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Assessment of the Physical, Chemical, Yield and Nutritional Quality Traits of Tropical, Temperate and Wild Dry Bean Species in Vietnam

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ABSTRACT

Background: Assessing agronomic and nutritional characteristics is one of the primary goals for assisting plant scientists in selecting promising grain legume crops for future food and nutritional security and increasing the income of smallholder farmers.

Methods: The experiment was conducted from September 2021 to February 2022 at the greenhouse of GRIS, Ton Duc Thang University, Vietnam. Yield components, agronomic characteristics and biochemical and nutritional parameters of two varieties of tropical beans (Velvet White Bean and Red Cowpea), two varieties of temperate beans (Dwarf Stick Bean and Soybean) and two varieties of wild beans when grown in Vietnam were evaluated in the present study.

Result: The results revealed the presence of a wide range of phenotypic variations in dry bean germplasm. The biochemical and nutritional properties of the bean types investigated revealed that the Velvet White Bean had a higher phenol content (0.42 mg GAE g^{-1}) and a lower phytic acid concentration (2.87 µg mL^{-1}) than the other species. The Dwarf stick vean had the highest flavonoid concentration among the types (0.017 mg RE g^{-1}) while the crude protein content of soybean (38.2 mg g^{-1}) was the highest. These findings serve as a foundation for breeders in selecting promising legumes to breed for Vietnam.

Key words: Agronomic, Beans, Flavonoid, Growth, Phenolic, Phytic acid, Protein, Yield.

INTRODUCTION

Legume grains play an important role in human nutrition, especially in the diets of low-income groups in developing countries. They are an essential and inexpensive protein, fiber and starch source for most of the world's population, mainly in developing countries. Beans are the best source of iron for humans, providing 23-30% of the recommended amount from a daily serving (Shimelis and Rakshit, 2005). Dried beans are a staple in the diets of many vegetarians and may contribute to some of the health benefits associated with this diet. The variety, as well as the quality of the products made from beans, are increasingly diversified. In India, fresh beans are used as vegetables, such as Faras or French beans, also widely grown there (Sofi *et al.*, 2011).

Genetic improvement is one of the best ways to get varieties with improved agronomic traits like yield, resistance to biotic and abiotic stress and nutritional qualities to satisfy customer needs (Bailey-Serres *et al.,* 2019). The assessment of germplasm based on physical and agronomic traits, as well as chemical composition parameters, is critical for plant scientists in the selection of superior grain legume crop breeds to ensure future food and nutritional security. Knowledge of the phenotypic variability supplied by different morphological and agronomical characteristics, such as seed, leaf, plant and fruit-related characteristics, is important for the conservation, breeding strategies, improvement and commercialization of new varieties with high yield (Gonçalves *et al.,* 2008). De Barros and Prudencio (2016) highlighted that the Saracura variety was a good option for both industrial and domestic use by evaluating the physical and chemical characteristics of some internal and external Brazilian and external markets of the common bean. Other study by Díaz-Batalla *et al.* (2006) found that Mexican common bean seeds contain dietary fibre, flavonols, phenolic acids, galactooligosaccharides and phytic acid.

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Kaga *et al*., (2012) noticed that the morphology of wild-type accessions was extremely similar, whereas the morphology of Asian accessions varied greatly. Besides morphological differences between wild species and cultivar, there are differences in the shape and size of a seed, germination rate, growth, reproductive behavior, response to habitat and resistance to pests, diseases and insects (Kazai *et al*., 2018). Elucidating the physiological properties and nutritional value of beans in general for some tropical, temperate and wild legume genetic resources has scientific and practical significance, helping scientists use adequate genetic resources in breeding varieties to deliver high nutritional value and adapt to different ecological regions.

Agriculture of the southern provinces of Vietnam is very diverse, where almost all major crops are concentrated in the strategy of developing commodity agriculture. Under the pressure of climate change and the upcoming Trans-Pacific Strategic Economic Partnership (TPP) Agreement, the production of beans in Vietnam in general, specifically the southern provinces, still faces many challenges and difficulties in expanding production. Therefore, besides establishing material areas, it is necessary to source stable, high-yielding legume parents with specific quality, resistance to pests and diseases and wide adaptability to biological conditions in Vietnam. Therefore, this study aimed to investigate the physiological, biochemical and nutritional properties of bean varieties, including wild plants under cultivation conditions in Vietnam, to focus on the breeding of bean varieties in the future.

MATERIALS AND METHODS

Plant materials

Two varieties of tropical beans (White Velvet bean (G1) and red cowpea (G2) and two temperate beans (dwarf stick bean (G3) and vegetable soybean (G4)) were selected from Genomic Research Institute and Seed (GRIS) and wild beans (*Strophostyles helvola* L.) (G5). Slick-seed fuzzy beans (*S. leiosperma*) (G6) were collected in Long An province and Tien Giang province of Southern Vietnam (Fig 1). The experiment was conducted from September 2021 to February 2022 at the greenhouse of GRIS, Ton Duc Thang University, Vietnam.

Seeds were planted in 33 × 27 × 25 pots of coir and rice husk ash soil with 30 pots for each variety. After sowing, bases will be covered in mud and watered twice daily in the morning and afternoon until they germinate. After 7-10 days, each pot was fertilized with 5 g of urea fertilizer (UREA, Vietnam). About 5 g of nitrogen and potassium (Vietnam) was applied to each pot after 10-15 days.

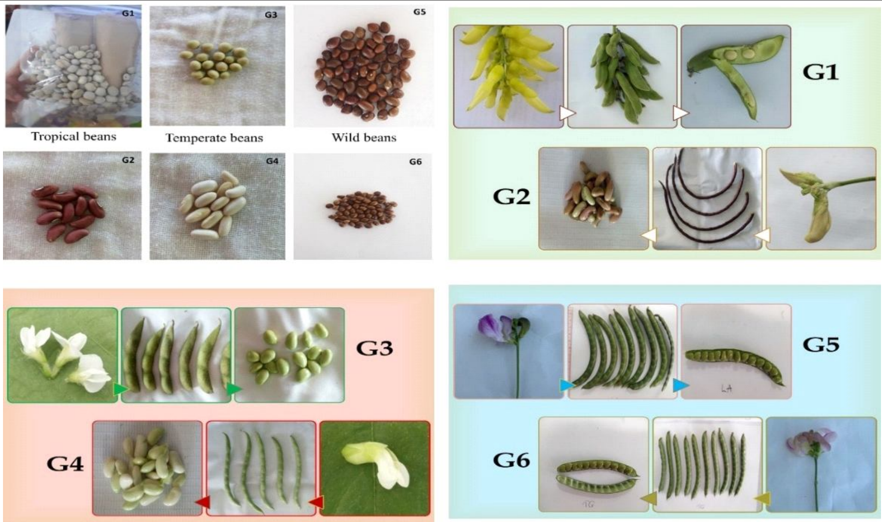
Morphological and yield characteristics

Four growth parameters as plant height (PH), leaf length (LL), leaf width (LW) and leaf number (LN) were evaluated from 30 randomly selected representative plants in each variety in the first and fourth weeks. All the agronomic parameters for measuring bean varieties, such as pod length and width, seed length (SL), seed width (SW), seed thickness (ST) and the number of seeds per pod (SN), were collected from 20 randomly chosen representative pods from 30 plants of each variety and measured according to Emire and Sudip (2005). Yield parameters as the PN per bunch (PN bunch^{-1}), the weight of 10 pods (10-pod W) and the weight of 50 seeds (50-seed W)) were measured from 30 plants in each variety (Emire and Sudip, 2005).

Chemical properties characteristics

Plant extraction

After harvesting 500 g of each bean variety, damaged seeds were removed, dried and ground into fine powder. The



Note: G1: Velvet white bean; G2: Thai red cowpea; G3: Japanese vegetable soybean; G4: American dwarf bean; G5: Long An wild bean; G6: Tien Giang wild bean.

Fig 1: Tropical, temperate and wild bean species were collected for this research.

sample extract was extracted by the method according to Obeidat *et al.* (2012). The extracts of the bean varieties were prepared individually in methanol (powder: solvent [1: 10], w/v), shaking overnight at room temperature. The extract was then filtered through filter paper. The solvent was removed by evaporation under a vacuum to obtain the dry extracts. The dry extracts were stored at 4°C in a refrigerator before use.

Total phenolic content (TPC)

The TPC of each seed extract was determined using the Folin-Ciocalteu reagent described by the method of Singleton *et al.* (1999). Accordingly, 0.5 mL of the extract (100 µg mL^{-1}) was dissolved in 2.5 mL of Folin-Ciocalteu reagent (0.2 N). The mixture was shaken well and kept at room temperature for 5 min and then 2 mL of sodium carbonate solution (75 g L^{-1}) was added. Incubate in the dark for 2h and measure the absorbance at 760 nm on the blank using a UV-Vis spectrophotometer. The procedure was repeated the same way, replacing the extract with the gallic acid solution used as the standard for the calibration curve and the product formed a blue complex. The concentrations of the criteria were 0, 0.2, 0.4, 0.6, 0.8 and 1 mg mL^{-1}, respectively. The TPC was performed in triplicate and the results were expressed as gallic acid equivalence (mg GAE g^{-1}).

Total flavonoid content (TFC)

The TFC of the extract was determined by the Dowd method, as Sawadogo *et al.* (2006) described. Accordingly, 2 mL of 2% $AlCl_3$ in methanol was mixed with 2 mL of each extract (100 µg mL^{-1}), mixed and kept for 10 min. A similarly performed blank consisted of 2 mL of methanol and 2 mL of each extract without $AlCl_3$. Absorbance was measured at 415 nm using a UV-Vis spectrophotometer. The procedure was repeated similarly, replacing the extract with the rutin solution used as the standard for the calibration curve. The concentrations of the standards were: 0, 0.02, 0.04, 0.06, 0.08 and 0.1 mg mL^{-1}, respectively. The TFC was performed in triplicate and the results were expressed as rutin equivalents (mg RE g^{-1}).

Nutritional quality characteristics

Protein extraction

1.5 g of seeds were finely ground with 1 mL of protein extraction buffer in liquid nitrogen until a thick paste was formed. The paste was then placed in a 1.5 mL microcentrifuge tube and centrifuged at 4! for 20 minutes at 12000 rpm. After that, 100 µL of the supernatant was transferred to another 1.5 mL microcentrifuge tube to quantify the extracted protein by the Bradford method (Bradford, 1976).

Protein estimation by bradford method

100 µL of protein solution containing 10-100µg was pipetted into different test tubes, then diluted the extract into different concentrations making up the volume to 100 µL with extraction buffer 5 mL of dye reagent was added to the test tube and mixed well. At the same time, a set of standards containing 5, 10, 20, 30, 40, 50 and 100 µL of Bovine Serum Albumin (BSA 2.0 mg mL^{-1} stock in extraction buffer) in separate tubes were prepared and made up the volume to 100 µL with extraction buffer. Then 5 mL of dye reagent was added and mixed well by vertexing. After 5 minutes and before one hour, the absorbance was read at 595 nm (OD595) against a reagent blank (100 µL of extraction buffer with 1 mL of dye reagent). The protein concentration in the extract was calculated by comparison with the standard curve.

Phytic acid

The sample (0.05 g) was ground to a fine powder, then mixed in 2 mL HCl 0.4 M and incubated at 4°C overnight. The solution was combined and 100 µL of the mixture was transferred to the cuvette. The volume of 1 mL was maintained by adding 900 µL of distilled water. Then, 1 mL of Chen's reagent [6N H2SO4: 2.5% ammonium molybdate: 10% ascorbic acid: distilled water (1: 1: 1: 2)] was added to the cuvette, covered with parafilm and mixed by inversion. The blank sample was used as a control with 1 mL of Chen's reagent and 1 mL of water (Chen *et al.*, 1956). Then, the samples were incubated at 37°C for 1.5 h. The phytic acid content was determined using a phosphate calibration curve established in 3 replicates of 1 mM KH_2PO_4 between 50, 100, 200, 300 and 400 µL.

Data analysis

Variations in the growth, agronomic and yield parameters of tropical, temperate and wild bean germplasm were the primary focus of the initial phase of the analysis. The mean, maximum and minimum values are the mean of n = 30 replicates. The coefficient of variation (CV), or relative standard deviation (RSD), is a standardized measure of the dispersion of a probability distribution or frequency distribution in Microsoft Excel 2010. Minitab for analysis of variance and Duncan's test at P = 0.05 were used to evaluate tropical, temperate and wild bean germplasm's chemical and nutritional qualities.

RESULTS AND DISCUSSION

Physiological characteristics

Plant height, leaf size and the number of leaves show significant genotypic effects, suggesting useful genotypic variation for breeding (Nadeem *et al.,* 2020). Table 1 shows that the CV (n= 30) was high (over 10%) in PH, LW and LL, except G4 (CV= 8.87%) in the first week, but particularly in LW, which ranged from 0.4 to 5 cm, averaging 2.31 cm with a high CV of 35.67% in G2.

The mean, maximum, minimum and CV values of PH and three leaf traits in six varieties at four weeks of growth were recorded. The CV was high (over 10%) in the four traits among germplasms except for PH, LL and LN in G3 and LN in G4. Particularly in PH, which ranged from 8.70 to

46 cm with a mean of 23.61 and a high CV of 48.02% in G5, from 12.30 to 68.50 cm with a mean of 39.88, CV= 47.04% in G6, from 16.50 to 73 cm with a mean of 28.82 cm, CV= 45.71 in G2.

In this study, PH, leaf size and LN plant^{-1} vary greatly between varieties. These traits are the most variable because they have the highest CV% values of any character. Inci and Toker (2011) also found that in cold-tolerant environments in the western Mediterranean, Faba beans (*Vicia faba* L.) grew to PH of 48 to 86 cm (2005-2006) and 20 to 69 cm (2006-2007). In addition, they studied wild bean varieties with PH of 18 to 54 cm (2005-2006) and 11 to 45 cm (2006-2007). Stoilova and Berova (2014) evaluated common bean accessions with PH between 30 and 42 cm and an average of 34 cm which type was best for conditions in Central South Bulgaria.

Agronomic criteria

Seed-related characteristics were deemed essential for common beans and were regarded as the most influential factor in determining the commercial acceptability of commercial varieties (Fuente *et al.,* 2013). All agronomic parameters, such as pod length and width, seed length, seed width, seed thickness and seed number per pod of bean varieties analyzed showed variation among bean germplasm in Table 2 (n= 30).

The mean, maximum, minimum and CV values for the characteristics of seeds revealed a broad range of phenotypic variations among bean germplasm (Table 2). Pod traits had a low variation coefficient (less than 10%) except for PN bunches^{-1} among germplasms, PL in G3 and PW in G2 and G4 (over 10%), which ranged from 0.60 to 1 cm, a mean of 0.79 cm and a high CV of 15.80%, from 0.70 to 1 cm, a mean of 0.87 and CV= 11.01%, respectively.

The size of the grain is very important to consumers, so one of the breeding goals is to select plants with bigger seeds that also possess advantageous technological characteristics. There was a high CV in ST and SN (over 10%), which ranged from 0.30 to 0.7 cm, a mean of 0.49 cm and a high CV of 23.57% in G3, from 0.70 to 1.6 cm, mean of 0.94, CV= 22.42% for ST and from 3.0 to 6.0 cm, mean of 4, CV= 22.15% for SN in G1. Table 2 includes the ranges of low CV of SL and SW traits (lower than 10%) studied in the six varieties except in G3 for SW and G6 (over 10%), but particularly in G6, which ranged from 0.50 to 0.60, with a mean of 0.55 and a CV of 26.90%.

According to Rana *et al.,* (2015), seed weight was positively correlated with leaf width, fruit width, seed length

Table 1: Variations in the growth parameters in 1st week and 4th week of tropical, temperate and wild bean germplasm.

Traits	Germplasms	1st week				4th week			
		Min	Max	Mean	CV%	Min	Max	Mean	CV%
PH (cm)	G1	4.00	11.00	7.71	22.88	15.50	47.00	23.53	34.52
	G2	5.00	7.50	6.19	12.31	16.50	73.00	28.82	45.71
	G3	5.00	10.50	7.06	19.57	30.00	40.20	35.60	8.32
	G4	4.00	6.50	5.17	14.40	18.00	28.90	23.03	12.07
	G5	2.80	7.50	5.33	24.93	8.70	46.00	23.61	48.02
	G6	2.90	7.30	4.87	26.31	12.30	68.50	39.88	47.04
LL (cm)	G1	4.00	9.80	7.46	18.49	6.10	12.00	8.92	17.67
	G2	1.30	5,40	3.47	25.92	4.00	9.40	7.06	17.58
	G3	3.10	6.00	4.34	16.74	10.00	15.00	13.00	8.43
	G4	2.90	4.10	3.52	8.87	6.00	11.60	7.43	14.75
	G5	1.30	3.00	2.17	19.74	3.20	7.00	4.72	22.24
	G6	2.10	4.40	3.21	15.25	3.20	7.00	4.52	19.16
LW (cm)	G1	2.00	8.50	6.28	21.95	4.50	8.90	7.08	12.03
	G2	0.40	5.00	2.31	35.67	2.30	6.70	4.23	23.67
	G3	2.10	4.30	2.59	17.47	6.40	10.00	8.12	11.32
	G4	1.70	3.10	2.29	13.38	3.00	7.70	4.62	18.88
	G5	1.00	2.50	1.52	23.98	1.60	7.00	3.11	26.07
	G6	1.70	3,20	2.41	13.98	2.30	4.60	2.65	16.47
LN	G1	6.00	8,00	8.00	9.69	24.00	60.00	30.00	27.14
	G2	7.00	8.00	8.00	6.05	21.00	50.00	29.00	23.25
	G3	6.00	8.00	8.00	7.32	21.00	24.00	24.00	3.48
	G4	7.00	8.00	8.00	6.05	19.00	24.00	23.00	6.86
	G5	4.00	5.00	5.00	7.84	12.00	42.00	19.00	43.35
	G6	4.00	5.00	5.00	7.10	10.00	57.00	29.00	44.62

Note: G1: Velvet white bean; G2: Thai red cowpea; G3: Japanese vegetable soybean; G4: American dwarf bean; G5: Long An wild bean; G6: Tien Giang wild bean. Coefficient of variation (CV%). PH: Plant height; LL: Leaf length; LN: Leaf number.

and seed width, indicating that these traits affected yield. Vidyakar et al. (2017) found that accession and phenotype could affect genetic variation (PH, 100-seed weight and the PN plant^{-1}), but fruit length and yield per plant were basic selection criteria. In addition, Nadeem *et al.* (2020) examined the phenotypic characteristics of 183 popular Turkish bean varieties for 22 agronomic traits, including fruit size (length and width), length, width and thickness of grain. Fruit length ranged from 8.3 to 14.7 cm, with an average of 11.4 cm and fruit width ranged from 5.9 to 14.01 mm, with an average of 9.3 mm. The grain length, width and thickness range from 7.4 to 16.4 mm, 5.3 to 9.7 mm and 4.02 to 10.90 mm, respectively (Nadeem *et al.,* 2020).

Yield parameters

As for yield evaluation and components of tropical and domestic dry bean germplasm, including wild species, the number of pods per bunch, the weight of 10 pods and the weight of 50 seeds (g), it was found that all types were recorded variables in Table 2.

According to the findings presented in Table 2, the CV was high (greater than 10%) in the PN bunch^{-1}, whereas the CV was low (lower than 10%) in terms of 10-pod W and 50-seed W, accepting G5. 100-seed weight is an important factor that has a positive and significant effect on the yield of common beans (Nadeem *et al.* 2020). However, seed weight was negatively correlated with days to flowering, fruit length and the number of seeds per fruit. These findings were confirmed by Okii *et al.* (2017) who found a significant and interesting correlation between days to flowering and the number of seeds per pod and yield seeds. However, seed weight was negatively correlated with days to flowering, fruit length and seed number per fruit. In this study, weight monitoring of 10 pods and 50 seeds clarified yield criteria. The G1 variety's 10 fruits and 50 seeds weighed 451.52 g and 57.24 g, respectively, due to their large size. The G2 had 200.8 g of 10 pods and 20.7 g of 50 seeds, the G3 had 70.01 g and 47.97 g and the G4 had 101.80 g and 13.80 g. The 10-pod W and 50-seed W were 39.28 g and 16.06 g for the G5 variety and 35.73 g and 12.47 g for the G6 variety. The G1 had 20.8, G2 and G4 had 2.6 and G3, G5 and G6 had 2.8 pods per bunch. The PN plant^{-1} (3-10 pods), SN pod^{-1} (4-6 seeds) and weight of 100- seed W (25-45 g, average 36.33 g) were observed in the previous study (Rai *et al.* 2010). A wide range of phenotypic variations and high heritability values were observed, with the PN plant^{-1} ranging from 13.33 to 79.67, the SN pod^{-1} from 3 to 5.67 and the 100- seed W from 11.33 to 67 g (Rai *et al.,* 2010).

Table 2: Variations in the agronomic and yield parameters of tropical, temperate and wild bean germplasm.

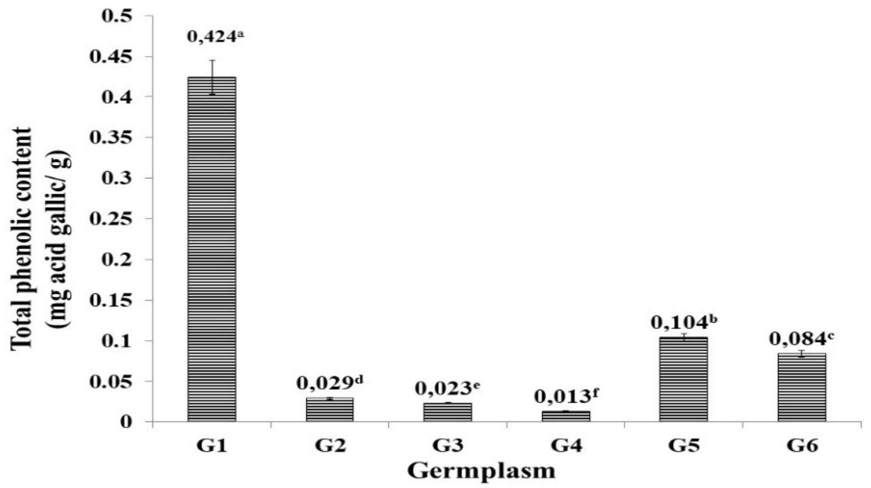
Germplasms	Values	PL (cm)	PW (cm)	SL (cm)	SW (cm)	ST (cm)	SN	PN	10-pod W (g)	50- seed W (g)
G1	Min	9.80	2.00	1.90	1.60	0.70	3.00	16.00	424.91	55.35
	Max	14.50	2.50	1.90	1.60	1.60	6.00	25.00	463.87	60.49
	Mean	12.00	2.21	2.28	1.81	0.94	4.00	20.80	451.52	57.24
	CV%	9.28	7.99	6.67	6.09	22.42	22.15	19.65	3.64	3.37
G2	Min	37.00	0.60	1.30	0.50	0.30	11.00	2.00	187.64	18.31
	Max	48.50	1.00	1.30	0.50	0.50	19.00	3.00	210.92	24.02
	Mean	42.24	0.79	1.45	0.53	0.41	15.00	2.60	200.83	20.70
	CV%	8.49	15.84	5.14	9.15	11.26	16.05	21.07	4.37	10.18
G3	Min	5.60	1.50	1.20	0.80	0.30	2.00	2.00	67.49	45.72
	Max	8.00	1.90	1.20	0.80	0.70	3.00	3.00	74.03	50.87
	Mean	6.45	1.69	1.49	0.97	0.49	3.00	2.80	70.01	47.97
	CV%	10.34	6.87	7.99	10.61	23.57	19.50	15.97	3.70	3.86
G4	Min	18.00	0.70	1.00	0.50	0.20	6.00	2.00	97.50	11.64
	Max	24.30	1.00	1.00	0.50	0.40	10.00	3.00	108.34	15.35
	Mean	20.54	0.87	1.11	0.58	0.31	9.00	2.60	101.83	13.82
	CV%	9.96	11.01	8.22	9.67	20.42	13.91	21.07	4.18	10.08
G5	Min	10.00	0.70	0.90	0.70	0.20	8.00	2.00	34.22	12.03
	Max	13.50	1.00	0.90	0.70	0.40	14.00	3.00	45.51	19.32
	Mean	11.63	0.81	0.97	0.75	0,55	11.00	2.80	39.28	16.06
	CV%	6.98	7.87	6.50	6.85	13.31	16.54	15.97	10.83	16.72
G6	Min	9.40	1.00	0.50	0.60	0.20	9.00	2.00	33.71	11.70
	Max	11.30	1.20	0.50	0.60	0.70	14.00	3.00	40.40	13.62
	Mean	10.21	1.08	0.55	0.82	0,31	12.00	2.80	35.73	12.47
	CV%	5.51	7.17	26.90	13.98	14.93	11.66	15.97	7.69	6.10

Note: PL: Pod length; PW: Pod wide; SL: Seed length; SW: Seed width; ST: Seed thickness; SN: Seed number; Number of pods/ bunches; 10-pod W: Weight of 10 pods; 50-seed W: Weight of 50 seeds (g).

Biochemical properties

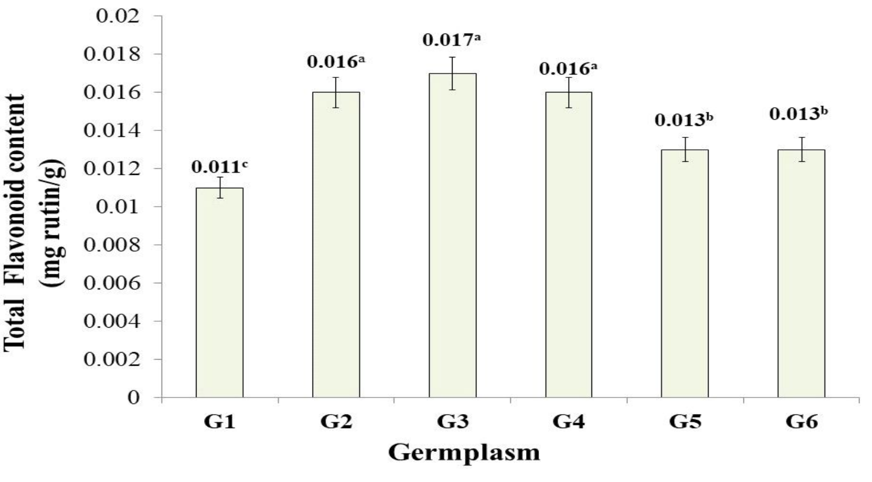
Polyphenols like flavonoids and phenolic content are antioxidant metabolites in plant extracts (Lim *et al.,* 2019). The present investigation reports on the determination of the TPC of six different bean varieties in Fig 2. The results indicate that the TPC of G1 was 0.424 mg GAE g^{-1}, while G2, G3 and G4 exhibited lower values of 0.029, 0.023 and 0.013 mg GAE g^{-1}, respectively. On the other hand, G5 and G6 displayed moderate levels of TPC, with values of 0.104 and 0.084 mg GAE g^{-1}, respectively. According to Aquino-Bolaños *et al.* (2016), common pea extract had 1.3-5.4 mg GAE g^{-1} of phenolics. Luthria and Pastor-Corrales (2006) found that all edible dried bean samples had 19.1 to 48.3 mg 100 g^{-1} of phenolics.

In recent years, plant phenol and flavonoid metabolites have received considerable interest for their usefulness in overcoming several human diseases (Ma and Chen, 2020). Legumes and pulses have been found to be rich in bioactive compounds and suitable for use in functional foods. Fig 3 shows that the TFC ranged from 0.011 to 0.017 mg RE g^{-1}. The G2, G3 and G4 varieties with an average TFC of 0.017, 0.016 mg RE g^{-1} were found to obtain the higher TFC among all the studied varieties ($P<0.05$). Shun-Cheng *et al.* (2012) reported TFC from 0.30 to 3.38 mg rutin g^{-1} pea meal of some Chinese legume cultivars. In Vietnam, Ha *et al.* (2020) also evaluated the TFC from different parts (leaves, pods and seeds) of a common bean (*Phaseolus vulgaris* L.), in which the seed extract contained flavonoid content was 9.29 mg RE g^{-1}. Among phenolics, flavonoids are the primary contributors to the antioxidant potential of pulses (Singh *et al*., 2017). Therefore, bean varieties with high phenol and flavonoid content need to be further bred and developed.



Note: Means followed by different letters are statistically significant ($p<0.05$).

Fig 2: Phenolic content of tropical, temperate and wild bean germplasm.



Note: Means followed by different letters are statistically significant ($p<0.05$).

Fig 3: Flavonoid content of tropical, temperate and wild bean varieties.

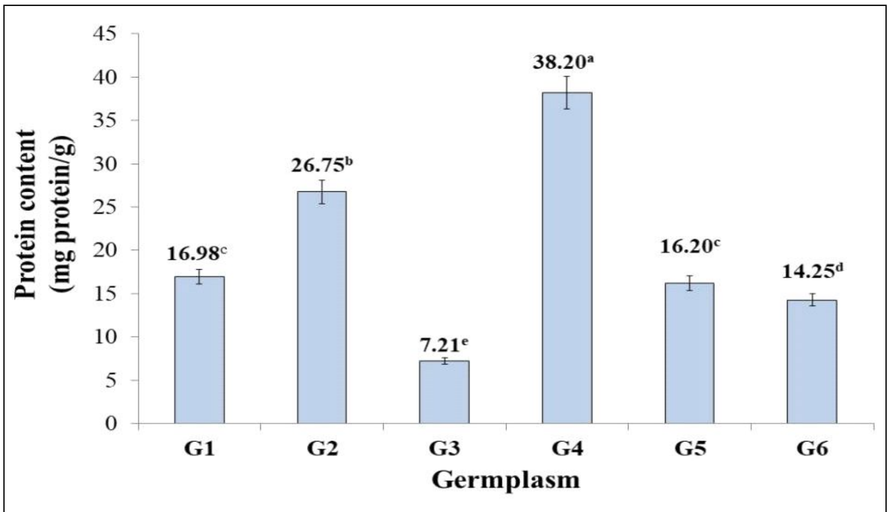
Nutritional content

Crude protein content (PC)

The results in Fig 4 showed that the PC in the extracts of the samples ranged from 7.214 to 38.203 mg g^{-1}. The PC reached the highest and lowest values in the G4 (38.203 mg g) and G3 (7.214 mg g^{-1}) varieties, respectively. Varieties of G1, G2, G5 and G6 had an average PC of 17.0, 26.7, 16.2 and 14.2 mg g^{-1}, respectively. Celmeli *et al*. (2018) found that the PC of common beans (*Phaseolus vulgaris* L.) and some modern bean varieties ranged from 16.54 to 25.23% and 19.70 to 24.30%, respectively. Tropical and temperate dry beans, including wild species, had 7.21–38.20% seed protein in this study. G4 and G2 had higher levels (38.20 and 26.75%, respectively).

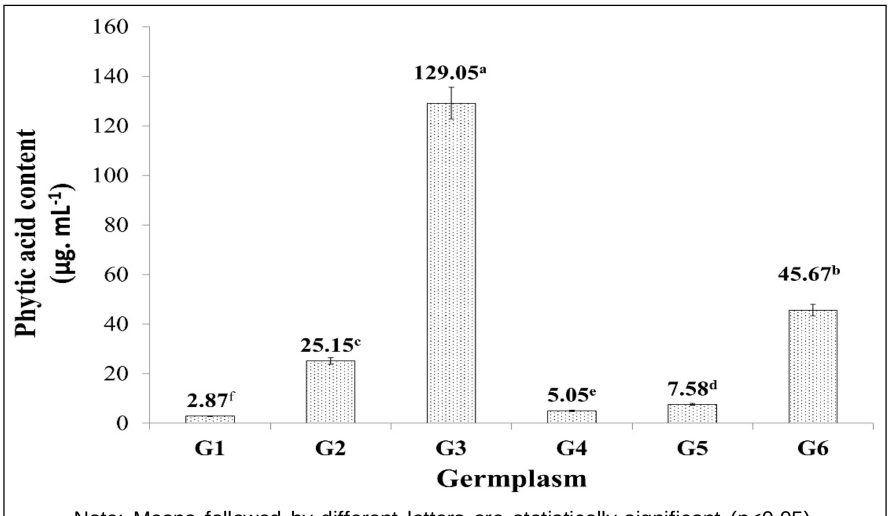
Phytic acid content (PAC)

Fig 5 showed that the PAC of tropical, temperate and wild bean varieties ranged from 2.874 to 129.050 µg mL^{-1}. Varieties G1, G4 and G5 had low PAC of 2.874, 5.050 and 7.579 µg mL^{-1}, respectively. Varieties G2 and G6, the relatively high amounts of phytic acid were 25.151 and 45.667 µg mL^{-1}, respectively. The PAC in the G3 variety reached the highest value of 129.050 µg mL^{-1}). Oomah *et al.* (2011) measured the PAC of Faba beans (*Vicia faba* L.) dragon fruit at two sites in north-central Alberta, Canada, ranging from 5.9 to 15.1 g kg^{-1}. This study found more phytic acid differences between tropical and dry temperate bean genotypes, including wild species. Tropical beans were the lowest and temperate beans were the highest. Vadivel and



Note: Means followed by different letters are statistically significant (p<0.05).

Fig 4: Protein content of tropical, temperate and wild bean varieties.



Note: Means followed by different letters are statistically significant (p<0.05).

Fig 5: Phytic acid content of tropical, temperate and wild bean varieties.

Biesalski (2012) examined bioactive compounds in velvet beans, which had 1.17 to 2.37 g 100 g^{-1} of dry seed meal phytic acid. G4 and G5 were significantly lower in dry temperate beans and wild species (5.05 and 7.58 mg g^{-1}, respectively).

CONCLUSION

This study found that most bean germplasm had physiological, agronomic and yield phenotype variation. Plant height, leaf length, leaf width, leaf number, pod length, pod width, seed length, seed width, seed thickness and seed number per pod varied among the bean germplasms. The number of pods per bunch, the weight of 10 pods and the weight of 50 seeds also varied among dry bean varieties. Compared to the other varieties, tropical variety G1 had a higher phenolic content and lower phytic acid content. G3 had the highest flavonoid content. G4's crude protein content was significantly higher than the others. These findings could help consumers choose bean varieties based on their nutritional value and lead to more research on bean nutrition. Bean breeding requires genotype-environment interactions to find genes that increase yield and combine them with those that regulate tolerance to environmental stresses and synthetic nitrogen use.

Conflict of interest: None.

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