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Seed yield, galactomannan content and quality traits of different guar (*Cyamopsis tetragonoloba* L.) genotypes

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ABSTRACT

The aim of this study was to assess the productive and qualitative traits of seeds of six guar genotypes coming from India, South Africa and the USA, grown in a Mediterranean environment, both for industrial use (galactomannans) and as animal feed (guar meal). Yield of the six varieties ranged from 1.49 t ha^{-1} to 2.05 t ha^{-1}. Galactomannan content reached values from 28.6 g/100 g to 34.6 g/100 g with the highest significative value exhibited by Indian genotype, Lewis and South African genotype. Galactomannan yield resulted 0.55 t ha^{-1}, on average, with small differences among genotypes. The mean values of protein content of the guar seeds showed an average value of all the genotypes of 283 g/kg on a DM basis of 896 g/kg with the significantly highest values in Indian and South African genotypes. Lipids (on a DM basis) was of 28.3 g/kg DM on average, with the significantly highest value in South African and Indian genotypes. Crude Fibre, ranged from 107 to 122 g/kg. The fibrous fractions were on average 496 g/kg DM, 133 g/kg DM and 5.08 g/kg DM for NDF, ADF and ADL, respectively. Polyphenols ranged from 3.61 mg gallic acid/g of Matador to 6.63 mg gallic acid/g of Kinman and tannins from 2.01 mg/g of catechin equivalents of Kinman to 4.05 mg/g of catechin equivalents of South African genotype. Monument showed the highest content of n6-PUFA, whereas, the highest content of n3-PUFA was observed in Indian genotype. The ratio n3/n6 PUFA, the Atherogenic and Thrombogenic indices underline the high quality of guar oil for human and animal nutrition. This study underlines the double aptitude of guar seed of gum extraction and the by-product, assessing, respectively, its productive traits for industrial use and nutritional traits for increasing its use in feedstuff in the Mediterranean crop-livestock system. This double use represents an important added value to promote the widespread cultivation of the crop.

1. Introduction

Guar (*Cyamopsis tetragonoloba* L.) is a legume species mainly cultivated for industrial use due to the galactomannans contained in its endosperm, and for its by-product as a valuable ingredient for animal feeding (Mudgil et al., 2014). Guar is a summer low-emission crop (Gresta et al., 2014) with an excellent drought tolerance ability, able to fix atmospheric nitrogen (Elsheikh and Ibrahim, 1999) which can be profitably introduced into crop rotation systems (Whistler and Hymowitz, 1979; Rao et al., 1995; Saxena et al., 1997). Its origin is not completely clear: it is commonly considered an Indian species, however, the most accepted scientific hypothesis reveals that it probably developed in Africa from a wild species named *Cyamopsis senegalensis* and was brought to India by Arab traders between the 9th and the 13th centuries where it has been cultivated and improved (Gopala Krishnan et al., 2011; Mudgil et al., 2014). It is cultivated in few areas of the world: mainly in India and, to a lesser extent, in Pakistan and the USA (Sharma, 2010). For these reasons, it can still be considered as a niche crop, but with a massive impact on the industrial market. In fact, the importance of guar lies in the galactomannans, commonly named gum, consisting of a backbone of mannose units with branching galactose units with a 2:1 ratio. Guar gum and its derivatives are extensively used as an emulsifier, thickener, strengthener and stabilizer in a wide range of industrial activities such as food, paper, printing, textiles, cosmetics, oil industries, etc. (Mudgil et al., 2014). Guar gum is, in fact, a hydrocolloid able to rapidly hydrate in cold water forming a thick solution with high viscosity. Moreover, another important income of guar seeds comes from the use of its by-product. In fact, after gum extraction, the remaining parts, seed coat and germ, named guar meal, consisting approximately the 60% of the whole seed (Salehpour and

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Table 1
Grain yield, yield components, and galactomannan content for six geographically diverse cultivars grown in Southern Italy in 2012.

Variety	Origin	Seeds per pod (n)	Unitary seed weight (g)	Seeds per plant (g)	Grain yield (t ha^{-1})	Galact.^{A}content (g/100 g)	Galact.^{A} yield (t ha^{-1})
India	India	7.90 abc	4.10 a	11.84 c	1.63 ab	34.6 a	0.56 ab
Kinman	USA	6.94 bcd	3.06 b	12.85 ab	1.78 ab	30.3 b	0.54 ab
Lewis	USA	6.32 d	3.14 b	13.30 a	2.05 a	32.2 ab	0.66 a
Matador	USA	6.80 cd	3.07 b	11.79 c	1.49 b	30.9 b	0.46 b
Monument	USA	7.36 ab	3.02 b	12.26 bc	1.69 ab	28.6 c	0.48 b
South Africa	Pakistan	6.90 bcd	3.23 b	13.17 ab	1.97 ab	31.3 ab	0.62 a
Average	–	7.0	3.48	12.5	1.88	31.0	0.55

Mean values with different letters (a-d) within the same column differ significantly ($P < 0.05$).
^{A}Galact. = Galctomannan.

Qazvinian, 2011) have a well-recognised application as feed for poultry (Gutierrez et al., 2007), lamb (Soleimani et al., 2015), cattle (Salehpour and Qazvinian, 2011) and fish (Brinker and Reiter, 2011). It contains from 35 to 47.5% of crude protein (Conner, 2002), with peaks of over 50% (Chiofalo et al., in press) and a price that in Europe is about 0.50 € per kg. So it may represent a significant extra benefit for the industry after gum extraction, able to sustain the economy of the crop. For the above-mentioned reasons, guar is now assuming a larger role among domesticated plants both for its peculiar gum properties and for the increasing use of guar meal in the feed manufacturing industry.

With this in mind, the aim of the present research was to assess productive traits, galactomannan content and qualitative characteristics of guar genotypes with different origin.

2. Materials and methods

2.1. Materials

Six guar genotypes were grown in a medium-sandy textured soil in Southern Italy, in an area devoted to the cultivation of cereals (wheat and barley) and artichokes. The origin of guar genotypes is reported in Table 1. These genotypes have been chosen for their wide representability of the guar-producing world and for their adaptability to Mediterranean environments (Gresta et al., 2013; Gresta et al., 2014). No specific information was available on Indian genotype; South African genotype was supplied by a South African company, but the seeds originally came from Pakistan, while Kinman, Lewis, Matador and Monument are all American varieties and have been supplied by the Texas A & M AgriLife Extension Services. Kinman and Lewis were released by Texas A & M AgriLife Extension Services in 1974 and in 1984, respectively; Matador and Monument are patented varieties and are owned by Texas Tech University. The environment where the trial was carried out (Gela plain; 60 m a.s.l., 37°03′01″N, 14°20′25″E) is characterised by a typical Mediterranean climate with rainfall concentrated in winter and a high-temperature dry summer. During the trial the minimum temperature was around 15 °C in May and the maximum temperature reached 35 °C in August. Useful rainfall was very little, with a few millimetres falling in May and July, while extensive rain, but not useful for the crop, fell in September and October (Fig. 1).

Sowing was carried out with a density of 20 plants m^{-2} in the first days of May 2012, on a 3 × 4 m plots, replicated three times in a randomized block design. Soil was an alkaline, clay loam soil (USDA classification) with a high value of total limestone (171 g kg^{-1}) rather poor of organic matter (10.1 g kg^{-1}). Before sowing, fertilization was executed with 28.6 kg/ha of nitrogen, 57.2 kg/ha of phosphorus and 41.6 kg/ha of potassium. Weeds were controlled with Stomp aqua (a.i. Pendimethalin) before emergence and Altorex (a.i. Imazamox) after emergence at the recommended doses as suggested by Avola et al. (2008) to tackle weeds in grain legumes. Seeds of all varieties were harvested at the beginning of October. Four irrigations (for a total of about 3.000 m^3 ha^{-1}) were applied to the crop at regular intervals with a drip system, to avoid possible stress conditions.

2.2. Determination of galactomannans

Whole seeds were milled into guar flour using a laboratory mill with a 0.50 mm hole screen. The dry weight of guar flour obtained after milling was determined in an air forced oven at a temperature of 105 °C till constant weight. From the weight difference determined at the end of the drying process, the water content percentage and the dry weight of the samples were calculated.

The method for galactomannans determination was based on McCleary (1981) as adapted by the Megazyme method "Galactomannan assay procedure" (www.megazyme.com) with the following modification: after elimination of the raffinose series oligosaccharides by repeated ethanol precipitation, samples of guar seed flour (milled seeds) were re-suspended in 100 mM acetate buffer, pH 4.5, and incubated for 4 min at 100 °C and stirred on a vortex mixer every 30 s and then incubated for 30 min at 100 °C with vigorous stirring on a vortex mixer every 10 min. Finally the samples were incubated for another 30 min at 50 °C and allowed to cool to 40 °C. This procedure is necessary to ensure complete hydration of the galactomannans (Gresta et al., 2013). Analyses were carried out in duplicate on each replication, so that the data reported represent the mean of six measurements. Galactomannan yield per hectare was obtained by multiplying the galactomannan value and the seed yield per hectare.

2.3. Determination of chemical composition

All the samples were ground to pass through a sieve of 1 mm diameter (Cyclotec 1093 Sample mill, FOSS Hillerød, Denmark), labelled and analysed for proximate composition as per AOAC (2012). The feed samples were dried at 135 ± 2 °C for 2 h ± 5 min (no. 930.15, AOAC, 2012) for the Dry Matter (DM) determination and incinerated in an electric muffle furnace at 600 °C for 2 h (no. 942.05, AOAC, 2012) for the ash calculation. Crude Protein (CP), Lipids and Crude Fibre (CF) were determined according to AOAC (2012) procedures (ID number: 2001.11, 920.39, 978.10, for CP, Lipids and CF, respectively).

The neutral detergent fibre (aNDFom) was determined according to AOAC (2012) method (n. 2002.04) assayed with a heat stable amylase and expressed exclusive of residual ash. The acid detergent fibre (ADFom), expressed exclusive of residual ash, and acid detergent lignin (ADL) were determined according to AOAC (2012) procedure (no. 973.18) The calculation of Non Fibrous Carbohydrates (NFC) content was obtained by difference method, as recommended by NRC (2001); NFC = [100-(NDF + CP + EE + Ash)].

The total phenol content was determined using Papoti and Tsimidou (2009) method. Each individual sample (500 mg) was extracted with 10 mL of methanol: distilled water (8:2 v/v) by using an ultrasonic bath at room temperature for 10 min and then in the dark at room temperature for 20 h. The methanolic phase was centrifuged for 15 min at 4500xg (C45, Medilab, Firenze, Italy). An aliquot of extract of 100 μL was mixed with 2 mL of Folin Ciocalteu reagent (1:10 diluted with distilled water) and 2.5 mL of Na_2CO_3 aqueous 7.5 (w/v) follow-