Industrial Crops & Products 114 (2018) 98–107

Contents lists available at ScienceDirect

Industrial Crops & Products

journal homepage: www.elsevier.com/locate/indcrop

Morphological, biological, productive and qualitative characterization of 68 guar (*Cyamopsis tetragonoloba* (L.) Taub.) genotypes

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A R T I C L E I N F O

Keywords:
Guar
Characterization
Genotypes
Productive and qualitative traits
Correlations

A B S T R A C T

Guar (*Cyamopsis tetragonoloba (L.) Taub.*) is a valuable industrial crop, widely cultivated in India and Pakistan for the high galactomannan content of its endosperm. The present multi-trait characterization of 68 guar genotypes was conducted to identify an ideotype combining desirable traits suitable for cultivation in a Mediterranean climate and that allows an easy harvest. Plant height, branch number, stem diameter, length of crop cycle, number of cluster, number of pods per plant, number of seeds per pod, 1000 seeds weight, seed production per plant, galactomannan and protein content were measured. In addition, correlations between morphological and productive traits were applied, calculating the relationships between traits, and giving biological meaning to the ideotype. To select high performance genotypes under Mediterranean climate, we mainly took into consideration non-branching (easy harvestability, uniformity of maturation) and short crop cycle genotypes with valuable productive and qualitative traits. From this viewpoint, the results showed that 17 genotypes resulted non-branching, 11 genotypes showed a short crop cycle and seven genotypes were characterized by a seed production greater than 50 g plant^{-1}. Four of the 17 genotypes (PI 288757, PI 340263, NC70300525and PI 288745) possess all these desirable traits along with good seed production and therefore should be selected as multi-trait high performance genotypes. As far as the galactomannan and protein contents are concerned, a lower coefficient of variation emerged when compared to those of the morphological or productive traits. Correlation analysis showed that plant production was related to cluster number, number of pods per plant, seeds per pod, number of branches and length of crop cycle. Finally, an interesting negative association between galactomannan and protein content was found.

1. Introduction

Guar (*Cyamopsis tetragonoloba (L.) Taub.*) or cluster bean, is an erect or bushy, herbaceous, summer legume. Being considered a minor crop, international official statistical data are unavailable for guar. Sharma (2010) reports that the 95% of the world production is in India and Pakistan, while minor cultivations are also reported for the USA, where it was introduced in 1903 (Hymowitz and Matlock, 1963). Guar is self-pollinating plant with a very small percentage of cross-pollination (Stafford and Hymowitz, 1980). Its origin is uncertain since it has not been found in the wild state. The most accepted theory reports that it could be derived from *Cyamopsis senegalensis,* whose centre of origin is located in Africa (or in the Arabian Peninsula), and that it was introduced as flotsam or as feed during horse trades by Arabs in India, where it was domesticated (Hymowitz, 1972). This is known as *trans-domestication* theory.

Once cultivated for cattle feed and human food (green pods), guar is now considered an industrial crop due to the high galactomannan (long branching polymers of mannose and galactose) content of its endosperm, named guar gum. Guar gum has exceptionally high viscosity – outperforming many other hydrocolloids – thanks to its ability to hydrate rapidly in cold water, which is not found in starches (Mathur, 2012; Mudgil et al., 2011). When dissolved in water it forms a gel used as stiffener, thickener, stabiliser and strengthener in a wide range of industries such as food, paper, explosives, textiles, cosmetics, oil well drilling, muds and ore flotation. In the past few years, the demand for guar gum has increased greatly mainly from the oil and gas industry. Although several chemical companies are working on developing synthetic polymers whose properties might rival those of guar gum, no substitute, as effective as guar is for hydraulic fracturing, has yet been developed (Beckwith 2012). After gum extraction, the by-product, composed of seed coat and germ, is a highly valuable protein-rich feed supplement for ruminants (Chiofalo et al., 2018; Gresta et al., 2017).

Guar is as heat tolerant and drought tolerant as any crop grown in

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https://doi.org/10.1016/j.indcrop.2018.01.070
Received 26 November 2017; Received in revised form 16 January 2018; Accepted 27 January 2018
Available online 16 February 2018
0926-6690/

the Mediterranean area. Guar, compared to other summer legumes, can be grown with few inputs (Gresta et al., 2014) and has a relatively low water requirement (Alexander et al., 1988). It is an inexpensive crop to grow. Guar is also considered an excellent soil improving crop, able to fit well into crop rotation systems of different areas of the world (Rao et al., 1995; Saxena et al., 1997). Guar thrives in sandy soil, but it also grows in clay soil if well ploughed and well drained, since it is very intolerant to waterlogging. It also tolerates low fertility and high salinity soils (Ashraf et al., 2005; Francois et al., 1990).

Previous researches have reported a wide variability for guar on many morphological, biological and productive traits (Manivannan et al., 2015; Mayank et al., 2016; Morris, 2010; Sultan et al., 2012). Guar genotypes, in fact, show very large variability: plant height ranges from 0.5 to 3.0 m; length of the crop cycle can range from 80 to 160 days or more, depending on the genotype and the environment; plant *habitus* varies from single-stem to basal branching pattern. As a general rule, guar also exhibits indeterminate growth: it flowers and sets pods from a few weeks after seed emergence until the end of biological cycle with a consequent lack of uniformity in seed maturity. Some determinate growth varieties have been developed in the USA (Stafford and Ray, 1985).

The commercial market of varieties is limited to some varieties produced in USA and others in India and Pakistan. On this topic, a rapid visual method to evaluate seed traits has been reported by Gresta et al. (2016b). Adaptation of guar to the Mediterranean region has been proved (Sortino and Gresta, 2007; Gresta et al., 2013; Gresta et al., 2016a), where its high drought and salinity tolerance fits well with the high temperature, poor erratic rainfall and elevated water salt content of the coastal areas. However, one of the main obstacles to its cultivation in the Mediterranean environment (and also in many other areas of the world) is the long crop cycle, since the crop is still in field when the rains of late summer season fall (end of September and beyond), causing problems with the combine harvest. Previous researches have been carried out on the identification of genotypes characterized by lower temperature requirements for seed germination and seedling emergence, in order to potentially sow earlier (Gresta et al. in press). However, very little research has been conducted to characterize and select appropriate genotypes for the Mediterranean environments together with high productive and qualitative traits. This notwithstanding, evaluating and characterizing guar germplasm has a key importance for future scenarios of its applications and its cultivation all over the world. This present research investigated 68 guar genotypes from a morphological, biological, productive and qualitative point of view.

2. Material and methods

2.1. General information and morphological, biological and productive traits

The trial was carried out in Botricello, Calabria, southern Italy (CZ, 19 m a.s.l., 38° 56′ 19″ North, 16° 52′ 55″ East) in 2014, on a sand-silt soil, the main characteristics of which are reported in Table 1. Sixty-eight genotypes were tested (Table 2): 63 accessions were provided by two different seed banks, the remaining five genotypes (placed at the end of the list) are registered varieties or genotypes owned by the Department of Agraria, University of Reggio Calabria, Italy.

A rotary hoeing was performed at the beginning of April to bury previous wheat residues. A 30–40 cm ploughing was executed at the end of April followed by a rotary harrowing. At the seedbed tillage, a fertilization using a total amount of 22 kg ha^{-1} N, 70 kg ha^{-1} P_2O_5 and 32 kg ha^{-1} K_2O was applied, using as fertilizer 11-22-16 plus simple super phosphate. As a consequence of the lack of nodulation observed during the crop cycle, 100 kg ha^{-1} of N as ammonium nitrate were added at the appearance of the eighth leaf.

Sowing was performed manually on May 10th on rows 1.0 m long, adopting an intra-row distance of 0.10 m and an inter-row distance of 0.50 m, therefore a density of 20 plants m^2 was used. Seeds were placed at 2–3 cm depth. The rows were north-south oriented to allow the best

Table 1
Chemical and physical properties of the soil (Botricello – RC, Southern Italy).

Property	Value
Skeleton (> 0,2 mm) (g kg^{-1})	36
Sand (0,02–0,2 mm) (g kg^{-1})	632
Silt (0,002–0,02 mm) (g kg^{-1})	274
Clay (< 0,002 mm) (g kg^{-1})	94
Total limestone ($CaCO_3$) (g kg^{-1})	89
Active limestone (CaCO3) (g kg^{-1})	14
Total nitrogen (N) (g kg^{-1})	0.5
Organic substance (g kg^{-1})	9.0
C/N	10.3
Phosphorus assimilable (P_2O_5) (mg kg^{-1})	31
Exchangeable potassium (K_2O) (mg kg^{-1})	208
pH	7.9
Conductivity (saturated extract) (dS m^{-1})	0.36
Cation exchange capacity (meq 100 g^{-1})	12.9
Exchangeable calcium (CaO) (mg kg^{-1})	3016
Exchangeable magnesium (MgO) (mg kg^{-1})	266
Exchangeable sodium (Na) (mg kg^{-1})	90

Table 2
Guar genotypes tested in this trial.

ID	Accession	Origin	Seed Bank	ID	Accession	Origin	Seed Bank
1	PI 323302	India	A	35	PI 198297	India	A
2	PI 340509	India	A	36	PI 340601	India	A
3	PI 288762	India	A	37	PI 426635	Pakistan	A
4	PI 340253	India	A	38	PI 426631	Pakistan	A
5	PI 288760	India	A	39	PI 426633	Pakistan	A
6	PI 164420	India	A	40	PI 275322	India	A
7	PI 288392	India	A	41	PI 547070	Texas	A
8	PI 340346	India	A	42	PI 340263	India	A
9	PI 288377	India	A	43	HALL 78000	Australia	B
10	PI 268228	India	A	44	CP31 61055	Australia	B
11	PI 271542	India	A	45	PUSA MAUSMI 300537	Australia	B
12	PI 288757	India	A	46	NAWABSHAR 300528	Australia	B
13	PI 288759	India	A	47	LASBELLA 95042	Australia	B
14	PI 212986	India	A	48	BROOKS 77998	Australia	B
15	PI 288745	India	A	49	KATHSEL 300538	Australia	B
16	PI 288742	India	A	50	TARI 300529	Australia	B
17	PI 288738	India	A	51	NC70 300525	Australia	B
18	PI 288362	India	A	52	95078 (NA 444 X Texas)	Australia	B
19	PI 288435	India	A	53	Q20023 95327	Australia	B
20	PI 288384	India	A	54	FINE BRACHING1 95046	Australia	B
21	PI 288394	India	A	55	S – 47–2 95069	Australia	B
22	PI 288347	India	A	56	MA20SAN 68794	Australia	B
23	PI 426639	Pakistan	A	57	FSSRQ 77999	Australia	B
24	PI 116034	India	A	58	HF118 61104	Australia	B
25	PI 288763	India	A	59	PUSA MAUSMI 61043	Australia	B
26	PI 236479	India	A	60	IC9229/P3 62437	Australia	B
27	PI 288758	India	A	61	CP380 61051	Australia	B
28	PI 288748	India	A	62	CP66 61044	Australia	B
29	PI 271646	India	A	63	VADAVALLI 61050	Australia	B
30	PI 288381	India	A	64	KINMAN	Texas	C
31	PI 288385	India	A	65	MONUMENT	Texas	C
32	PI 288749	India	A	66	LEWIS	Texas	C
33	PI 255928	India	A	67	INDIA 2	India	C
34	PI 254368	India,	A	68	INDIA 3	India	C

Seed bank:
A = ARS-USDA, Georgia.
B = Australian Grains Genebank, Canberra.
C = University of Reggio Calabria.