two species. Percentages of total seed Ca in seed coats ranged from 67% to 81% for the common bean genotypes and from 17% to 27% for the soybean genotypes. Percentages of total seed Mg in the seed coats ranged from 16% to 28% for the common bean genotypes and from 6% to 10% for the soybean genotypes. Percentages of seed dry matter in the seed coats were 9.3–11.0% for the common bean genotypes and 7.0–12.4% for the soybean genotypes. Four common bean and two soybean genotypes were next grown under similar environmental conditions in a greenhouse experiment. Results confirmed that seed coats of common bean are enriched in Mg and especially Ca relative to dry-matter distribution. In contrast, seed coats of soybean are enriched in Ca, but to a lesser extent than in common bean, and are not enriched in Mg.

Keywords: Common bean seed; Genetic diversity; Hard-to-cook seeds; Seed calcium; Seed magnesium; Soybean seed

1. Introduction

Seed of common bean and soybean, both legumes, are important foods. To ensure healthy diets, increasing emphasis is being placed on the content of essential elements in seeds (Frossard, Bucher, Mächler, Mozafar, & Hurrell, 2000). Seed consists of seed coats (maternal tissue) and embryos, including cotyledons, (filial tissue) with no direct vascular connections between the two tissues (Wolswinkel, 1992). Common bean seed is consumed, either fried or cooked, whole or strained, with resultant seed-coat removal (Bressani & Elias, 1974). Although cooked whole soybean seeds are consumed in Africa (Latunde-Dada, 1991), and used to make foods such as tofu and natto (Haytowitz & Matthews, 1989), most soybean seed is used for oil extraction. Seed coats, sometimes called seed hulls, are removed prior to oil extraction. The oil-depleted embryonic tissue is used to make soy flour and soy protein concentrates (Haytowitz & Matthews, 1989). Soybean seed coats, an effective Fe source in bakery goods (Lykken, Hunt, Nielsen, & Dintzis, 1987), are used mainly as a fibre source for cattle, in pet foods, and as a bulk additive in animal foods (Sessa, 2004).

The Ca content of legume seed, an important component of vegan diets, is low and its availability is reduced by oxalate and to a lesser extent phytate (Weaver & Plawecki, 1994). Legume seed is a concentrated source of Mg in human nutrition (Schwartz, 1988). Although controversial, Ca and Mg, chemically bound to pectates, may be associated with the hard-to-cook defect in legume seed (Reyes-Moreno & Paredes-López, 1993;

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Stanley & Aguilera, 1985). Separation of cells within legume seed during cooking is possibly associated with removal of Ca and Mg from bridge positions within the pectinaceous matrix of the middle lamella (Rockland & Jones, 1974). Cell walls of common bean cotyledons with the hard-to-cook defect contained more Ca than normal seeds (Garcia, Lajolo, & Swanson, 1993). Calcium was more abundant than Mg at the cell wall/middle lamella. Seed Ca concentration [Ca] of Navy bean was related to the lightness-of-colour (*L* value) of canned beans (Lu & Chang, 1996). Increasing the Ca level of soak, blanch water and brine during canning of dry bean resulted in a linear decrease in hydration coefficient and percent washed drained weight, but a linear increase in texture, presumably due to the formation of Ca–pectin complexes (Balasubramanian, Slinkard, Tyler, & Vandenberg, 2000).

There is considerable variability in seed [Ca] and seed Mg concentration [Mg] in "market–basket" samples of soybean and common bean in the United States (USDA, 2004). The market data indicate that soybean is appreciably higher in seed [Ca] and [Mg] than common bean. For instance, seed [Ca] (corrected to a dry-weight basis) was 3.03 g Ca kg^{-1} (SD = 0.49; $n = 71$) for soybean, 1.77 g Ca kg^{-1} (SD = 0.42; $n = 45$) for Navy bean, and 0.94 g Ca kg^{-1} (SD = 0.40; $n = 50$) for Red Kidney bean. The corresponding Mg values were 3.06 g of Mg kg^{-1} (SD = 0.70, $n = 49$) for soybean, 1.97 g Mg kg^{-1} (SD = 0.42; $n = 39$) for Navy bean, and 1.56 g Mg kg^{-1} (SD = 0.35; $n = 49$) for Red Kidney bean. Analysis of "market–basket" samples provides little information regarding the relative importance of environmental and genetic factors on seed mineral composition.

Soybean genotype influences seed [Ca] and seed [Mg]. The mean seed [Ca] of 38 soybean genotypes grown on an acid soil in Illinois was 2.7 g Ca kg^{-1} (SD = 0.3; range = 1.8–3.4) (Raboy, Dickinson, & Below, 1984). The corresponding mean seed [Mg] was 2.7 g Mg kg^{-1} (SD = 0.5; range = 2.2–3.4). Neither seed [Ca] nor seed [Mg] was correlated with seed weight.

Both environmental and genetic factors affect Ca accumulation in common bean seed (Quenzer, Huffman, & Burns, 1978). The mean seed [Ca] of 36 common bean cultivars grown under similar conditions in Washington State was 1.68 g Ca kg^{-1} (SD = 0.34; range = 1.22–2.40) (Koehler, Chang, Scheier, & Burke, 1987). The corresponding mean seed [Mg] was 1.60 g Mg kg^{-1} (SD = 0.15; range = 1.28–1.89). Seed [Ca] and seed [Mg] of eight common bean cultivars (two Navy, one Great Northern, one Pinto, one Pink, one Cranberry, and two Red Kidney) grown at five locations in North Dakota were negatively correlated with seed weight (Moraghan & Grafton, 2001).

In contrast to whole-seed data, data concerning within-seed distribution of Ca and Mg in soybean and common bean genotypes are limited. The seed coat is enriched in Ca in both soybean and especially common bean. For instance, although the dry matter in the seed coat of common bean is generally less than 10% of that of the whole seed, approximately 70% (Lombardi-Boccia et al., 1998) and 43% (Singh, Singh, & Sikka, 1968) of the total seed Ca were in the seed-coat fraction. The percentage of total seed Ca in the seed-coat fraction of soybean is about 20% (Laszlo, 1990). The overall Ca dialysability, possibly related to bioavailability, of common bean seed was mainly influenced by [Ca] of the seed coat (Lombardi-Boccia et al., 1998).

More background information is needed by food scientists on the diversity in seed Ca and Mg accumulation within the soybean and common bean germplasm pools. The objective of this study was to determine total and within-seed distribution of these two elements in selected soybean and common bean genotypes.

2. Materials and methods

2.1. Description of experiments

2.1.1. General

Within-seed distributions of Ca and Mg were first determined in seed of 12 genotypes from separate replicated soybean and common bean experiments. Markedly different Ca and Mg accumulation patterns were found in seeds of the two species. A greenhouse experiment was next established to determine whether these seed differences also occurred when soybean and common bean were grown under the same environmental conditions.

2.1.2. Common bean experiment

This experiment was conducted at Montecillo, Mexico. Calcium, Mg and dry matter were determined in seed coats and embryos (including cotyledons) of 12 common bean genotypes grown in a greenhouse experiment designed to determine the influence of added Fe chelate on within-seed Fe accumulation in *Phaseolus vulgaris*. There were 24 treatments, comprising each of 12 genotypes from the Middle American gene pool (Voyager, T39, Bayo 400, Negro 8025, Tacana, and Rio Tibagi from the Mesoamerican race; NG94060, Mexico 332, and Puebla 152 from the Jalisco race; and A800, Negro Durango, and Pinto Villa from the Durango race) with and without 4 mg FeEDTA–Fe kg^{-1}. All treatments were replicated four times and arranged in a completely randomized design. The greenhouse soil was a Mexican soil with Andic properties (pH = 7.0). Seed was separated into seed coats and embryos and analyzed for Fe, Ca, Mg and selected other elements. Specific details of the experiments and the seed-Fe data are available elsewhere (Moraghan, Padilla, Etchevers, Grafton, & Acosta-Gallegos, 2002). Added Fe had no effect on Ca and Mg accumulation. Calcium, Mg and dry matter accumulations, for the 12 genotypes grown in this experiment with 4 mg FeEDTA–Fe kg^{-1} of air-dried soil, are given in this report.

2.1.3. Soybean experiment

Seed of 12 soybean genotypes, from each of two different 2002 field-variety trials conducted at Mooreton and Great Bend, ND was obtained from Dr. Ted Helms, North Dakota State University. The two seed samples for each genotype were composite subsamples from three replicates arranged in a randomized complete block design at the relevant sites. Seed was separated into seed coats and embryos, and analyzed for Ca, Mg, and dry matter. The 12 genotypes, identified in Table 3 (see below), were yellow-seeded types. The soil at the Great Bend site was a Gardena silt loam (pH 7.4), while that at the Mooreton site was a Wyndmere fine sandy loam (pH 8.0). The two locations are treated as replications in this report.

2.1.4. Soybean-common bean experiment

Four common bean (Voyager, Dicta 113, UI 911, and Sacramento) and two soybean (Traill and Council) genotypes were replicated four times in a randomized complete block design and grown at Fargo, ND on a Wheatville loam soil (pH 8.2) for seed production under greenhouse conditions. Voyager and UI 911 are from Navy bean and Black bean seed classes, respectively, of the Middle American gene pool. Dicta 113, obtained from CIAT in Columbia, is a burgundy-coloured seed bean from the Middle American gene pool. Sacramento is a light Red Kidney bean from the Andean gene pool. Traill and Council are commercial, yellow-seeded soybean genotypes.

The basic experimental unit was 4.5 kg of air-dried soil in a polyethylene-lined pot. A basal dressing of 70 mg NH_4NO_3–N kg^{-1}, 90 mg K_2SO_4–K, 60 mg $Ca(H_2PO_4)_2$–P kg^{-1} and 8 mg $ZnSO_4$–Zn kg^{-1} was mixed with the soil in a twin-shell blender before addition to the pots. Iron (2 mg FeEDDHA–Fe kg^{-1}) and B (1.0 mg $Na_2B_4O_7$–B kg^{-1}), in liquid form, were added to the soil surface of all pots prior to bringing the soil moisture content to the approximate field capacity. Greenhouse temperatures were generally maintained between 18 and 25 °C. Details about planting, supplementary light and distilled-water techniques were similar to those described previously (Moraghan & Grafton, 1999). Each pot, after thinning, contained 3 plants pot^{-1}. Seed was harvested at maturity and weighed. A subsample was taken for gravimetric determination of moisture and calculation of oven-dry yields. A second seed subsample was taken, separated into seed coats and embryos, and analyzed for Ca and Mg.

2.2. Seed-coat removal

Harvested mature seed was placed in capped containers until required for analysis. Processing of seeds in Experiment 2.1.1 is described elsewhere (Moraghan et al., 2002). For Experiments 2.1.2 and 2.1.3 at least 20 seeds were washed (Wikoff & Moraghan, 1986), air-dried and placed in a desiccator with a saturated water atmosphere at 22 °C for 72 h before seed coats and embryos were manually separated. The seed coats were dried at 70 °C for 24 h, weighed and added directly to digestion tubes for analysis. The embryos were dried at 70 °C for 72 h, weighed, ground in an agate mortar with an agate pestle to pass a 60-mesh sieve, redried, and subsampled for analysis.

2.3. Chemical analyses

Subsamples of the two seed fractions were digested on an Al block with 4 ml HNO_3, 2 ml $HClO_4$ and a drop of kerosene. The unground seed-coat samples were shaken frequently to avoid foaming as the temperature of the digests was initially brought to 100 °C. Calcium and Mg were determined in separate diluted digests by atomic absorption spectroscopy. Final solutions for Ca analyses of standards and unknowns contained 10 g La l^{-1} to prevent interference from refractory compounds. Standard Reference Material 1515 from the National Institute of Standards and Technology (Gaitersburg, MD) was digested and analyzed with each digestion lot to provide an indication of the accuracy of the analytical procedures.

2.4. Statistical analyses

Statistical analyses for the experiments were performed with SAS procedures (SAS Institute, 1996). Differences among mean values were compared by use of Tukey's test ($p \leqslant 0.05$) (Snedecor, 1956).

3. Results

3.1. Common bean experiment

Seed-coat [Ca] (7.5–16.5 g kg^{-1}) was much higher than embryo [Ca] (0.33–0.57 g kg^{-1}) for all 12 genotypes (Table 1). Seed [Ca] differed greatly among the genotypes, ranging from 1.02 to 2.05 g kg^{-1}. Seed weight of the genotypes, all from the Middle American gene pool, varied appreciably (164–451 mg $seed^{-1}$). Seed [Ca] was not correlated with seed weight, $r = -0.03$ ($p = 0.86$).

Seed coat [Mg] (3.21–4.85 g kg^{-1}) was also higher than embryo [Mg] (1.33–2.08 g kg^{-1}) for all genotypes (Table 1). Genotypic seed [Mg] ranged from 1.67 to 2.23 g kg^{-1}. Seed [Mg] was not correlated with seed

Table 1
Seed Ca, Mg and dry matter accumulation in 12 common bean genotypes

Genotype	Seed weight (mg seed^{-1})	Ca (g kg^{-1} dry weight)			Mg (g kg^{-1} dry weight)		
		Seed coat	Embryo	Seed	Seed coat	Embryo	Seed
A800	304	14.2	0.51	1.77	3.99	1.71	1.91
Bayo 400	381	10.5	0.47	1.55	3.60	2.00	2.17
Mexico 332	280	14.2	0.57	2.05	3.42	1.79	1.97
Negro 8025	193	10.6	0.42	1.40	3.77	1.78	1.97
Negro Durango	451	14.4	0.50	1.86	4.85	1.33	1.67
NG94060	329	10.6	0.54	1.47	3.84	1.67	1.87
Pinto Villa	380	13.2	0.48	1.71	3.21	1.78	1.91
Puebla 152	311	7.5	0.33	1.02	3.96	2.00	2.18
Rio Tibagi	180	12.0	0.42	1.56	3.78	1.68	1.88
T39	187	15.4	0.43	1.84	3.44	1.63	1.80
Tacana	176	11.3	0.34	1.55	3.51	2.08	2.23
Voyager	164	16.5	0.43	1.97	3.54	1.85	2.01
Mean	278	12.5	0.45	1.64	3.74	1.77	1.97
Range	164–451	7.5–16.5	0.33–0.57	1.02–2.05	3.21–4.85	1.33–2.08	1.67–2.23
% CV	7	16	11	13	9	9	8
Tukey (0.05)	45	4.9	0.13	0.52	0.78	0.38	0.38

weight, $r = -0.16$ ($p = 0.26$). Seed [Ca] was negatively correlated, albeit weakly, with whole seed [Mg], $r = -0.29$ ($p < 0.05$).

The majority of the seed dry matter, which was little affected by genotype, was in the embryo fraction (Table 2). Only 9.3–11.0% of the whole seed dry matter was in the seed-coat fraction. In contrast, seed Mg and especially seed Ca, relative to dry matter distribution, were enriched in seed coats of all genotypes. Percentages of total seed Ca in the seed-coat fractions ranged from 67% to 81%. In contrast, percentages of seed Mg in the seed-coat fractions ranged from 16% to 28%.

Table 2
Percentages of seed dry matter, Ca and Mg in the seed coats of 12 common bean genotypes

Genotype	Percentage seed quantity in seed coat		
	Dry matter	Ca	Mg
A800	9.3	74	19.3
Bayo 400	10.8	81	17.9
Mexico 332	10.9	75	18.9
Negro 8025	9.7	73	18.5
Negro Durango	9.7	76	28.3
NG94060	9.3	67	19.1
Pinto Villa	9.7	75	16.3
Puebla 152	9.7	71	17.5
Rio Tibagi	9.8	75	19.6
T39	9.4	78	18.4
Tacana	11.0	80	17.3
Voyager	9.5	80	16.8
Mean	9.9	75	19.0
Range	9.3–11.0	67–81	16.3–28.3
% CV	6	4	8
Tukey (0.05)	1.4	7	3.7

3.2. Soybean experiment

Seed-coat [Ca] was higher than embryo [Ca] in all 12 soybean genotypes, but the disparity was less pronounced than in the Common Bean Experiment (Table 3). Seed-coat [Ca] ranged from 4.40 to 5.45 g kg^{-1}; embryo [Ca] ranged from 1.28 to 2.27 g kg^{-1}. Genotype greatly influenced seed [Ca] (1.56–2.52 g Ca kg^{-1}). Likewise, genotype greatly influenced seed weight (73–217 mg seed^{-1}). Seed [Ca] was negatively correlated with seed weight, $r = -0.72$ ($p < 0.001$). Seed [Ca] was not correlated with seed [Mg], $r = 0.21$ ($p = 0.31$).

Eleven of the 12 soybean genotypes had higher embryo [Mg] than seed coat [Mg] (Table 3). Consequently, the mean genotypic seed-coat [Mg], 2.16 g kg^{-1}, was less than the mean genotypic embryo [Mg], 2.45 g kg^{-1}. Seed [Mg] differed among the 12 genotypes, ranging from 2.19 g to 2.71 g kg^{-1}. Seed [Mg] was not correlated with seed weight, $r = 0.14$ ($p = 0.51$).

From 7.0% to 12.4% of the seed dry matter was in the seed-coat fraction (Table 4). The two small-seeded, natto-type soybean genotypes (BS 2103N and EX 9228N) had proportionately larger percentages of their seed dry matter in the seed-coat fraction than had the large-seeded genotypes. The seed coats, containing 17.2% to 26.8% of the total seed Ca, were enriched in Ca relative to dry matter distribution. Percentage distributions of Mg and dry matter between the seed coats and embryos were relatively similar.

3.3. Soybean-common bean experiment

Seed yields of the four common bean genotypes were relatively similar, but exceeded yields of the two soybean genotypes (Table 5). The seed weight of Sacramento

Table 3
Seed Ca, Mg and dry matter accumulation in 12 soybean genotypes

Genotype	Seed weight (mg seed^{-1})	Ca (g kg^{-1} dry weight)			Mg (g kg^{-1} dry weight)		
		Seed coat	Embryo	Seed	Seed coat	Embryo	Seed
Barnes	176	5.21	1.49	1.77	2.05	2.42	2.39
BS 2103N	81	4.91	1.96	2.28	1.89	2.55	2.48
BS 2117N	87	4.84	2.27	2.52	2.30	2.48	2.46
BS 920H	217	5.45	1.43	1.71	2.62	2.33	2.35
DSR 061	123	5.24	1.57	1.87	2.07	2.39	2.36
DST 0810	178	5.04	1.58	1.85	2.23	2.63	2.60
EX 9228N	73	5.22	2.02	2.41	1.79	2.25	2.19
GC Sonora	186	5.15	1.28	1.56	2.00	2.44	2.41
GCX 3203	146	4.87	1.57	1.84	2.21	2.45	2.43
M 91205053	178	5.12	1.82	2.07	2.22	2.39	2.38
M 94221-2	140	5.45	2.25	2.50	2.49	2.73	2.71
MK 9532	98	4.40	1.79	2.03	2.02	2.34	2.31
Mean	140	5.07	1.75	2.03	2.16	2.45	2.42
Range	73–217	4.40–5.45	1.28–2.27	1.56–2.52	1.79–2.62	2.25–2.73	2.19–2. 71
% CV	4	2	6	5	8	3	3
Tukey (0.05)	25	0.45	0.43	0.41	0.68	0.31	0.28

Table 4
Percentages of seed dry matter, Ca and Mg in the seed coats of 12 soybean genotypes

Genotype	Percentage seed quantity in seed coat		
	Dry matter	Ca	Mg
Barnes	7.5	22.1	6.39
BS 2103N	10.6	22.9	8.09
BS 2117N	9.9	19.0	9.25
BS 8920H	7.0	22.3	7.78
DSR 061	8.3	23.1	7.28
DST 0810	8.0	21.7	6.83
EX 9228N	12.4	26.8	10.15
GC Sonora	7.1	23.6	5.93
GCX 3203	8.1	21.4	7.35
M 91205053	7.5	18.5	6.96
M 94221-2	7.9	17.2	7.23
MK 9532	9.2	20.0	8.03
Mean	8.6	21.6	7.61
Range	7.0–12.4	17.2–26.8	5.93–10.15
% CV	4	4	7
Tukey (0.05)	1.4	3.7	2.19

(702 mg seed^{-1}), the common bean genotype from the Andean gene pool, was much larger than that of the other three bean genotypes (191–247 mg seed^{-1}) from the Middle American gene pool. The larger seed weight was associated with a lower number of seeds per pot. Seed [Ca] varied appreciably among the four common bean genotypes. Dicta 113 and Sacramento, which differed in seed size, had low seed [Ca]. Seed [Ca] of Voyager and UI 911, the two other common bean genotypes, were not vastly different from those of Traill and Council, the two soybean genotypes. The soybean genotypes had markedly higher seed [Mg] than each of the common bean genotypes.

Relative to dry-matter distribution, seed coats of both common bean and soybean genotypes were enriched in Ca (Table 6). However, the enrichment was much more pronounced in common bean than in soybean. Over 69% of the total seed Ca was in seed coats of all four common bean genotypes. This contrasted with only 20.9% and 22.6% of the seed Ca in the seed coats of the two soybean genotypes. Seed coats of the common bean genotypes, but not of the two soybean genotypes, were enriched in Mg. From 7.1% to 9.5% of the seed dry matter of the four common bean genotypes was in the seed-coat fraction. This contrasted with 10.3% to 18.3% of seed Mg in this fraction.

4. Discussion

4.1. General

In separate experiments with multiple genotypes, differences in seed [Ca] and [Mg] of soybean and common bean were found. Seed coats of common bean were enriched in Mg and especially Ca. In contrast, seed coats of soybean were enriched in Ca, but to a lesser extent than in common bean, and were not enriched in Mg. Results of a greenhouse experiment with genotypes of both species confirmed the genetic basis of these differences.

4.2. Seed Ca accumulation

Striking differences were found in within-seed distribution of Ca in soybean and common bean. Seed coats were enriched in Ca, relative to dry-matter distribution, in both species. The enrichment was much greater in common bean than in soybean. As a result, embryo [Ca] was appreciably higher in soybean than common bean. The contrasting distribution patterns indicate that Ca movement between the seed coat and embryo of

Table 5
Seed characteristics of selected common bean (CB) and soybean (S) genotypes in a greenhouse experiment

Genotype	Yield (g pot^{-1})	Number (seeds pot^{-1})	Weight (mg seed^{-1})	Ca (g kg^{-1})	Mg (g kg^{-1})
Voyager (CB)	22.0	114	197	2.98	2.09
Dicta 113 (CB)	23.7	98	247	1.59	2.06
UI 911 (CB)	22.4	118	191	2.40	1.96
Sacramento (CB)	21.5	31	702	1.56	1.50
Traill (S)	10.6	63	168	2.67	3.52
Council (S)	17.3	86	207	2.49	3.07
% CV	8	8	6	9	5
Tukey (0.05)	3.6	15	40	0.49	0.27

common bean is more restricted during seed development. The presence of prominent, insoluble Ca oxalate crystals in mature seed coats of common bean (Barnabas & Arnott, 1990), but not in mature seed coats of soybean (Ilarslan, Palmer, & Horner, 2001), may explain this discrepancy.

Phytates in globoid bodies of cotyledons likely reduce the bioavailability of the approximately 80% of the seed Ca in the embryo fraction of soybean (Prattley & Stanley, 1982). Phytates are not as common in seed coats as in embryos of legume seed (Deshpande, Sathe, Salunke, & Cornforth, 1982). However, the bioavailability of the approximately 80% of the seed Ca in the seed coat of common bean is likely reduced by the presence of Ca oxalate crystals in this seed fraction (Libert & Franceschi, 1987; Weaver, Heaney, Proulx, Hinders, & Packard, 1993).

No relationship was found between seed [Ca] and seed weight of the 12 common bean genotypes from the Middle American gene pool. This contrasted with results from an earlier common bean study (Moraghan & Grafton, 2001) with eight genotypes from the Middle American and Andean gene pools. The previous finding was possibly associated with the inclusion of Andean genotypes. Seed [Ca] was negatively correlated with seed weight in the Soybean experiment. Although seed [Ca] in one genetic population of chickpea (*Cicer arietinum* L.), another legume, was negatively correlated with seed weight, Abbo, Grusak, Tzuk, and Reifen (2000) concluded that seed [Ca] in this species was mainly determined by genetic factors other than grain-weight genes. Thus, results from seed weight-seed [Ca] studies likely depend on genotype selection.

Table 6
Percentages of seed dry matter, Ca and Mg in the seed coats of selected common bean (CB) and soybean (S) genotypes in a greenhouse experiment

Genotype	Percentage seed quantity in seed coat		
	Dry matter	Ca	Mg
Voyager (CB)	8.3	83.0	14.4
Dicta 113 (CB)	9.5	80.7	18.3
UI 911 (CB)	8.3	83.2	17.3
Sacramento (CB)	7.1	68.8	10.3
Traill (S)	7.2	20.9	7.4
Council (S)	6.4	22.6	8.1
% CV	8	4	8
Tukey (0.05)	1.5	5.5	2.2

Accumulation of seed Ca differed among the soybean and common bean genotypes. Transport of Ca through the xylem to the ventral side of the pod and subsequent apoplastic movement to the seed coat occurs in common bean (Mix & Marschner, 1976a), and presumably in soybean. Differences in pod [Ca] in common bean is a genetic trait (Grusak, Stephens, & Merhaut, 1996; Quintana, Harrison, Nienhuis, Palta, & Kmiecik, 1999), and may contribute, at least partly, to seed [Ca] diversity. The low [Ca] of common bean seed is due to restricted Ca translocation, compared to dry matter translocation, to this organ (Mix & Marschner, 1976b).

4.3. Seed Mg accumulation

Although most of the seed Mg of both species was in the embryo, a larger proportion of Mg in common bean seed, compared to soybean seed, was in the embryo fraction. Phytates in embryos store Mg (Lott, Ockenden, Raboy, & Batten, 2000), the bioavailability of which in soybean products is high (Reddy, Sathe, & Salunkhe, 1982).

Seed [Mg] of common bean and soybean was not correlated with seed weight in the current study. In a previous study (Moraghan & Grafton, 2001), seed [Mg] of common bean was negatively correlated with seed weight. The inclusion of genotypes, from both the Andean and the Middle American gene pools in the earlier study likely caused the discrepancy. Seed [Mg] of soybean genotypes, as previously reported (Raboy et al., 1984), was not correlated with seed weight.

Little information is available concerning genetic factors affecting accumulation and within-seed distribution of Mg. Magnesium, unlike Ca, may undergo limited redistribution from leaf tissue of soybean (Derman, Rupp, & Noodén, 1978). The relative importance of direct movement via the phloem and apoplastic movement from xylem tissue on the ventral side of the pod to the seed coat for seed Mg accumulation has not been established.

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