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PAULO HENRIQUE CERUTTI

INTEGRATION OF ROOT PHENOTYPING METHODS AND PHENOLOGICAL STAGES IN COMMON BEAN BREEDING FOR SELECTION OF SUPERIOR GENOTYPES

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Thesis presented as a partial requirement to obtain the title of Doctor in Plant Production by the Postgraduate Program in Plant Production, under the line of research in Genetic Improvement and Resources, at the Centro de Ciências Agroveterinárias – CAV, at the Universidade do Estado de Santa Catarina.

Advisor: Prof. Dr. Jefferson Luís Meirelles

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Lages, 16th of february 2024

To students of agricultural sciences, especially those involved in the fantastic area of plant breeding.

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A ship in port is safer, but that’s not what ships were made for.”

John A. Shedd.

RESUMO

A cultura do feijão se destaca no cenário de produção agrícola. Isso porque os grãos dessa leguminosa são uma das fontes de proteínas mais acessíveis a população. Com base nisso, programas de melhoramento genético tem desenvolvido genótipos com elevada produtividade (acima de 4000 kg ha^{-1}), e com caracteres adaptativos. Dentre os caracteres adaptativos, se destaca o aprimoramento do sistema radicular. Desse modo, esta tese está dividida em quatro capítulos, que contemplam experimentos executados com a cultura do feijão, visando aprimorar a seleção de genótipos promissores para o sistema radicular. Os capítulos um, dois e três apresentam a integração de métodos de fenotipagem de raízes ("Shovelomics e WinRHIZO"), e estádios de desenvolvimento (V_{4-4}; V_{4-8}; R_5; R_6; R_7 e R_8) na avaliação do sistema radicular de populações fixas e segregantes de feijão. Já o capítulo quatro, relata a associação entre caracteres da parte aérea com os radiculares, no intuito de favorecer a seleção indireta de duas ou mais características nas etapas de condução e seleção de populações segregantes de feijão. Os resultados dos três primeiros capítulos salientaram que métodos específicos de fenotipagem foram indicados para melhoria da avaliação radicular de acordo com o grupo gênico dos genótipos (Mesoamericanos e Andinos). O método Shovelomics foi útil para fenotipar genótipos Andinos, pela sua particularidade de medida (manualmente e de forma superficial no solo). Já o método WinRHIZO, foi recomendado para fenotipagem de genótipos Mesoamericanos, pois estes apresentam um sistema radicular mais ramificado e profundo, comparativamente ao Andino. Dessa forma, medições automatizadas obtidas pelo método WinRHIZO facilitaram a medição radicular destes genótipos. Além disso, foram diagnosticadas associações significativas entre caracteres do sistema radicular e de parte aérea, com destaque para as características: teor de clorofila b *versus* comprimento horizontal esquerdo de raízes (τ = -0,22) e teor de clorofila a *versus* comprimento total de raízes (τ = 0,24). O desdobramento desses valores em efeitos diretos e indiretos pela análise de trilha indicaram a elevada contribuição dos teores de clorofila sobre o desenvolvimento radicular. Este resultado facilita a seleção indireta, com melhorias simultâneas entre caracteres radiculares e de parte aérea, já que avaliações de caracteres acima do solo são fáceis de serem executadas.

Palavras-chave: *Phaseolus vulgaris* L; Avaliação radicular; Shovelomics; WinRHIZO, Análise de trilha.

ABSTRACT

Common bean cultivation stands out in the agricultural production scenario. This is because the grains of this legume are one of the most accessible sources of protein for the population. Based on this, genetic improvement programs have developed genotypes with high productivity (above 4000 kg ha^{-1}), and with adaptive characters. Among the adaptive characters, the improvement of the root system stands out. Therefore, this thesis is divided into four chapters, which include experiments carried out with common bean crop, aiming to improve the selection of promising genotypes for root system. Chapters one, two and three present the integration of root phenotyping methods ("Shovelomics and WinRHIZO"), and phenological stages (V_{4-4}; V_{4-8}; R_5; R_6; R_7 and R_8) in the evaluation root system in fixed and segregating common bean populations. Chapter four reports the association between aerial and root characters, with the aim of favoring the indirect selection of two or more characteristics in the stages of conduction and selection of segregating populations. The results of the first two chapters highlighted that specific phenotyping methods were indicated to improve root evaluation according to the genotype gene group (Mesoamerican and Andean). The Shovelomics method was useful for phenotyping Andean genotypes, due the particularity of measurement (manually and superficially in the soil). The WinRHIZO method was recommended for phenotyping Mesoamerican genotypes, as they have a more branched and deeper root system, compared to Andean. Thus, automated measurements obtained by the WinRHIZO method facilitated the root measurement of these genotypes. Furthermore, significant associations were diagnosed among characters of the root system and shoots, with emphasis on the characteristics: chlorophyll b content versus root left horizontal length (τ = -0.22) and chlorophyll a content versus total root length (τ = 0.24). The breakdown of these values into direct and indirect effects by path analysis indicated the high contribution of chlorophyll levels to root development. This result facilitates indirect selection, with simultaneous improvements between root and shoot traits, since evaluations of above-ground traits are easy to perform.

Keywords: *Phaseolus vulgaris* L; Root Evaluation; Shovelomics; WinRHIZO, Path Analysis.

ILLUSTRATIONS LIST

Figure 1 - Dispersion of standardized canonical scores for the first two canonical discriminant functions (FDC) estimated for the phenotyping methods Shovelomics and WinRHIZO.....31
Figure 2 - Dispersion of standardized canonical scores for the first canonical discriminant function (CDF), estimated for the interactions between: a) genotype, and phenological stages and b) phenotyping method and developmental stage in common bean.....44
Figure 3 - Representation of weather data: maximum, minimum, mean temperature (T max, T min, T mean, ºC), cumulative rainfall (Rain, mm) and indication of time when evaluations were carried out, according to each phenological stage.....45
Figure 4 - Dispersion of standardized canonical scores for the two canonical discriminant functions (CDF), estimated for the factors phenological growth stages, genotypes and phenotyping methods (M1= Shovelomics, M2= WinRHIZO) in common bean.....49
Figure 5 - Dispersion of standardized canonical scores for the first canonical discriminant function (CDF), estimated for genotype * stage interaction, for each phenotyping method (Shovelomics, WinRHIZO).....68
Figure 6 - Estimates of kendall's correlation coefficients (τ) among 13 response variables for each of the root phenotyping methods.....85

TABLES LIST

Table 1 - Six common bean (Phaseolus vulgaris) genotypes (G1–G6) used to evaluate root phenotyping methods and the ideal phenological stages to quantify the root system 23
Table 2 - Joint multivariate analysis of variance using Wilks' lambda test (λ) of the factors replicate, replicate within blocks, genotype, phenotyping method, phenological stage, and cultivation sites of common bean (Phaseolus vulgaris) 27
Table 3 - Multivariate contrasts based on Wilks' lambda (λ) test for the factors phenotyping method and phenological stage of common bean (Phaseolus vulgaris) in the cultivation sites of Concórdia (L1) and Lages (L2), in the state of Santa Catarina 29
Table 4 - Multivariate analysis of variance based on Wilks' Lambda test (λ), for the effects of the experimental factors replication, blocks within replications, genotype, phenotyping methods (Shovelomics and WinRHIZO) and phenological stages 42
Table 5 - Multiariate contrasts based on the Wilks' Lambda test (λ), considering all response variables, for the simple effects of the experimental factors phenotyping methods and genotype for each of the phenological stages in the common bean 47
Table 6 - Descriptive analysis for basal root angle (RA, °); vertical root length (VL, cm); horizontal root length/ left side (LL, cm) and horizontal root length/ right side (RL, cm) evaluated by Shovelomics phenotyping method 64
Table 7 - Descriptive analysis of total root length (TL, cm), projected root area (PA, cm^2), root volume (RV, cm^3) and mean root diameter (RD, mm), evaluated by the WinRHIZO phenotyping method 65
Table 8 - Multivariate analysis of variance based on Wilks' Lambda test (λ) for the effects of the experimental factors for each phenotyping method, considering the response variables of each method 66
Table 9 - Multivariate contrasts based on the Wilks' Lambda test (λ) for the simple effects of genotype * stage interaction for Shovelomics phenotyping method 69
Table 10 - Multivariate contrasts based on the Wilks' Lambda test (λ) for the simple effects of genotype * stage interaction for WinRHIZO phenotyping method 70
Table 11 - Broad-sense heritability coefficients (h^2b) for the response variables obtained by the phenotyping methods (Shovelomics and WinRHIZO) 72
Table 12 - Descriptive statistics of mean, deviation (Sd) and mean standard error, for the 13 traits considering the Shovelomics phenotyping method 83

Table 13 - Statistics of mean, deviation and mean standard error, for the 13 response traits considering the WinRHIZO phenotyping method.....84
Table 14 - Estimates of direct and indirect effects considering the left and right horizontal length traits as the main ones, for the Shovelomics phenotyping method 89
Table 15 - Estimates of direct and indirect effects considering the main variables total length and mean diameter of roots, for the WinRHIZO phenotyping method.....90

SUMARY

1 INTRODUCTION 17

REFERENCES 19

2 PHENOTYPING METHODS AND PHENOLOGICAL STAGES TO QUANTIFY THE ROOT SYSTEM OF COMMON BEAN 21

2.1 INTRODUCTION 21

2.2 MATERIAL AND METHODS 22

2.3 RESULTS AND DISCUSSION 25

2.4 CONSLUSIONS 32

2.5 REFERENCES 32

3 IMPROVEMENT OF COMMON BEAN ROOT SYSTEM PHENOTYPING FOR IDENTIFICATION OF SUPERIOR GENOTYPES 37

3.1 INTRODUCTION 37

3.2 MATERIAL AND METHODS 38

3.3 RESULTS AND DISCUSSION 41

3.4 CONCLUSIONS 50

3.5 REFERENCES 51

4 WHICH ROOT PHENOTYPING METHOD IS BEST? THAT DEPENDS ON THE PHENOLOGICAL STAGE 59

4.1 INTRODUCTION 59

4.2 MATERIAL AND METHODS 60

4.3 RESULTS AND DISCUSSION 62

4.4 CONCLUSIONS 73

4.5 REFERENCES 73

5 LINEAR RELATIONSHIPS BETWEEN ROOT AND ABOVE-GROUND TRAITS IN COMMON BEAN SEGREGANT GENERATIONS 79

5.1 INTRODUCTION 79

5.2 MATERIAL AND METHODS 80
5.3 RESULTS AND DISCUSSION 82
5.4 CONCLUSIONS 92
5.5 REFERENCES 92
6 FINAL CONSIDERATIONS 97

1 INTRODUCTION

Common bean (*Phaseolus vulgaris* L.) is one of the main foods that make up the diet of population of South America and the African continent. The main reason associated with the consumption of this legume is associated with the quality and quantity of protein present in its grains. (Souter *et al*., 2017). At a national level, according to information provided by the Companhia Nacional de Abastecimento (CONAB), the area currently cultivated with common bean in Brazil is 2.775,900 hectares, with grain productivity of 1091 kg ha-1 in the 2023/24 harvest (Conab, 2024).

Among the various areas of research aimed at improving the productivity of common bean grains, plant breeding, associated with the areas of genetics, biochemistry, plant physiology and crop plants, were the main responsible for the increase in production over the years. In particular, plant breeding has sought, through art and science, the development of bean genotypes with agronomic characteristics superior to those already cultivated today.

However, even with the development and use of genetically improved cultivars, in many cultivation situations the maximum productive potential of the common bean crop is not reached. This is because the expression of a certain characteristic is due to the genetic effect, added to the environmental effect (Allard, 1971; Fritshe-Neto; Borém, 2013). The cultivation environment can in some situations inhibit the maximum expression of the genetic effect (Fageria *et al*, 2005). The lack or excess of some environmental resource can develop a stress condition (scarcity or abundance of water, low availability of nutrients or inadequate temperatures).

One of the ways to mitigate environmental stress is the development of common bean genotypes with an improved root system, capable of capturing soil resources (water and mineral elements) in limiting cultivation conditions. Common bean plants with an improved root system (greater root length and volume) enhance water acquisition in environments with water stress. This minimizes the negative effects that a lack of water can cause at some critical moments in the crop, such as flowering (Polania *et al*., 2016).

Despite the vast importance of the root system, there are still gaps to be filled in literature, such as, which phenotyping method is the best to quantify populations in common bean breeding? And at what phenological moment in the culture is this phenotyping effective?

Therefore, this work aims to study the expression of the root system in common bean genotypes, seeking to integrate root phenotyping methods and phenological development

stages, to improve the evaluation of roots in the stages of conduction and selection of agronomically superior genotypes.

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6 FINAL CONSIDERATIONS

The genetic improvement of bean crops focused on root traits is essential for the development of plants with potential tolerance to stress caused by the environment.

By carrying out work focused on root phenotyping, the high effect of environment on root expression was observed, that is, root characters show plasticity to environmental conditions. This fact must be considered when selecting superior plants, seeking to eliminate non-genetic effects that hinder selection.

The improvement of root evaluation in common bean crop, considering fixed and segregating genotypes, was obtained through the integration between specific development stages with the evaluated root phenotyping methods. This integration helps breeders choose the best bean genotypes considering root variables.

The association between root and shoot traits stands out as a useful tool for the facilitated selection of genotypes simultaneously improved for root system and above-ground traits.