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Nutrient composition of selected newly bred and established mung bean varieties

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ABSTRACT

Seven newly bred and three established varieties of mung bean were analysed for proximate composition, minerals, anti-nutrients and *in vitro* mineral accessibility. They contained 18–23 g protein, 4.0–5.6 g crude fibre and 2.5–4.1 g ash per 100 g dry sample. Iron, zinc, calcium, sodium and potassium ranged from 3.4 to 4.6, 1.2 to 2.3, 79 to 115, 8.1 to 13.5 and 362 to 415 mg/100 g dry weight, respectively. Phytic acid and polyphenols averaged 769 and 325 mg/100 g dry weight, respectively. Varieties differed significantly in terms of nutrient and anti-nutrient contents. Phytic acid and polyphenols were negatively correlated with *in vitro* mineral accessibility and nutrient digestibility. Protein and starch digestibility ranged from 53 to 67 g/100 g dry weight and 20 to 29 mg maltose released/g dry weight, respectively. Average molar ratios of phytic acid to iron and zinc were 16.8 and 52.7, respectively. Differences in *in vitro* iron and zinc accessibility could not be explained by phytic acid to calcium nor magnesium molar ratios. However, the phytic acid amount in mung beans suffices to bind all minerals into indigestible complexes. The newly bred varieties have better agronomic yields but no better nutritional potential than the established varieties tested.

1. Introduction

Mung bean (*Vigna radiata* (L.) R. Wilczek) is an important legume in the diet of the majority of Indians, who consume it in different forms like dhals, sweets, snacks and savoury food products. Mung bean has a protein content comparable to that of chick pea (*Cicer arietinum*) but contains less anti-nutritional (Chitra, Vimala, Singh, & Geervani, 1995) and flatulence factors than soya bean (Abdullah, Baldwin, & Minor, 1984). Mung bean is rich in micronutrients and can be used to deliver minerals to malnourished populations if processed well to retain them in the diet. Mung bean varieties are grown in wide agro-climatic zones and have diverse agronomical, processing and nutritional characteristics (Bisht et al., 2005; Makeen, Abrahim, Jan, & Singh, 2007; Tomooka, 1991). The suitability of a particular variety for processing and consumption depends primarily on its quality characteristics, particularly physical properties and chemical composition.

The presence of anti-nutrients such as phytic acid (PA) and polyphenols was shown to reduce the digestibility (Binita & Khetarpaul, 1997) and bioavailability of nutrients present in mung bean (Dave, Yadav, & Tarafdar, 2008; Mubarak, 2005). There are several approaches to increase nutrient bioavailability and digestibility at the primary production level. The first is by breeding varieties with better abilities to acquire nutrients from the soil, and the second is to optimize agronomic practices like fertilisation. Furthermore it is also possible to use breeding techniques for increasing the concentration of mineral enhancers like ascorbic acid and for decreasing the concentration of nutrient inhibitors like phytic acid, polyphenols, etc. (Frossard, Bucher, Machler, Mozafar, & Hurrell, 2000).

Most of the mung bean breeding research in India has focused on high and stable yield, early and uniform maturity, resistance to pests, pathogens and drought (Singh & Ahlawat, 2005). These selection criteria may have produced varieties with altered nutritional composition of the grains. Moreover, breeding for improved nutritional composition is limited by the fact that some plant components that are undesirable from nutritional point of view are physiologically important for the plant itself. For instance, phytic acid is required for seed germination, but it is detrimental to micronutrient uptake in humans (Coelho, Santos, Tsai, & Vitorello, 2002).

To date, little effort has been made to evaluate the nutrient composition of new varieties of mung bean, which were bred for

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Table 1
Characteristics of the selected mung bean varieties.

Mung bean varieties		Level of resistance to mung bean yellow mosaic virus	Growing season	Yield (kg/hectare)	Crop duration (Days)
Established varieties	Asha	Tolerant	Autumn	1000	60
	Muskan	Resistant	Autumn	1000	80
	Satya	Resistant	Autumn	1300	66
Newly bred varieties	MH 124	Resistant	Autumn	1300	65
	MH 125[a]	Resistant	Autumn	1200	65
	MH 318	Resistant	Autumn/Summer	1500	58
	MH 421	Resistant	Autumn/Summer	1300	60
	MH 539	Resistant	Autumn/Summer	1400	60
	MH 560	Resistant	Autumn/Summer	1600	60
	MH 564	Resistant	Autumn/Summer	1500	60

[a] Notified for farmers' use in 2009.
Source: Kumar, pers. comm. (2010) Senior Scientist at CCS Haryana Agricultural University, Hisar (India).

their disease resistance and high yield, and established varieties with respect to their contribution to human nutrition. Therefore, in the present study, seven newly bred varieties and three established varieties of mung bean were investigated for nutritional quality.

2. Materials and methods

2.1. Sampling

The mung bean varieties used for the study (Table 1) were grown using identical agronomic practices (e.g. fertilizer, irrigation) by the Department of Plant Breeding, CCS Haryana Agricultural University, Hisar, India. Raw, fully mature, disease-free mung bean grains were cleaned of extraneous matter, broken grains and weed grains, dust and other foreign materials, mixed well and ground to fine powder in an electric grinder (Cyclotec M/s Tecator, Hoganas, Sweden) and passed through a 0.5 mm sieve. Powders were stored in sealed air-tight plastic containers in a refrigerator at 5 °C until analysis.

Pepsin, pancreatin, pancreatic amylase and bile were obtained from Sigma–Aldrich Co. USA. All other reagents used for the analyses were of analytical grade and glassware was acid (1 g/100 mL HCl) washed.

2.2. Selection and description of mung bean varieties

Ten mung bean varieties were selected, namely seven newly bred at CCS Haryana Agricultural University and three established in Haryana state in India.

2.3. Analytical methods

2.3.1. Proximate composition

The following AOAC methods (1990) were used to determine proximate composition: drying at 105 °C for 24 h for moisture (AOAC 925.10), incineration at 550 °C for ash (AOAC 923.03), defatting in Soxhlet apparatus using hexane for crude lipids (AOAC 920.39), digestion with NaOH and H_2SO_4 for crude fibre (AOAC 962.09) and microKjeldahl method for crude protein (AOAC 960.52). For conversion of Nitrogen to crude protein, a conversion factor of 6.25 was used. The carbohydrate content was estimated by difference of protein, fibre, ash, fat and 100. Energy was calculated using Atwater energy conversion factors of 4.0, 4.0 and 9.0 kJ/g, for protein, carbohydrate and fat, respectively. Proximate composition was determined using dried samples. Values are presented as g/100 g on dry weight basis.

2.3.2. Mineral composition

Calcium, iron and zinc contents were determined by first digesting 1 g of sample using 25 ml diacid mixture ($HNO_3/HClO_4$: 5/1, v/v) after which the digested solution was filtered through Whatman no. 42 filter paper. Volume of the solution was made up to 50 ml and then the mineral content was determined by Atomic Absorption Spectrophotometer 2380, Perkin–Elmer (Waltham, USA) using the method of Lindsey and Norwell (1969).

2.3.3. In vitro protein and starch digestibility

In vitro protein digestibility was determined by the method of Mertz, Kirleis, and Axtell (1983). The method involved treatment of 250 mg sample with 20 ml pepsin reagent (0.1 mol/L KH_2PO_4 (pH 2.0) containing 0.2 g/100 mL pepsin) and then incubating at 37 °C for 3 h with constant shaking. The digested protein was then separated by sedimenting residual protein with 5 ml of 50 g/100 mL trichloroacetic acid and centrifugation at 16,770 × *g* for 10 min. The Nitrogen content of the supernatant containing digested protein was determined by the microKjeldahl method (AOAC, 1990).

In vitro starch digestibility was assessed by using pancreatic amylase. Twenty-five milligram of the defatted sample was dispersed in 1 ml 0.2 mol/L phosphate buffer (pH 6.9). Half a millilitre of pancreatic amylase was added and then the suspension was incubated at 37 °C for 2 h. After incubation, 3 ml of 3, 5-dinitrosalicyclic acid reagent was quickly added and then heated for 5 min in a boiling water bath. Next, the mixture was cooled and distilled water was added to get 25 ml. This solution was filtered and liberated maltose was measured colorimetrically at 550 nm. Maltose was used as standard and the values are expressed as mg of maltose liberated per gram of sample (Singh, Kherdekar, & Jambunathan, 1982).

2.3.4. In vitro mineral accessibility

In vitro iron accessibility was determined by digesting the sample with a single enzyme method as described by Rao and Prabhavathi (1978). This method is convenient, requires a minimum of chemicals, and is well suited for comparative purposes. Obviously, it does not necessarily predict exactly what will happen in-vivo, but neither do the more sophisticated in-vitro approaches.

The method involved incubation of 2 g of powdered sample with 25 ml 0.5 g/100 mL pepsin in 0.1 mol equi/L HCl solution in a water bath of 37 °C for 90 min, after adjusting the pH to 1.3 using HCl. The mixture was then centrifuged at 1000 × *g* for 45 min and the supernatant was filtered through Whatman no. 44 filter paper. Iron in the filtrate was determined according to the AOAC (1995) method by treating with 1 ml hydroxylamine hydrochloride solution and 5 ml acetate buffer solution and then reacted with α, α′ dipyridyl to yield colour which was read at 510 nm.

In vitro zinc and calcium accessibility were assessed with the multiple enzyme method of Kim and Zemel (1986). The method involved hydration of 2 g sample with 3 ml distilled water. Hydrated samples were then treated with 20 ml pepsin solution (0.1 g/100 mL pepsin in 0.1 mol equi/L HCl solution). Next the pH was adjusted to 1.5 followed by incubation at 37 °C for 1 h in a controlled temperature chamber cum shaker (BTI-100B, Biotechnologies Inc., New Delhi). After incubation the pH was raised to 6.8 with NaOH and 2.5 ml of a suspension containing 0.5 g/100 mL pancreatin and 5 g/100 mL bile was added and again incubated for 1 h at 37 °C in the controlled temperature chamber cum shaker. Next, the volume was increased to 50 ml with distilled water and immediately centrifuged at 1000 × *g* for 45 min at 5 °C. Supernatants were removed and again centrifuged at 28,350 × *g* for 45 min at 5 °C. The supernatant was digested with diacid mixture (HNO_3/$HClO_4$: 5/1, v/v) and then soluble calcium and zinc were determined by an Atomic Absorption Spectrophotometer 2380, Perkin–Elmer (Waltham, USA) using the method of Lindsey and Norwell (1969). Lanthanum chloride was added during the determination according to Vaessen and Van de Kamp (1990).

2.3.5. Phytic acid and polyphenol content

Phytic acid (PA) was estimated colorimetrically by the method of Davies and Reid (1979), by incubating 500 mg of sample with 20 ml of 0.5 mol/L HNO_3 for 3 h with continuous shaking. The suspension was then filtered through Whatman no. 1 filter paper. One millilitre of this suspension was made up to 1.4 ml using distilled water and then mixed with 1 ml ferric ammonium sulphate solution containing 50 μg of Fe. The test tube containing this suspension was placed in boiling water for 20 min. Next, the suspension was cooled to room temperature and 5 ml iso-amyl alcohol was added followed by 0.1 ml ammonium thiocyanate solution (100 g/l). The content was mixed well, and centrifuged at 1000 × *g* for 10 min. Colour intensity in alcohol was read at 465 nm using a spectrophotometer (BTI-1100, Biotechnologies Inc., New Delhi, India). For phytic acid determinations, phytic acid sodium salt hydrate (Sigma, P0109) was used for calibration purposes.

Total polyphenols were extracted from 500 mg of defatted sample by refluxing with 50 ml methanol containing 1 g/100 mL HCl for 4 h. The extract was concentrated by evaporating methanol on a boiling water bath and brought to 25 ml with methanol-HCl solution (Singh & Jambunathan, 1981). Half a millilitre of extract was made up to 8.5 ml with distilled water, mixed with 0.5 ml Folin Denis reagent and shaken. After 3 min, 1 ml of saturated sodium carbonate was added, followed by shaking. After an h, the absorbance was read at 725 nm. Calculations were done using absorbance and expressed as tannic acid equivalent (Swain & Hills, 1956). The PA:Zn, PA:Ca and PA:Fe molar ratios were calculated using the method of Wyatt and Triana-Tejas (1994).

2.4. Statistical analysis

Three samples of each mung bean variety were analysed. Mean ± standard deviation values were calculated. Comparison of means was performed by one way analysis of variance (ANOVA) followed by Tukey multiple comparison test. Significance was accepted at $P < 0.05$ (Panse & Sukhatme, 1961). Pearson linear correlation coefficients were determined to relate the nutrient digestibility and accessibility with concentrations of anti-nutritional factors. All statistical analyses were performed with PASW Statistics (Version 18.0.2).

3. Results and discussion

3.1. Proximate composition

Crude protein contents were significantly different ($P < 0.05$) among the mung bean varieties (Table 2). However, they all fall within the range of data published elsewhere for mung bean (Kochhar & Hira, 1997; Lotika & Bains, 2007). This implies that the newly bred varieties are not necessarily better suppliers of protein than the established varieties, which is supported by the fact that even higher protein contents, i.e. 26.9 g/100 g (Grewal & Jood, 2009) and 27.7 g/100 g (Ghavidel & Prakash, 2007) have been reported in mung bean. Moreover, crude protein may contain nutritionally less important non-protein nitrogen. Therefore, varieties with a higher content of crude protein may not necessarily have a better protein quality. The crude lipid contents did not differ significantly ($P < 0.05$) among the varieties and were within normal ranges as published elsewhere, with the highest concentration (1.3 g/100 g) found in MH 564. The ash contents of the mung bean varieties ranged from 3.1 to 4.1 g/100 g dry weight which is also within the range of other published values (Lin & Lai, 2006). MH 560 had the highest ash content. In contrast, MH 125 had highest content of accessible minerals. This could be due to the presence of lower concentrations of anti-nutritional factors in the latter variety. Crude fibre contents in the mung bean varieties were not different from values reported elsewhere (Lotika & Bains, 2007). The tested varieties could be distinguished into groups of similar nutrient composition. MH 125 and MH 539 had the highest crude protein, whereas MH 124, MH 421 and MH 560 contained the least crude protein. Among newly bred varieties, crude fibre was highest in MH 125 with considerable amounts present in MH 124, MH 421 and MH 564. Among the established varieties, the highest crude fibre

Table 2
Proximate composition of newly bred and established mung bean varieties.

Mung bean varieties		Moisture	Crude protein	Crude fat	Crude fibre	Ash	Carbohydrate*	Energy**
Established varieties	Asha	9.2 ± 0.2^{de}	20.0 ± 0.50^{bc}	1.32 ± 0.09^{a}	4.2 ± 0.10^{ab}	3.21 ± 0.10^{abcd}	71.3 ± 0.5^{de}	1578 ± 4.0
	Muskan	9.7 ± 0.0^{cde}	22.1 ± 0.20^{def}	1.22 ± 0.1^{a}	5.2 ± 0.17^{d}	3.27 ± 0.23^{bcd}	68.2 ± 0.4^{abc}	1557 ± 3.2
	Satya	8.7 ± 0.2^{bc}	22.8 ± 0.10^{f}	1.31 ± 0.1^{a}	4.2 ± 0.09^{ab}	2.79 ± 0.26^{a}	68.9 ± 0.3^{abc}	1585 ± 3.0
Newly bred varieties	MH 124	8.7 ± 0.2^{bc}	19.1 ± 0.01^{ab}	1.24 ± 0.1^{a}	4.6 ± 0.29^{bc}	3.12 ± 0.11^{abc}	71.9 ± 0.3^{ef}	1571 ± 3.1
	MH 125	8.3 ± 0.2^{ab}	22.9 ± 0.95^{f}	1.23 ± 0.2^{a}	5.4 ± 0.19^{d}	3.08 ± 0.04^{abc}	67.4 ± 1.0^{a}	1557 ± 6.1
	MH 318	9.7 ± 0.2^{f}	20.8 ± 0.08^{bcd}	1.51 ± 0.11^{a}	4.1 ± 0.09^{a}	3.65 ± 0.09^{de}	69.9 ± 0.2^{cd}	1575 ± 2.7
	MH 421	8.8 ± 0.1^{cd}	17.9 ± 0.10^{a}	1.16 ± 0.1^{a}	4.4 ± 0.10^{abc}	3.37 ± 0.26^{cd}	73.3 ± 0.3^{f}	1510 ± 3.1
	MH 539	8.9 ± 0.1^{cd}	22.7 ± 1.05^{ef}	$1.36 + 0.19^{a}$	4.7 ± 0.10^{c}	3.35 ± 0.13^{bcd}	67.9 ± 1.1^{ab}	1568 ± 6.6
	MH 560	8.0 ± 0.1^{a}	19.6 ± 0.26^{abc}	1.48 ± 0.4^{a}	5.2 ± 0.10^{d}	4.08 ± 0.01^{e}	69.7 ± 0.5^{bcd}	1550 ± 5.0
	MH 564	9.5 ± 0.2^{ef}	21.1 ± 1.0^{cde}	1.64 ± 0.1^{a}	4.5 ± 0.09^{abc}	2.89 ± 0.10^{ab}	69.9 ± 1.0^{cd}	1585 ± 6.1

Values (g/100 g) are expressed as Mean ± Standard Deviation ($n = 3$) on dry matter basis (except for moisture).
Means in the same column with the different superscripts are significantly different at $P < 0.05$.
*Calculated by difference from protein, fat, ash, fibre and dry matter.
**Energy (kJ/100 g) = (Fat (g) × 9.0 + Protein (g) × 4.0 + Carbohydrate (g) × 4.0) × 4.184.

Table 3
Mineral composition of newly bred and established mung bean varieties.

Mung bean varieties		Iron	Zinc	Calcium	Magnesium	Sodium	Potassium
Established varieties	Asha	3.9 ± 0.06^{c}	1.2 ± 0.03^{a}	103 ± 1.6^{d}	157 ± 2.4^{d}	9.4 ± 0.3^{ab}	363 ± 1.5^{a}
	Muskan	3.6 ± 0.15^{a}	1.7 ± 0.05^{cd}	98 ± 0.4^{c}	137 ± 3.0^{b}	10.6 ± 0.4^{cd}	403 ± 1.7^{e}
	Satya	3.9 ± 0.10^{c}	1.3 ± 0.05^{ab}	95 ± 1.5^{c}	129 ± 3.0^{a}	8.7 ± 0.4^{a}	389 ± 3.1^{c}
Newly bred varieties	MH 124	3.9 ± 0.03^{c}	1.4 ± 0.05^{ab}	97 ± 3.0^{c}	158 ± 1.1^{d}	8.5 ± 0.4^{a}	380 ± 1.3^{b}
	MH 125	4.6 ± 0.10^{d}	1.7 ± 0.14^{d}	114 ± 1.0^{e}	166 ± 1.6^{e}	13.2 ± 0.3^{f}	411 ± 1.2^{fg}
	MH 318	4.4 ± 0.14^{d}	1.5 ± 0.05^{abc}	90 ± 0.6^{b}	156 ± 1.6^{d}	10.4 ± 0.3^{bc}	407 ± 2.5^{eg}
	MH 421	4.4 ± 0.09^{d}	2.1 ± 0.14^{e}	104 ± 1.6^{d}	147 ± 1.4^{c}	10.0 ± 0.2^{bc}	398 ± 1.1^{d}
	MH 539	3.4 ± 0.01^{a}	1.3 ± 0.02^{a}	81 ± 1.2^{a}	159 ± 1.0^{d}	11.7 ± 0.4^{de}	382 ± 1.6^{b}
	MH 560	3.4 ± 0.15^{a}	1.4 ± 0.04^{ab}	105 ± 0.9^{d}	150 ± 1.4^{c}	11.8 ± 0.5^{e}	414 ± 1.1^{f}
	MH 564	3.8 ± 0.13^{bc}	1.5 ± 0.13^{cd}	94 ± 2.3^{c}	157 ± 2.3^{d}	8.8 ± 0.3^{a}	394 ± 1.6^{d}

Values (mg/100 g dry matter) are expressed as Mean ± Standard Deviation ($n = 3$).
Means in the same column with the different superscripts are significantly different at $P < 0.05$.

was found in Muskan (5.2 g/100 g), which is comparable to that of newly bred variety MH 125 (5.4 g/100 g).

3.2. Mineral content

The mineral concentrations are presented in Table 3. Although there are statistically significant differences between mineral levels among the varieties, their levels are within the expected range for mung bean (Jood, Bishnoi, & Sehgal, 1998). The significant difference in the mineral content of the varieties may have several reasons, but are most likely due to the ability of the root to absorb minerals from the soil, the physiological role of minerals in the plant and the translocation of minerals in the plant as suggested by Frossard et al. (2000). These authors also concluded that the mineral uptake mechanism varies among varieties, depending on root mycorrhiza and plant architecture. The cumulative mineral contents represent only about 30% of the total ash content; this is due to the fact that the minerals are determined as elements and the ash contains their salts. Ash may also contain salts of which the elements were not determined.

MH 125 had the highest content of iron, calcium, magnesium and sodium and might thus be of nutritional interest. In addition, MH 421 had the highest zinc content and considerable amounts of iron, calcium and magnesium.

The presence of large amounts of particular minerals can influence the absorption of others. Competition can take place, i.e. a higher amount of calcium and magnesium compared to iron and zinc may reduce their accessibility, but may also be favourable when such major minerals occupy binding sites on mineral chelating compounds such as phytic acid and polyphenols. All varieties contained considerable amounts of magnesium, and higher amounts of iron and zinc than found in wheat and rice (Srikumar, 1993). Therefore, mung bean may contribute to mineral intake when eaten with cereals, particularly products of refined cereal flour. However, the favourable mineral content of mung beans does not necessarily result in high dietary mineral intake. Optimum food processing methods are essential to avoid losses and enhance the accessibility of minerals for adequate intake.

3.3. Phytic acid and polyphenols

Phytic acid and polyphenol contents are presented in Table 4. Phosphorus in mung bean is mainly stored in the form of phytic acid. The phytic acid content of the tested varieties was within the range reported elsewhere (Jood et al., 1998; Kataria, Chauhan, & Punia, 1989). However, some authors reported considerably lower phytate contents, i.e. 236 mg/100 g (Lestienne, Verniere, Mouquet, Picq, & Treche, 2005) and 201.3 mg/100 g (Philip & Prema, 1998). The differences from previous studies could be due to the method of analysis. Lestienne et al. (2005), for instance, determined phytate in mung bean by the estimation of the myo-inositol hexaphosphate content obtained by anion exchange HPLC separation, which is a more specific method for inositol-hexa-phosphate than the method used by us, which determines all inositol phosphates. However, much higher phytic acid contents (1020–1480 mg/100 g) have also been reported in mung bean (Chitra, Vimala, Singh, & Geervani, 1995). Phytic acid molecules are negatively charged at physiological pH and bind with divalent ions making them unavailable for absorption. Nutritionally there is no significant variation in the phytic acid as its amount is sufficient to bind the minerals to form indigestible complexes.

Among the selected mung bean varieties, polyphenol contents were highest in MH 318 and lowest in MH 125. The polyphenol concentrations in the tested varieties are within the normal range published elsewhere (Jood et al., 1998; Kataria et al., 1989). This range (270.5–353.0 mg/100 g) is genetically determined

Table 4
Phytic acid (PA), polyphenols & molar ratios of phytic acid to minerals of newly bred and established mung bean varieties.

Mung bean varieties		Phytic acid (mg/100 g)	Polyphenols (mg/100 g)	PA:Fe molar ratio	PA:Zn molar ratio	PA:Ca molar ratio	PA:Mg molar ratio
Established varieties	Asha	748 ± 4.6^{abc}	353.0 ± 3.5^{de}	16 ± 0.3	62 ± 1.5	0.44 ± 0.01	0.17 ± 0.002
	Muskan	734 ± 11.0^{ab}	317.2 ± 4.2^{c}	17 ± 0.8	46 ± 1.6	0.46 ± 0.01	0.20 ± 0.005
	Satya	765 ± 7.5^{cd}	272.7 ± 3.5^{a}	17 ± 0.5	58 ± 2.1	0.49 ± 0.01	0.21 ± 0.005
Newly bred varieties	MH 124	789 ± 12.2^{de}	325.2 ± 3.2^{c}	17 ± 0.3	58 ± 2.1	0.50 ± 0.02	0.18 ± 0.003
	MH 125	726 ± 6.8^{a}	270.5 ± 5.0^{a}	14 ± 0.3	42 ± 3.4	0.39 ± 0.00	0.16 ± 0.002
	MH 318	807 ± 8.5^{e}	363.9 ± 5.4^{e}	16 ± 0.5	55 ± 2.0	0.55 ± 0.01	0.19 ± 0.003
	MH 421	765 ± 9.5^{cd}	293.4 ± 5.0^{b}	15 ± 0.4	35 ± 0.5	0.45 ± 0.01	0.19 ± 0.003
	MH 539	786 ± 11.5^{de}	352.7 ± 5.5^{ade}	20 ± 0.3	61 ± 1.3	0.60 ± 0.01	0.18 ± 0.003
	MH 560	806 ± 9.3^{e}	345.9 ± 2.1^{d}	20 ± 0.9	62 ± 2.0	0.47 ± 0.01	0.20 ± 0.003
	MH 564	760 ± 4.6^{bc}	347.2 ± 3.0^{d}	17 ± 0.6	49 ± 4.3	0.49 ± 0.01	0.18 ± 0.003

Values are expressed as Mean ± Standard Deviation ($n = 3$) on dry matter basis.
Means in the same column with the different superscripts are significantly different at $P < 0.05$.

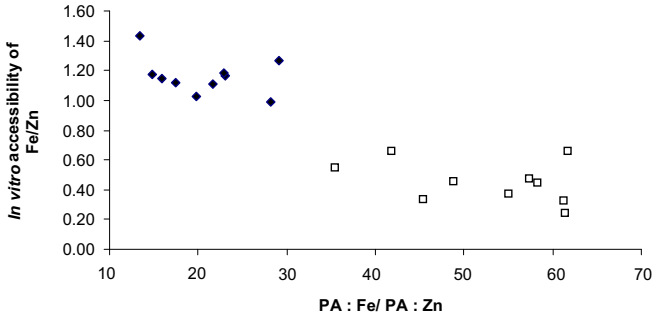

Fig. 1. *In vitro* accessibility of Fe and Zn as affected by PA:Fe and PA:Zn molar ratios, respectively. ◆ PA:Fe, □ PA:Zn. PA: phytic acid, Fe: iron, Zn: zinc.

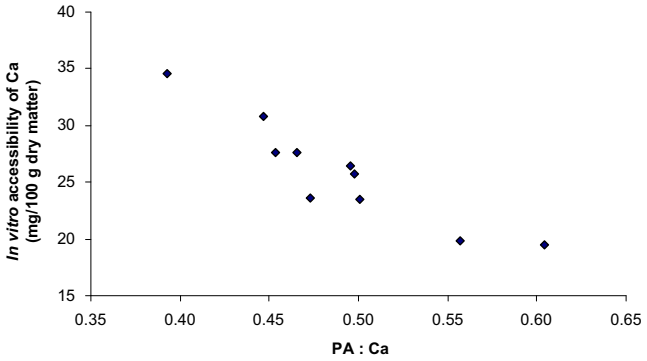

Fig. 3. *In vitro* calcium accessibility as affected by PA:Ca molar ratio. PA: phytic acid, Ca: calcium.

(Dicko et al., 2002). Polyphenols are mainly present in the seed coat (Barroga, Laurena, & Mendoza, 1985); they are present in higher amounts in coloured or darker legume varieties (Salunkhe, Jadhav, Kadam, & Chavan, 1982). The newly bred varieties tested still contain considerable polyphenol concentrations, and as such they do not represent an improvement compared to the established varieties. Polyphenols in mung bean are considered as anti-nutrient compounds with respect to mineral accessibility, but may also have positive health benefits (Randhir, Lin, & Shetty, 2004).

Phytic acid to mineral molar ratios (Table 4) are used as an indicator for the bioaccessibility of minerals. The average PA:Fe and PA:Zn of the varieties are 16.8 and 52.7 respectively. This is much higher than the values of 2.8 and 8.2 respectively, as reported by Lestienne et al. (2005). The PA:Fe molar ratio in mung bean is lower than in cereals like maize (34.4), sorghum (22.8) (Lestienne et al., 2005) and rice (49.5) (Liang, Han, Han, Nout, & Hamer, 2007), but higher than in soya bean (10.1) (Lestienne et al., 2005). The PA:Zn ratio in mung bean is lower than in sorghum (62.8) (Lestienne et al., 2005), but higher than in rice (42.0) (Liang et al., 2007) and maize (40.6) (Lestienne et al., 2005).

Critical values of molar ratios of phytic acid to a mineral for adequate mineral absorption have been reported as <0.24 for phytate/calcium (Morris & Ellis, 1980), <1 for phytate:iron (Hallberg, Brune, & Rossander, 1989), <10 for phytate:zinc (Morris & Ellis, 1980) and <3.5 for phytate × calcium:zinc (Fordyce, Forbes, Robbins, & Erdman Jr., 1987). High PA:Zn and PA:Fe ratios indicate poor iron and zinc accessibility. These ratios vary among mung bean varieties, showing that varieties with lower phytic acid to mineral ratios have comparatively higher mineral accessibility. The values of PA:Ca are much lower than PA:Fe and PA:Zn due to the presence of higher amounts of calcium in the mung bean varieties. In the selected varieties it seems that *in vitro* iron and zinc accessibility was not affected by PA:Fe and PA:Zn (Fig. 1) in the tested range. The divalent calcium cation, because of its higher concentration and stronger affinity for phytate, may exert a sparing action for iron and zinc by forming phytate–calcium complexes. However, when assuming that all calcium would be complexed with PA, there would still remain enough phytic acid to make insoluble complexes with iron and zinc. Fig. 2 shows that *in vitro* iron and zinc accessibility did not improve as a function of PA:Fe (9.3–12.9) and PA:Zn (22.7–39.8) ratios calculated with amounts of phytic acid left after binding with all calcium. This suggests that the molar ratios PA:Fe and PA:Zn were still too high to allow a better accessibility of Fe and Zn. Fig. 3 shows that PA:Ca is one of the possible factors affecting the *in vitro* calcium accessibility. Calcium can also form calcium–zinc–phytate complexes, which have a lower solubility product than phytic acid–zinc or phytic acid–calcium complexes (Fordyce et al., 1987). The magnesium content in the varieties is even higher than of calcium, which indicates possibilities of formation of magnesium–phytate complexes and thus making phytate unavailable for iron and zinc. But, as indicated in Fig. 4, it seems that the concentration of magnesium is not determining iron and zinc accessibility, which is also supported by the *in vivo* studies that suggested that the concentration of magnesium does not have a significant impact on zinc bioavailability as compared to the concentration of calcium (Forbes, Parker, & Erdman Jr., 1984). None of the phytic acid to mineral ratios could explain the lower mineral accessibility and thus predict mineral bioavailability. This may be because the phytate concentrations were excessively high and also because mineral ratios depend on other factors like pH, temperature, ionic strength and presence of other mineral ions.

In terms of improvement in varieties through breeding techniques, MH 125 seems to be improved nutritionally as it had the lowest phytate to mineral ratios, which indicate higher mineral bioavailability. However, agronomically there is no significant

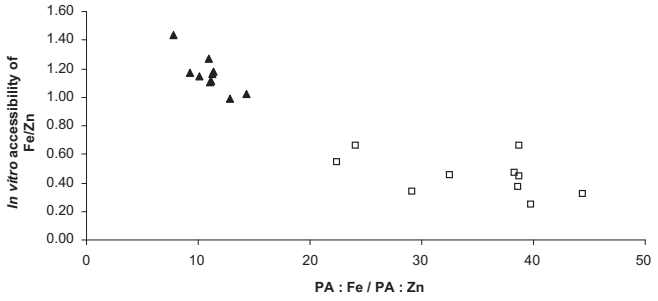

Fig. 2. *In vitro* accessibility of Fe and Zn as affected by PA:Fe and PA:Zn molar ratios respectively (as calculated by phytic acid available after binding with all calcium present). ▲ Fe, □ Zn. PA: phytic acid, Fe: iron, Zn: zinc.

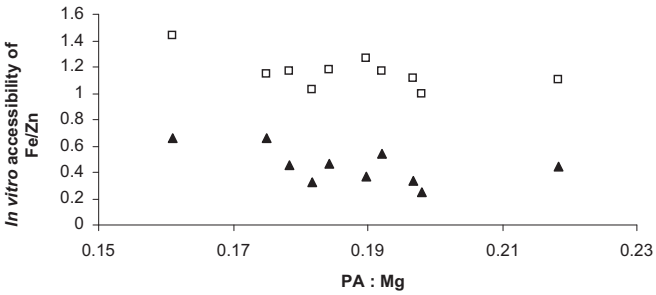

Fig. 4. *In vitro* accessibility of Fe and Zn as affected by PA:Mg molar ratio. ▲ Zn, □ Fe. PA: phytic acid, Fe: iron, Zn: zinc, Mg: magnesium.

Table 5
In vitro nutrient digestibility and mineral accessibility of newly bred and established mung bean varieties.

Mung bean varieties		*In vitro* protein digestibility (g/100 g dw)	*In vitro* starch digestibility (mg maltose released/g)	*In vitro* iron accessibility		*In vitro* zinc accessibility		*In vitro* calcium accessibility	
				mg/100 g	g/100 g	mg/100 g	g/100 g	mg/100 g	g/100 g
Established varieties	Asha	63 ± 0.3^{e}	26.5 ± 0.23^{d}	1.15 ± 0.03^{ab}	28.9	0.65 ± 0.02^{e}	29.1	30.8 ± 0.29^{e}	29.5
	Muskan	63 ± 0.7^{e}	24.4 ± 0.39^{c}	1.12 ± 0.08^{ab}	31.4	0.33 ± 0.03^{b}	23.1	27.6 ± 0.45^{d}	28.3
	Satya	65 ± 0.6^{ef}	24.6 ± 0.54^{c}	1.10 ± 0.02^{ab}	28.5	0.44 ± 0.01^{c}	23.0	26.5 ± 0.09^{cd}	27.8
Newly bred varieties	MH 124	58 ± 0.3^{cd}	22.5 ± 0.26^{b}	1.19 ± 0.14^{abc}	30.2	0.47 ± 0.03^{c}	25.0	23.5 ± 0.4^{b}	24.4
	MH 125	67 ± 0.2^{f}	28.6 ± 0.15^{e}	1.40 ± 0.12^{c}	31.4	0.66 ± 0.02^{e}	28.1	34.6 ± 0.34^{e}	30.5
	MH 318	54 ± 0.7^{ab}	19.6 ± 0.57^{a}	1.27 ± 0.04^{bc}	29.1	0.37 ± 0.01^{b}	23.3	19.9 ± 0.19^{a}	22.2
	MH 421	59 ± 0.5^{d}	21.8 ± 0.49^{b}	1.17 ± 0.15^{ab}	26.7	0.54 ± 0.01^{d}	26.2	27.6 ± 0.33^{d}	26.2
	MH 539	56 ± 1.1^{bc}	21.6 ± 0.26^{b}	1.02 ± 0.01^{a}	30.5	0.32 ± 0.01^{b}	26.1	19.5 ± 0.95^{a}	24.5
	MH 560	53 ± 1.1^{a}	19.6 ± 0.72^{a}	0.99 ± 0.08^{a}	29.0	0.24 ± 0.01^{a}	20.3	23.6 ± 0.06^{b}	22.4
	MH 564	58 ± 0.4^{d}	22.5 ± 0.26^{b}	1.16 ± 0.03^{ab}	30.8	0.45 ± 0.02^{c}	25.1	25.7 ± 0.22^{c}	27.5

Values are expressed as Mean ± Standard Deviation ($n = 3$) on dry matter basis.
Means in the same column with the different superscripts are significantly different at $P < 0.05$.

improvement due to its lower yield as compared to MH 560 and MH 564.

3.4. *In vitro* nutrient digestion and mineral accessibility

In vitro protein digestibility of varieties showed significant diversity ranging from 53.1 g/100 g dry weight in MH 560 to 67.1 g/100 g dry weight in MH 125 (Table 5). The remaining protein may be indigestible due to the presence of trypsin inhibitors and hemaglutinins in mung bean, which has been reported as the main reason for lower protein digestibility in legumes (Mubarak, 2005). Negative correlations between phytic acid and *in vitro* protein digestibility were found ($R^2 = -0.85$) as shown in Fig. 5. Thus, the presence of different amounts of phytic acid in these varieties might also have caused the variation in *in vitro* protein digestibility, as phytic acid–mineral complexes bind with peptides to form insoluble phytic acid–mineral–peptide complexes (Bhatia & Khetarpaul, 2009). Protein digestibility in mung bean has been reported to be lower than that of lentils (Singh & Jood, 2009).

In vitro starch digestibility was found to be lowest (19.6 mg maltose released/g) in MH 560 and highest (28.6 mg maltose released/g) in MH 125 (Table 5). The results of the present study are consistent with that of earlier studies (Grewal & Jood, 2009; Jood et al., 1998). Except for MH 125, all high yielding newly bred varieties showed considerably lower starch digestibility than the established varieties. There was a negative correlation of *in vitro* starch digestibility with phytic acid ($R^2 = -0.83$) and polyphenols ($R^2 = -0.47$) as shown in Fig. 5. This difference in starch digestibility among varieties may be due to differences in amounts of anti-nutrient factors like phytic acid (Yoon, Thompson, & Jenkins, 1983) and polyphenols (Farias et al., 2007) due to their inhibition of amylase. The native starch is present in granules, which are only affected by hydrolytic enzymes if damaged; further processing such as heating may cause gelatinization, and this will increase susceptibility to enzymatic activity. Other food processing methods such as grinding, hydration and disruption of the native granule starch structure have also been found to increase starch digestibility (Bhama & Sadana, 2004).

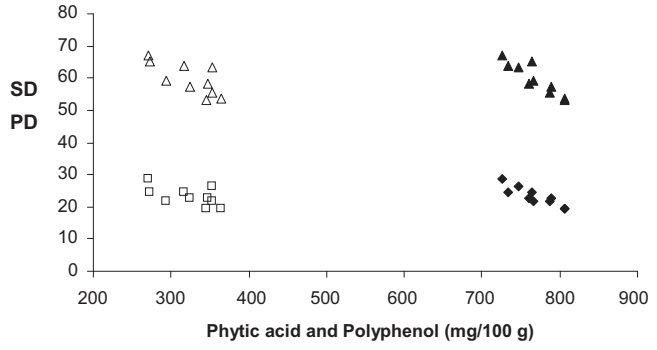

Fig. 5. *In vitro* Protein and Starch digestibility as a function of phytic acid and polyphenol. SD: starch digestibility (mg maltose released/g dry weight); PD (g/100 g dry weight). ◆ Phytic Acid vs. Starch Digestibility, □ Polyphenol vs. Starch Digestibility, ▲ Phytic Acid vs. Protein Digestibility, △ Polyphenol vs. Protein Digestibility.

In vitro mineral accessibility can be a global index of *in vivo* mineral bioavailability. Mung bean (100 g) should cover 12–16% of iron, 8–14% of zinc and 20–29% of calcium according to the recommended daily intake (RDI) based on the total amount of these minerals. However, due to the lower bioavailability it only covers 3.5–5.1% of iron, 1.6–4.4% of zinc and 4.9–8.6% of calcium of the RDI. Mung bean varieties like MH 318, with a high amount of phytic acid, were found to have the lowest amounts of accessible minerals. The values of the present study support those of Jood et al. (1998) in mung bean cultivars. Significant negative correlations of phytic acid and polyphenol were found with *in vitro* mineral accessibility. The differences in mineral accessibility among varieties may be related to their contents of anti-nutrients such as phytic acid, polyphenols as well as dietary fibre; and to their contents of respective minerals, iron, zinc and calcium. As mung beans do not contain any mineral uptake enhancer such as vitamin C, the effects of the anti-nutrients mentioned earlier need to be minimised to achieve a better mineral bioavailability. A possible way to achieve this is by dephytinization. Wet processing such as fermentation and germination was shown to contribute to dephytinization (Hemalatha, Platel, & Srinivasan, 2007; Lotika & Bains, 2007; Nout, 2009). Dehulling and cooking can reduce the polyphenol concentrations, thereby increasing the nutritional value of the grain (Madhuri, Pratima, & Rao, 1996). This also suggests that mung bean products obtained through fermentation, germination and soaking may achieve higher levels of mineral bioavailability.

4. Conclusion and recommendations

Farmers are predominantly interested in the agronomic characteristics of their mung bean varieties as this result in higher yields and revenues. However, agricultural extension services should also pay attention to nutritional characteristics of the mung bean varieties.

We recommend that plant breeders should focus on a combination of crop yield, with nutritional value and consumer preference traits. A low phytic acid content may be a desired property from a nutritional point of view, but it may hamper the growth of the plants

when too low (Coelho et al., 2002). Thus, phytic acid contents need to be reduced by appropriate breeding techniques without compromising seed germination (Bohn, Meyer, & Rasmussen, 2008), or by processing methods such as fermentation. Another target for plant breeding is to improve the mineral content to enhance micronutrient availability. It should be realized that the investigated cultivars were grown under identical conditions on the same plot and during the same season, so the data presented could only be seen as comparative and not absolute, in the absence of performance data in different locations or seasons. However, from this study we conclude that although the newly bred varieties hold promise for better agronomic yields, their nutritional potential is not better than that of established varieties.

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