Root traits of common bean genotypes used in breeding programs for disease resistance

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Abstract – The objective of this work was to assess root traits of 19 common bean genotypes, used in breeding programs for disease resistance. Genotypes DOR 364 and G 19833 were used as deep and shallow basal root checks, respectively. The number of whorls and basal roots were assessed on five-day old seedlings grown in germination paper. Growth pouch studies were conducted to evaluate basal root gravitropism and lateral root length from primary roots, in seven-day old seedlings. The following root gravitropic traits were estimated: basal growth angle, shallow basal root length (localized in the top 2 cm), and relative shallow basal root growth. Number of whorls varied from 1.47 to 3.07, and number of basal roots ranged from 5.67 (genotype TO) to 12.07 (cultivar Jalo MG-65). Cultivars BRS MG Talismã, Carioca, BRS Pioneiro, and Diamante Negro exhibited shallow basal roots, while genotypes Vi-10-2-1, TU, AB 136, and México 54 showed deep basal roots. Cultivar Jalo MG-65 showed more lateral roots from the primary root than the other genotypes. Genotypes used on common bean breeding programs for disease resistance have great variability on basal and primary root traits.

Index terms: *Phaseolus vulgaris*, basal roots, lateral roots, primary root, root gravitropism.

Características de raízes de genótipos de feijão usados em programas de melhoramento para resistência a doenças

Resumo – O objetivo deste trabalho foi avaliar características de raízes de 19 genótipos de feijão, usados em programas de melhoramento como fontes de resistência a doenças. Os genótipos DOR 364 e G 19833 foram usados como testemunhas de raízes basais superficiais e profundas, respectivamente. O número de verticilos e raízes basais foi avaliado em plântulas com cinco dias de idade que cresceram em papel de germinação. Foram conduzidos estudos em recipientes de crescimento para avaliar o gravitropismo de raízes basais e o comprimento das raízes laterais, na raiz principal de plântulas com sete dias. As seguintes características relacionadas ao gravitropismo das raízes foram avaliadas: ângulo de crescimento de raízes basais, comprimento de raízes basais superficiais (localizadas nos 2 cm superiores) e crescimento relativo de raízes basais superficiais. O número de verticilos variou de 1,47 a 3,07, e o número de raízes basais, de 5,67 (genótipo TO) a 12,07 (cultivar Jalo MG-65). As cultivares BRS MG Talismã, Carioca, BRS Pioneiro e Diamante Negro apresentaram raízes basais superficiais, enquanto os genótipos Vi-10-2-1, TU, AB 136 e México 54 apresentaram raízes basais profundas. A cultivar Jalo MG-65 apresentou mais raízes laterais na raiz principal do que os demais genótipos. Os genótipos usados em programas de melhoramento de feijão para resistência a doenças têm elevada variabilidade nas características das raízes basais e primárias.

Termos para indexação: *Phaseolus vulgaris*, raízes basais, raízes laterais, raiz principal, gravitropismo de raízes.

Introduction

The bean root system consists of a primary root, a variable number (generally 8 to 16) of basal roots, hypocotyls-borne roots (termed adventitious roots in earlier literature), and lateral roots developing from each of the other root classes (Basu et al., 2007; Rubio & Lynch, 2007). According to Lynch & Brown (2001), the primary root of beans has strong positive gravitropism and usually grows straight downward. Basal roots arise from the base of the hypocotyl. In conjunction with the lateral roots that emerge from them, basal roots usually comprise the majority of total root length. Basal root gravitropism is determinant of the overall shallowness of the root system, since basal roots form the scaffold on which most of the bean root system develops. Hypocotyl-borne roots arise from the hypocotyls and explore soil domains close to the soil surface.

Phosphorus availability regulates many features of root architecture, including hypocotyls-borne rooting, basal root elongation, basal root-growth angle, lateral rooting, and the density and length of root hairs (Bates & Lynch, 1996; Bonser et al., 1996; Liao et al., 2001; Ma et al., 2001; Miller et al., 2003). Besides root architecture, plant adaptation to low P availability includes symbioses with mycorrhizal fungi and exudation of P-mobilizing compounds such as protons, organic acids, and phosphatases (Marschner, 1995), but these processes are, themselves, distributed in the soil by root architecture, which reinforces the importance of this trait to plants.

Basal roots develop from 1–4 definable whorls, within three days of germination. Generally, four roots emerge in a tetrarch pattern from a given whorl (Basu et al., 2007). The diversity in root architecture of common bean is generated partly by the variation in the number of basal roots and by variation in the growth angles of basal roots (Basu et al., 2007). Plagiogravitropic growth of roots strongly affects root architecture and the layers of soil explored, which is important for the acquisition of water and nutrients (Ho et al., 2005). In common bean, drought tolerance has been associated with depth of rooting (Sanders & Markhart, 1992), while greater P acquisition has been associated with increased soil exploration by roots in surface layers (Lynch & Brown, 2001). Architectural strategies that optimize P acquisition would be beneficial for the acquisition of other immobile resources, such as the micronutrient metals, whereas traits optimizing water acquisition would be also beneficial for the acquisition of soluble mobile resources such as nitrate (Ho et al., 2004).

Root gravitropism is relatively difficult to observe and quantify under field conditions in a nondestructive manner, and is subject to environmental plasticity. A growth pouch system was developed and permits the analysis of root geometry in two dimensions, including the distribution of roots in different layers and the measurement of root growth angles (Liao et al., 2004). Basal root gravitropism can be measured by the growth angle of the root axis or by proportion of basal roots in the topsoil related to the total amount of basal roots (Liao et al., 2001). The significant correlation of root distribution in growth pouches and field studies supports the validity of the growth pouch system, for rapid screening of genotypes for root gravitropic traits (Bonser et al., 1996; Liao et al., 2001, 2004).

Diseases, drought and low soil fertility are among the most widespread and endemic production problems of cultivated beans in Brazil. As many genotypes of beans are good sources of disease resistance, bean breeders concentrate their efforts on this trait. Breeders have used genotypes like AB 136, Cornell 49-242, G 2333, Kaboon, México 54, México 309, Ouro Negro, Pi 207262, TO, TU to incorporate genes conferring disease resistance to new cultivars. However, root traits of these genotypes are unknown, and they are part of the solution for drought and low soil fertility problems.

The objective of this work was to attain information about root traits of common bean genotypes, used for disease resistance in Brazilian breeding researches.

Materials and Methods

Nineteen common bean genotypes were used. Nine of them are high-yielding cultivars or lines: Carioca, Ouro Negro, Diamante Negro, BRS Valente, BRS MG Talismã, Jalo MG-65, Carnaval MG, BRS Pioneiro, and Vi-10-2-1; ten are genotypes used for disease resistance in breeding programs: AB 136, Cornell 49-242, G 2333, Kaboon, México 54, México 309, Pi 207262, TO, TU, VC-4. Seeds of all genotypes were harvested from the same area and with the same fertilization. Genotypes DOR 364 and G 19833 were also used as checks of deep and shallow basal root, respectively. They were obtained from the International Center for Tropical Agriculture. The genotypes Jalo MG-65, Carnaval MG, G 19833, Kaboon, and México 54 belong to the Andean gene pool, while the remaining genotypes belong to the Mesoamerican gene pool.

Seeds of all genotypes were surface sterilized with 0.5% NaOCl for one minute, rinsed thoroughly with distilled water, and scarified with a razor blade. They were placed 2 cm from the top of a brown germination paper soaked in 0.5 mM $CaSO_4$, and with radical pointed downwards. The paper was then rolled into moderately tight 'cigar roll' configuration, and placed in 1 L beaker, with 100 mL of 0.5 mM $CaSO_4$. Beakers were wrapped with cellophane plastic punctured evenly with small holes to improve aeration, before being placed in a germination chamber at 28°C, in darkness. Twelve hours later, hila were removed from the seeds. Five days after germination started, the number of whorls and basal roots were counted in 15 seedlings of each genotype.

For basal root gravitropism and length of lateral roots from primary root evaluations, seedlings of the genotypes were grown in a growth pouch system. This system consisted of a 24.1x30.5 cm sheet of phosphorus-free blue germination paper, inserted into a polyethylene bag of the same size. The polyethylene bag was punctured evenly (2x2 cm) with holes to improve aeration. At the upper center of the germination paper, a V-shaped notch was made. A seedling with an emerging radical with 1–2 cm in length (produced as described previously), of each genotype, was placed in the notch with the primary root on one side, and the seed on the opposite side. The pouches were stiffened by placing perforated plexiglass sheets behind the germination paper to stabilize the pouch. Pouches were suspended in a rectangular container (60x30 cm) with 3 cm of nutrient solution, without phosphorus, at the bottom. Pouches were open at the bottom to allow direct contact of the germination paper with the nutrient solution (in μM): 3,000 KNO_3, 2,000 $Ca(NO_3)_2$, 250 $MgSO_4$, 25 KCl, 12.5 H_3BO_3, 1 $MnSO_4$, 1 $ZnSO_4$, 0.25 $CuSO_4$, 0.25 $(NH_4)_6Mo_7O_{24}$, and 25 Fe-Na-EDTA, as used by Liao et al. (2001). The nutrient solution containers with growth pouches were exposed to 400 μmol photons m^{-2} s^{-1} of photosynthetically active radiation, for 12 hours at 25°C, alternated with a 12-hour dark period at 20°C. The top of the nutrient solution containers was covered with aluminum foil to prevent illumination of the roots. The experimental design was of randomized blocks in time, with four replicates (each replicate was represented by one plant).

In the following day after transplanting, basal roots growth from back whorls (closer to the blue paper) of each seedling was sketched daily, at the same time, with a waterproof pen over the polyethylene bag, using alternating colors to distinguish day of growth. The basal roots that arose from the front whorls were not measured, because they were not affixed to the blue paper and, therefore, had variable growth angles. Thus, for genotypes with two whorls, four basal roots were considered instead of eight. Five days after transplanting, intact root systems on the germination paper and the polyethylene bag with the sketches were scanned into a computer as digital images. The daily basal root growth angle was measured using the sketches with the program Image J version 1.31. The angle, in relation to the vertical axis, was determined by making a straight line joining the edges of a daily segment of the basal roots of each plant. The program GIMP was used to measure total basal root length, basal root length in the top 2 cm, and lateral root length from primary roots, on the blue germination paper images. Percentages of basal root length in the top 2 cm, in relation to total basal root length, were calculated (modified from Liao et al., 2001).

Data related to basal root gravitropism and length of lateral roots from primary root were analyzed by analysis of variance using the software SAEG (Ribeiro Júnior, 2001), and means were compared by a cluster analysis method for grouping means using the Scott-Knott test, at 5% probability. Correlations between different variables were assessed using Pearson's correlation coefficient.

Results and Discussion

Large-seed genotypes Carnaval MG, Jalo MG-65, and G 19833 had approximately three whorls and 11.53 to 12.07 basal roots. These genotypes have distinct plant types (Table 1). Genotype Kaboon (seed weight of 0.51 g) had 2.70 whorls and 10.70 basal roots.

Table 1. Seed and plant characteristics, and average values and standard deviation (between brackets) for number of whorls and basal roots of 21 genotypes of common beans.

Genotype	Seed color(1)	Plant type(2)	Seed weight (g)	No. of whorls(3)	No. of basal roots(3)
AB 136	Red	IV	0.29	2.00 (0.00)	7.73 (0.18)
Carnaval MG	Multicolored	I	0.43	2.93 (0.46)	11.67 (0.41)
Carioca	Carioca	III	0.27	2.27 (0.46)	8.73 (0.36)
Cornell	Black	III	0.24	1.93 (0.26)	7.80 (0.20)
Diamante Negro	Black	II	0.27	2.47 (0.52)	9.33 (0.39)
DOR 364	Red	II	0.24	2.07 (0.26)	8.13 (0.21)
G 19833	Multicolored	IV	0.48	3.07 (0.46)	11.53 (0.45)
G 2333	Red	IV	0.31	2.20 (0.41)	8.67 (0.21)
Jalo MG 65	Yellow	III	0.44	3.07 (0.26)	12.07 (0.32)
Kaboon	White	I	0.51	2.70 (0.67)	10.70 (2.79)
México 54	Pink	IV	0.48	2.00 (0.00)	8.00 (0.00)
México 309	Black	III	0.28	2.13 (0.35)	8.20 (0.33)
Ouro Negro	Black	III	0.26	2.40 (0.51)	9.27 (0.37)
Pi 207262	Carioca	III	0.30	2.20 (0.41)	8.13 (0.31)
Pioneiro	Carioca	I	0.22	2.07 (0.26)	8.33 (0.16)
Talismã	Carioca	II	0.24	2.07 (0.26)	8.20 (0.22)
TO	Carioca	I	0.34	1.47 (0.52)	5.67 (0.39)
TU	Black	III	0.23	2.53 (0.52)	9.73 (0.34)
Valente	Black	II	0.22	2.47 (0.64)	9.80 (0.47)
VC-4	Yellow	III	0.22	2.00 (0.00)	8.13 (0.09)
Vi-10-2-1	Black	II	0.26	2.27 (0.46)	8.87 (0.34)

(1)Carioca, cream color of the background and the brown color of the stripes. (2)I, determinate habits; II, indeterminate bush types; III, indeterminate semiclimber; IV, indeterminate climber. (3)Average values of 15 seedlings.

Occasionally, seedling of this genotype had five roots emerged from a given whorl, due to two roots emerged from the same position. Genotype TO (seed weight of 0.34 g) had an average of 1.47 whorl and 5.67 basal roots, which means that many seedlings of this genotype had just one whorl and four basal roots. Except for the large-seed genotype México 54, the other genotypes, which had between 1.93 and 2.53 whorls, have small seeds. Correlations between seed weight and number of whorls or number of basal roots were significant ($r = 0.50$, $p<0.01$). Basal roots, in conjunction with the lateral roots that emerge from them, usually comprise the majority of total root length (Rubio et al., 2003). Thus, for better soil foraging, a greater number of basal roots is desirable.

Considering the sum of the angles at each day, genotypes G 19833 (multicolored seeds), BRS MG Talismã, Carioca, BRS Pioneiro, TO (carioca types), and Diamante Negro (black seeds) had the shallowest root system (Table 2). At the 4th day, genotype G 19833 stood out as the shallowest root system. This genotype was

Table 2. Basal root growth angle response to phosphorus deficiency of 21 genotypes of common beans(1).

Genotype	Basal root growth angle (degrees from vertical)(2)				
	Day 1	Day 2	Day 3	Day 4	Total
AB 136	62.2	38.0d	24.2d	29.0c	153.5c
Carnaval MG	67.5	46.7c	34.0c	26.2c	174.5c
Carioca	72.2	58.7a	47.7a	37.2b	216.0a
Cornell	79.2	54.7b	38.2b	27.2c	199.5b
Diamante Negro	76.7	59.7a	43.2b	36.2b	216.0a
DOR 364	66.7	42.2c	23.2d	14.7d	147.0c
G 19833	72.0	62.2a	53.7a	52.5a	240.5a
G 2333	66.7	44.5c	32.0c	25.0c	168.2c
Jalo MG 65	69.5	51.7b	38.5b	26.7c	186.5b
Kaboon	65.2	50.7b	39.7b	30.7c	186.5b
México 54	64.0	42.2c	26.7c	15.0d	148.0c
México 309	75.5	51.7b	38.2b	35.2b	200.7b
Ouro Negro	72.0	49.0b	32.0c	26.7c	179.7b
Pi 207262	69.5	51.2b	38.7b	29.7c	189.2b
Talismã	72.2	59.7a	49.0a	41.0b	222.0a
Pioneiro	68.5	60.2a	50.5a	37.2b	216.5a
TO	67.2	53.2b	44.0b	43.5b	208.0a
TU	58.5	36.2d	22.2d	15.2d	132.2d
Valente	73.7	51.2b	34.0c	25.2c	184.2b
VC-4	65.5	44.5c	31.0c	21.0c	162.0c
Vi-10-2-1	55.7	29.2d	13.2e	9.7d	108.0d
Mean	68.6	49.4	35.9	28.8	182.8
CV (%)	11.9	14.3	16.9	24.2	11.1

(1)Means with equal letters belong to the same group, according to Scott-Knott test, at 5% probability. (2)Sum of daily angles of basal roots, one day after seedlings with emerging radicles 1–2 cm length have been transferred to growth pouches; mean of four replications.

the only one with both shallow root system and three whorls. Furthermore, this genotype has abundant root hairs in both basal roots and primary root (Vieira et al., 2007). In general, genotypes Vi-10-2-1 and TU (black seeds) exhibited the deepest root system. At the 3rd day, Vi-10-2-1 had the deepest basal root growth. Genotypes AB 136, DOR 364, and México 54 were also among the ones with deep basal roots. This evaluation was made as an average of all back whorls but, according to Basu et al. (2007), the whorl closest to the shoot produces the shallowest roots, and lower whorls produce deeper roots. Correlations between basal growth angle and number of basal roots were not significant. Manschadi et al. (2008) found the same lack of correlation between growth angle and number of seminal root axes in wheat.

There was no significant effect of genotypes on basal root length (Table 3), which correlated inversely with basal root growth angle (4th day), and total basal root growth angle (Table 4). Genotypes with approximately three whorls (Carnaval MG, G 19833, and Jalo MG-65) exhibited higher basal root length at the top 2 cm (Table 3). Except for genotype TO, all genotypes with shallow basal roots, as measured by basal roots growth angle, were also among genotypes with the highest percentage of basal root length in the top 2 cm. Under low P conditions in the field, shallow-rooted genotypes have greater shoot biomass and P content than deep-rooted ones (Liao et al., 2004). The utility of root shallowness may depend on several interacting factors, in addition to P availability. For example, one disadvantage of shallow root systems could be a decreased ability for acquiring resources located deeper in the soil profile, such as water. Furthermore, since dry conditions near the soil surface are common in field, mortality of fine roots in shallow root systems could be greater than in deeper ones (Espeleta & Eissenstat, 1998). Shallow-rooted genotypes being produced with irrigation and under no-till system, however, would be more efficient for nutrient foraging at the top soil than the deep-rooted ones.

Percentage of basal root length in the top 2 cm correlated with daily and total basal root angles, even when measurements were made at the 1st day (Table 4). This might imply that, when a large number of genotypes

Table 3. Basal root length, and concentration of basal roots and primary root laterals in the top 2 or 3 cm of growth pouches(1).

Genotype	Basal root length(1) (cm)	Basal root length in the top 2 cm(2)	Basal root in the top 2 cm (%)	Lateral root length (cm) from primary roots	Lateral root length in the top 3 cm of the primary root (cm)(3)	Lateral roots in the top 3 cm (%)(4)
AB 136	1.83 (72.3)	1.34 (22.3)c	33.5b	109.2b	1.26 (17.4)c	4.07 (16.2)b
Carnaval MG	1.92 (84.1)	1.54 (35.5)a	42.0b	104.6b	1.59 (37.9)b	6.07 (36.5)a
Carioca	1.82 (66.7)	1.51 (32.4)b	49.6a	55.4c	1.32 (19.8)c	6.02 (35.7)a
Cornell	1.79 (64.8)	1.42 (26.3)c	43.8a	97.8b	1.35 (21.7)c	4.77 (22.4)b
Diamante Negro	1.82 (71.3)	1.51 (32.4)b	50.1a	56.3c	1.24 (17.3)c	5.68 (32.4)a
DOR 364	1.78 (63.0)	1.34 (22.1)c	38.4b	35.5c	1.32 (19.9)c	7.83 (62.5)a
G 19833	1.81 (65.7)	1.60 (40.0)a	61.0a	111.0b	1.48 (29.8)b	5.23 (27.1)b
G 2333	1.72 (54.4)	1.32 (21.2)c	41.3b	78.6c	1.50 (32.9)b	6.41 (42.2)a
Jalo MG 65	1.98 (96.3)	1.64 (43.6)a	45.6a	154.0a	1.82 (64.8)a	6.54 (42.3)a
Kaboon	1.71 (53.5)	1.44 (28.2)b	54.0a	51.7c	1.40 (24.7)c	7.32 (56.6)a
México 54	1.92 (83.6)	1.42 (26.2)c	31.6b	102.0b	1.40 (24.3)c	4.99 (24.7)b
México 309	1.74 (57.5)	1.39 (24.6)c	44.9a	69.2c	1.38 (22.9)c	5.79 (33.1)a
Ouro Negro	1.84 (71.1)	1.48 (30.9)b	43.6a	80.3c	1.06 (11.0)d	3.73 (13.5)b
Pi 207262	1.82 (68.6)	1.41 (26.4)c	41.6b	51.1c	1.15 (15.2)d	5.30 (29.0)b
Talismã	1.77 (60.7)	1.48 (31.0)b	51.1a	102.7b	1.53 (32.8)b	5.83 (33.9)a
Pioneiro	1.80 (64.8)	1.46 (29.2)b	46.1a	69.1c	1.21 (15.6)d	4.90 (23.9)b
TO	1.64 (44.3)	1.21 (16.8)c	37.6b	25.9c	1.04 (10.1)d	6.44 (42.3)a
TU	1.86 (73.8)	1.44 (28.5)b	38.7b	72.5c	1.25 (16.9)c	5.42 (31.8)b
Valente	1.78 (61.9)	1.46 (29.4)b	48.3a	58.9c	1.37 (22.5)c	6.24 (38.6)a
VC-4	1.85 (71.8)	1.36 (23.3)c	33.1b	61.6c	1.32 (21.0)c	6.15 (40.6)a
Vi-10-2-1	1.89 (79.1)	1.38 (24.4)c	31.3b	91.0b	1.36 (22.2)c	5.02 (24.7)b
Mean	1.81 (68.1)	1.44 (28.3)	43.2	78.0	1.35 (12.4)	5.70 (33.8)
CV (%)	5.5	6.1	17.5	25.0	7.3	18.7

(1)Means followed by equal letters belong to the same group, according to Scott-Knott test, at 5% probability. (2)Measured four days after transferred to growth pouches; before analysis of variance, means were transformed by logarithm (number in parentheses refers to original data). (3)Measured four days after transferred to growth pouches; before analysis of variance, means were transformed by logarithmic (x + 1) (number in parentheses refers to original data). (4)Measured four days after transferred to growth pouches; before analysis of variance, means were transformed by $(x + 0.5)^{0.5}$ (number in parentheses refers to original data).

Table 4. Correlation coefficients (r) between daily basal root growth angles and basal root length.

Daily basal root growth angle	Basal root length	Basal root length in the top 2 cm	Basal root length in the top 2 cm (%)
Day 1	-0.24	0.31	0.61**
Day 2	-0.31	0.44*	0.80**
Day 3	-0.35	0.42*	0.79**
Day 4	-0.45*	0.29	0.73**
Total(1)	-0.38*	0.39*	0.80**

(1)Sum of the daily angles. * and **Significant at 0.05 and 0.01 probability levels, respectively.

are tested, basal root angle could be evaluated earlier, after seedlings are transplanted to the growth pouches. Again, Vi-10-2-1, TU, AB 136, DOR 364, and México 54 were among the genotypes with the deepest basal roots. Oyanagi (1994) reported that Japanese winter wheat cultivars, adapted to drier environments, possess a narrow seminal root angle and consequently a deeper root system, whereas genotypes developed for wetter environments express a more horizontal seminal root growth and superficial root system.

Basal roots of genotype G 2333 were relatively deep (Tables 2 and 3), a trait more favorable for water acquisition than for P acquisition. This genotype, however, has a trait favorable for P acquisition: abundant root hairs (Vieira et al., 2007). According to Yan et al. (2004), total acid exudation was positively correlated with basal root-hair density and length. Its vigorous root system (Yan et al., 1995) is also an advantage for both water and P acquisition.

Genotype Jalo MG-65 presented the greatest lateral roots length (154 cm) from the primary root and, also, the greatest lateral root length in the top 3 cm of the primary root (64.8 cm) (Table 3). AB 136, Carnaval MG, Cornell 49-242, G 19833, México 54, BRS MG Talismã, and BRS Pioneiro followed Jalo MG-65, as genotypes with larger amounts of lateral roots from the primary root, but just Carnaval MG and BRS MG Talismã had high concentrations of lateral roots in the top 3 cm. The utility of genotypic variation in this trait is not clear. Large number of primary lateral roots, especially in the topsoil, could improve early-season P acquisition. However, according to Lynch & Brown (2001), in soils with low nutrient availability, it would be advantageous for main roots to grow with few lateral roots, so that greater volumes of soil could be explored at low metabolic cost, until resources can be found.

In the present work, it was adopted the method of growth pouch system to investigate genotypic variation in basal root gravitropism and length of primary root laterals, among a set of common bean genotypes. This technique allowed for simple, rapid, and cost-effective screening of basal root traits and, therefore, appears to be suited for large-scale screening of seedling root characteristics in common bean improvement programs.

Conclusions

1. Genotypes used in breeding programs for disease resistance have great variability in number of basal roots, basal root growth angle, and length of lateral roots from primary root.
2. High-yielding cultivars have, in general, shallower basal roots than the genotypes used in breeding programs as a source of disease resistance.

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