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Drought impact on rainfed common bean production areas in Brazil

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ABSTRACT

Common bean production in Goiás, Brazil is concentrated in the same geographic area, but spread across three distinct growing seasons, namely, wet, dry and winter. In the wet and dry seasons, common beans are grown under rainfed conditions, whereas the winter sowing is fully irrigated. The conventional breeding program performs all varietal selection stages solely in the winter season, with rainfed environments being incorporated in the breeding scheme only through the multi environment trials (METs) where basically only yield is recorded. As yield is the result of many interacting processes, it is challenging to determine the events (abiotic or biotic) associated with yield reduction in the rainfed environments (wet and dry seasons). To improve our understanding of rainfed dry bean production so as to produce information that can assist breeders in their efforts to develop stress-tolerant, high-yielding germplasm, we characterized environments by integrating weather, soil, crop and management factors using crop simulation models. Crop simulations based on two commonly grown cultivars (Pérola and BRS Radiante) and statistical analyses of simulated yield suggest that both rainfed seasons, wet and dry, can be divided in two groups of environments: highly favorable environment and favorable environment. For the wet and dry seasons, the highly favorable environment represents 44% and 58% of production area, respectively. Across all rainfed environment groups, terminal and/or reproductive drought stress occurs in roughly one fourth of the seasons (23.9% for Pérola and 24.7% for Radiante), with drought being most limiting in the favorable environment group in the dry TPE. Based on our results, we argue that even though drought-tailoring might not be warranted, the common bean breeding program should adapt their selection practices to the range of stresses occurring in the rainfed TPEs to select genotypes more suitable for these environments.

1. Introduction

Beans are considered the most important grain legume for direct human consumption worldwide, with a global production of ca. 23000 t (FAOSTAT, 2015). Among bean species, those of the genus *Phaseolus* are the most widely grown, occupying more than 85% of bean production area globally (Singh, 2001). *Phaseolus vulgaris* L., hereafter referred to as common bean, accounts for 80% of the bean species consumed (Wander, 2007). Common bean is cultivated in a wide range of production systems, representing different climates, soils, cultivars and levels of technology.

Brazil is the largest world edible bean producer and consumer (~2.5 million ton in 2013—IBGE, 2015; Thung and Rao, 1999; FAOSTAT, 2015). Beans constitute a primary source of protein in the diet of the Brazilian population (per capita consumption estimated at 17.8 kg year^{-1}) (Embrapa Arroz e Feijão, 2015). Rainfed systems represent 93% (2.8 million ha) of common bean Brazilian production area (IBGE, 2015). In the state of Goiás, one of the main bean-producing states in Brazil and the focus of this paper, crop production is concentrated in the same geographic area, but spread across three distinct growing seasons, namely wet (sowing

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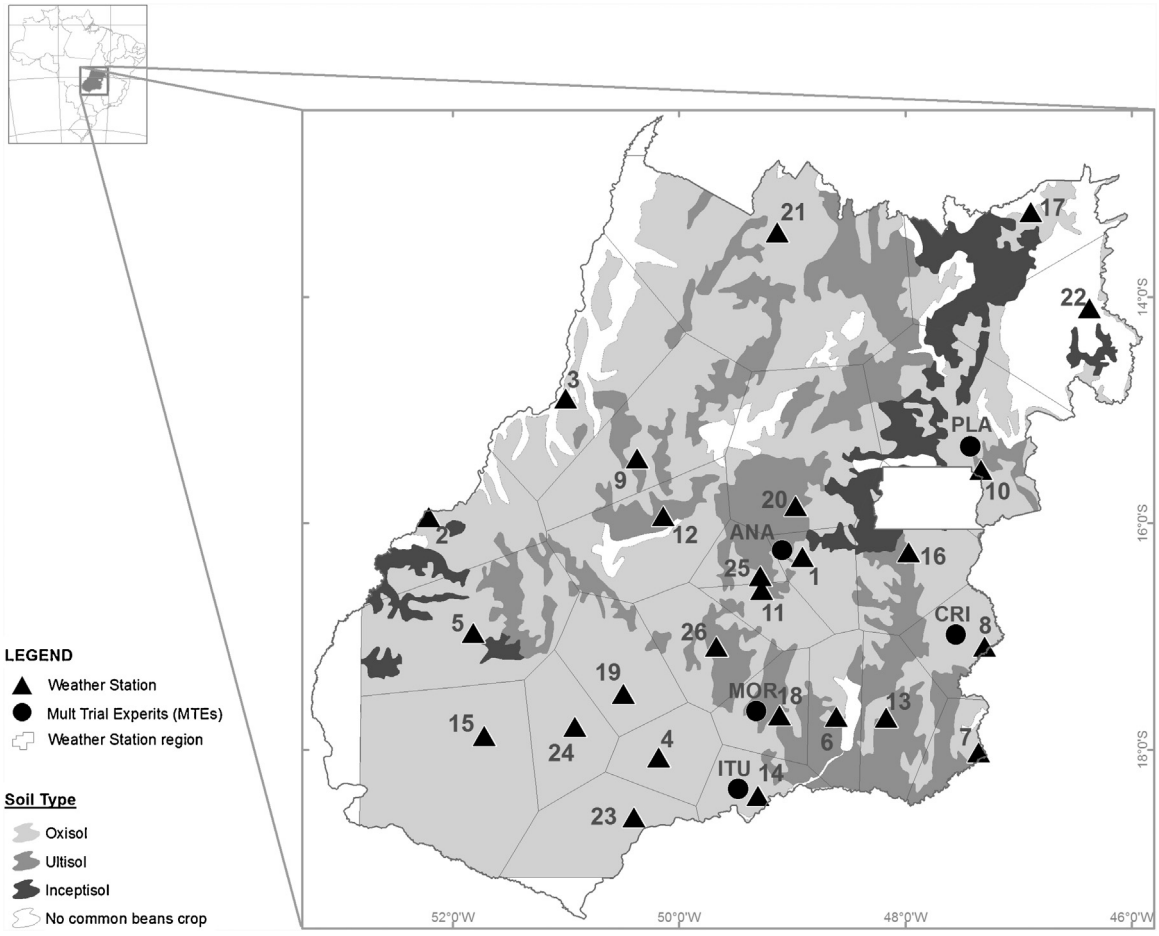

Fig. 1. Common beans target population of environments(TPE) in the Goiás State, the geographic distribution of weather station locations (full triangles), multi- experiments trials (METs) (ANA – Anápolis; CRI – Cristalina; ITU – Itumbiara; MOR – Morrinhos; PLA – Planaltina and RVE – Rio Verde) described in Table 1 (full circles), weather station locations (full triangles) and their coverage area (polygons). Grey shading indicates soil types (Oxisol; Ultisol and Inceptisol). Numbers represent weather station identifiers described in Supplementary Table S1. Zoom window shows the Goiás TPE localization in Brazil.

from 1 Nov to 31 Dec), dry (sowing from 01 Jan to 28 Feb) and winter (sowing from 1 May to 30 Jun). In the wet and dry seasons, common beans are grown under rainfed conditions, whereas the winter sowing is fully irrigated. Due to environmental variability, the performance of cultivars varies substantially across seasons, with average yield being 1700, 1500 and 2700 kg ha^{-1} for the wet, dry and winter seasons, respectively (IBGE, 2015). The differences in yield between the winter and the two rainfed (wet and dry) seasons imply the occurrence of stresses that limit crop productivity (Beebe et al., 2011).

Common bean crops grown in the rainfed seasons (wet and dry) suffer from both abiotic and biotic production constraints. The most widespread abiotic constraints are low soil fertility, drought (Beebe et al., 2011; Müller et al., 2014; Singh, 2001) and nitrogen deficiency due to poor nitrogen fixation (Rao, 2001). Additionally, several bacterial, fungal, and viral diseases reduce bean production (Barcelos et al., 2014; Beebe et al., 2011; Melo et al., 2012; Singh and Schwartz, 2010; Souza et al., 2013—see Supplementary Table 1). In fact, currently, a major limitation for growing bean in the dry season is an increase in the prevalence of whitefly (*Bemisia tabaci*), vector of the bean gold mosaic virus (BGMV), due to mainly soybean harvest (whiteflies are forced to migrate to other crops such as common bean). The development of stress resistant cultivars has typically been a successful strategy to counter the yield impacts of both biotic and abiotic stresses (Araujo et al., 2015).

Generally, conventional common bean breeding programs focus largely on developing germplasm for local needs as the most appropriate strategy for developing adapted cultivars for a range of environments (Kelly and Cichy, 2013). Conversely, the Brazilian common bean breeding program led by Embrapa's Rice and Beans unit focuses on broad adaptation for all Brazilian bean production regions. The early generation screening yield trials (nursery) in the Goiás State are performed only in the winter season under well-watered conditions (i.e. fully irrigated) and target mainly direct selection for grain yield (Melo, 2009). This means that, as in other Brazilian breeding programs (e.g. upland rice, Heinemann et al., 2015), common bean genotype selection under the winter irrigated scheme may increase the risk of developing genotypes specialized for highly favorable environments and which lack plasticity and hence perform poorly under stress. Due to the range of stresses and their interactions in the rainfed seasons, it is currently unclear to breeders what the major constraints that affect the crop are and how those constraints vary spatiotemporally. As most bean production occurs under low input agriculture on small-scale farms, knowledge of the major constraints that affect the crop in rainfed seasons is critical for developing technologies and knowledge for yield improvement (De Luque and Creamer, 2014).

In this study, we applied a characterization of environments that integrates weather, soil, crop and management factors using a crop simulation model, with the aim of producing information that can assist breeding strategies in their efforts to develop stress-tolerant high-yielding germplasm for the rainfed seasons (Chapman 2008; Chauhan et al., 2013; Chenu, 2014; Heinemann et al., 2015; Löffler et al., 2005). Our specific objectives were to (a) develop a charac-