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A meta-analysis of bioenergy conversion relevant traits in sorghum landraces, lines and hybrids in the Mediterranean region

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ABSTRACT

Sorghum crop demonstrated high yield potential under drought and wet environments with a better energy balance than several cultivated plants. Sorghum biomass can contribute to solving the pressing issue of reducing reliance on fossil fuel. Africa and Asia are sorghum centers of diversity, and landraces therefrom can be of great breeding and production interests in the Mediterranean region. Several works evaluated biomass sorghums, but results on comparative performance between lines, landraces and hybrids are lacking. The objective of this work was to assess the performance of these genotypic groups for traits relevant for biofuel conversions, by carrying out a meta-analysis of data from twenty-four trials conducted in different Mediterranean locations in Italy over seven years. Obtained results showed sorghum hybrids as the best biofuel feedstock option as they outperformed landraces and lines for most traits including biomass yield. Landraces represented an attractive alternative to hybrids and lines as they outyielded lines and were second only to hybrids in terms of biomass production and cellulosic content. Biomass yield advantage was explained by increased plant tallness and cellulosic content in hybrids, and cellulosic content in landraces, and to a lesser extent, by plant maturity in hybrids and landraces. Based on biomass quality and quantity, hybrids and landraces can supply thermal, thermochemical and biochemical biofuel conversion industries. Sorghum lines could be better used in first generation biofuel and energy bioconversion technologies requiring lower lignin containing feedstocks. Landraces and lines could be targeted to areas where hybrid seed production industry is not developed.

1. Introduction

Producing biofuel from plant biomass is an attractive alternative to fossil sources, not only because the latter are non-renewable and environmentally harmful, but also because of the pressing issue for nations to get independent of foreign energy sources. Several countries worldwide have initiated programs to convert biomasses into biofuels and, in European countries, dedicated biomass crops are being increasingly developed (Stefaniak et al., 2012; El Bassam, 2010). Biofuel-dedicated biomass cultivars will have to meet critical requirements of high and cost-effective productivity, and the ability to economically convert into bio-based commodities. Biomass sorghum [*Sorghum bicolor* (L.) Moench] meets these requirements as far as the Mediterranean region is concerned. It demonstrated high aboveground dry mass production potential and has one of the highest rates of dry matter accumulation per day and unit surface among cultivated plants (Habyarimana et al., 2004a; Amaducci et al., 2000) with a better energy balance than several crops such as maize and sugarcane (Loomis and Williams, 1963). Sorghum aboveground dry mass yields as high as 33–51 and 20–29 t ha^{-1} were obtained by Heichel (1976) and Habyarimana et al. (2004a) in irrigated and rain-fed experiments, respectively, and similar results were reported elsewhere (Garofalo and Rinaldi, 2013).

Historically, sorghum was mostly known as a grain and forage crop (Hoffmann et al., 2013). Grain sorghums are generally shorter (usually having recessive alleles at three of the four *Dw* genes) than biomass sorghums (having recessive alleles at two *Dw* genes at most), and have been selected to have the grain as the primary

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sink for photosynthates. Biomass sorghum of biofuel production interest includes high tonnage sorghum and sweet sorghum (Damasceno et al., 2014; Hoffmann et al., 2013; Prakasham et al., 2014). The latter translocates photosynthates to seeds and stem, their stems are juicy (*d* recessive to *D*) instead of dry, and sweet (*x* recessive to *X*) instead of nonsweet (Rooney, 2000). Sweet sorghums are high biomass and sugar yielding crops and were traditionally bred for syrup or molasses production. High tonnage sorghums include high biomass yielding genotypes that are being developed for feedstock production. Sorghum can therefore supply several products including starch, soluble sugars, structural carbohydrates, and organic matter for energy production purposes. For instance, ethanol can be produced directly from starch and non-structural carbohydrates (first generation biofuel), or from fermentable sugars derived from structural carbohydrates using the second generation biofuel technologies (ICRISAT, 1982; Gomez et al., 2011; Li et al., 2014). Biofuel can also be produced through pyrolysis, gasification, and anaerobic digestion of complex particulate organic material into biogas (Gujer and Zehnder, 1983; El Bassam, 2010). Clearly, biomass sorghum can be an alternative to sugarcane under the tropics, and to sugar beet and corn in the temperate regions. It represents a good alternative to perennial crops as it can provide similar dry matter yields, while offering the advantage of an annual crop, i.e., the flexibility for making changes in the actual crop rotation systems without incurring higher costs like in the case of Arundo donax (Amaducci and Perego, 2015).

Sorghum materials of production interest can be grouped into landraces, lines, and hybrids (Doggett, 1988; House, 1985; Rattunde et al., 2013). These groups have distinct genetic structures which can be harnessed differently. Landraces are heterogeneous and heterozygous in nature, which makes them resilient to adverse conditions and allows them a high production stability (Habyarimana et al., 2004b; Haussmann et al.,1998). Landraces are a rich source of resistance to diseases, insect pests and other stresses such as high temperature and drought. They are also sources of traits to improve food and fodder quality, animal feed and industrial products. Sorghum landraces represent an important reservoir of genetic variability available in Africa where domestication first occurred, and in Asia where further diversity occurred due to the early introduction of the crop (Doggett, 1988). Lines on the other hand, are inbreds developed to fixation particularly for desirable traits, whereas hybrids are developed through controlled crosses, can express heterosis and developmental homeostasis, resulting in superior phenotypic performance (Hoffmann et al., 2013).

In most studies, sorghum genotypes were evaluated with the aim of identifying superior individuals (e.g., Habyarimana et al., 2004a,b, 2002; Lorenzoni et al., 2005) without a statistical discrimination between different genotypic groups i.e., landraces, lines, and hybrids. For instance, Amaducci et al. (2004) and Lorenzoni et al. (2005) evaluated sorghum hybrids and lines, Habyarimana et al. (2004a) evaluated hybrids, while Habyarimana et al. (2004b) evaluated sorghum lines, hybrids, and tropical landraces for biomass production, but neither the experimental design layouts, nor the analyses performed allowed for between-category comparisons.

The aim of this study was therefore to compare the performance of biomass sorghum landraces, lines, and hybrids, combining the results obtained from twenty-four different sorghum trials conducted over seven years (1994, 1998, 2001–2004, 2014) at the Università Cattolica del Sacro Cuore in Piacenza and the Research Center for Industrial Crops (CREA-CIN), in Italy. A meta-analysis was used in order to identify patterns useful for biomass sorghum breeding for biofuel production purpose. Meta-analysis is a quantitative statistical approach using the effect size as a numerical index to describe empirical results produced by several studies and combine the estimates into a summary. This approach was described and successfully implemented in previous studies (Faraone, 2009; 2008; Feng et al., 2013; Hedges et al., 1999; Rusinamhodzi et al., 2011; Witjaksono et al., 2013; van Groenigen et al., 2010; van Kessel et al., 2013).

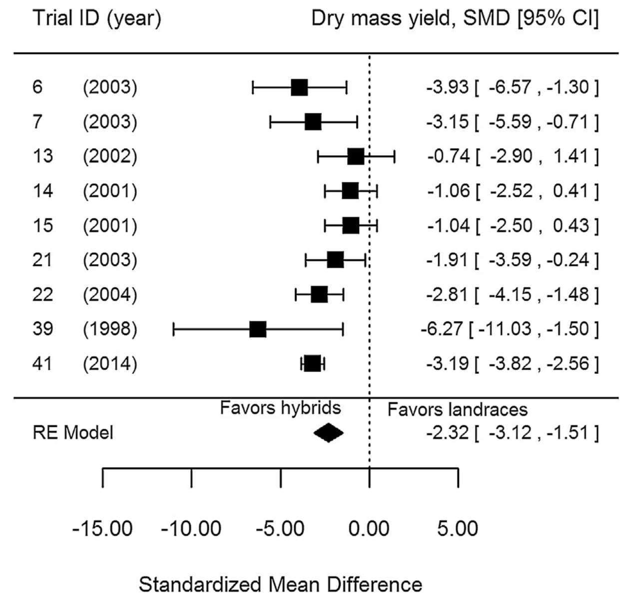

Fig. 1. Landraces vs. hybrids effect size for aboveground biomass production. ID, SMD, CI, RE, respectively, identification number, standardized mean difference, confidence interval, random effects. Refer to text (Section 3) for the description of the plot.

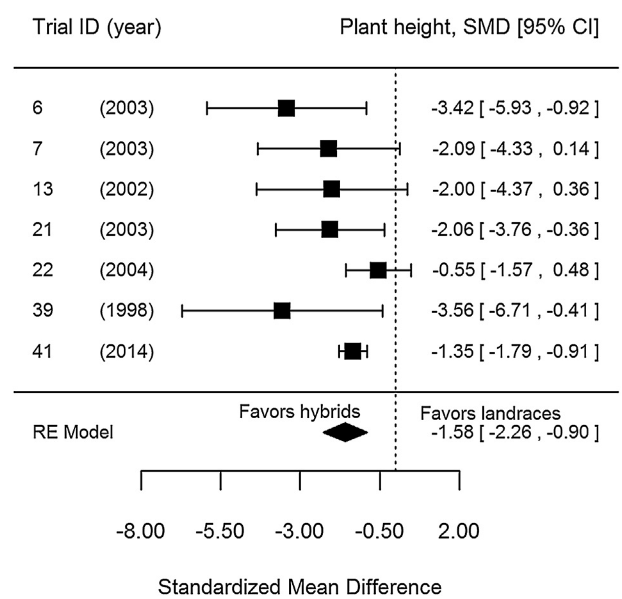

Fig. 2. Landraces vs. hybrids effect size for plant height. Refer to Fig. 1 and text (Section 3) for explanation of abbreviations and description of the plot.

2. Materials and methods

2.1. Plant materials and phenotypic data

Sorghum lines were introduced from ICRISAT (India & Kenya), American public research institutes (Texas A & M University, Texas; Sugar Crop Field Station, Mississippi; and Germplasm Resource Laboratory, Maryland), seed companies and Italian breeding institutes. Commercial and experimental hybrids were mainly developed in Europe using grain sorghum as seed parent and