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The effect of *Bradyrhizobium* inoculation on yield and seed quality of guar (*Cyamopsis tetragonoloba* L.)

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Abstract

Bradyrhizobium strains TAL 169 and TAL 1371 (introduced) and strains ENRRI 16A and ENRRI 16C (local) were used to inoculate five guar cultivars, namely, HFG-75, HFG-182, HFG-363, HFG-408 and WB-195 in a factorial field experiment. The objective of the experiment was to study the effect of inoculation on yield, proximate analysis and mineral composition. Most of the *Bradyrhizobium* strains significantly increased yield, protein, crude fibre, and mineral content. The locally-isolated strains affected these parameters more than the introduced ones. This study revealed that inoculation with *Bradyrhizobium* strains improved yield and seed quality of guar.

1. Introduction

Guar is a leguminous crop with good capabilities to fix atmospheric nitrogen. According to Asher, Bell, and Edwards (1990), inoculation with various *Bradyrhizobium* spp. increased dry matter production and nitrogen fixation of guar cultivars. Similarly, inoculation of guar with *Bradyrhizobium japonicum* significantly increased the number of nodules, nodule fresh weight, plant dry weight, nitrogen fixation, total nitrogen content and seed yield (Mand, Dahiya, & Lakshminarayana, 1991; Weaver, Arayangkool, & Schomberg, 1990). Fertilization trails with biological, chemical and organic fertilizers were found to improve seed quality of legumes (Babiker, Elsheikh, Osman, & El Tinay, 1995; Elsheikh, & Elzidany, 1997a,b).

Many cultivars of guar are grown for seed production, fodder and carbohydrate contents. The seed of guar cultivar HFG-182 contained higher crude protein than cultivars HFG-119 and FS-277 (Khatta, Kumar, & Gupta, 1988). Guar cultivars are, in general, rich in protein which could be used for poultry and animal nutrition. Guar carbohydrate content has a great economical importance because of its capacity to give a high level of viscosity, which is useful in tobacco, petroleum, mining, textile, cosmetics, pharmaceuticals and food industries.

No trials have yet been conducted to observe the response of guar to inoculation and its impact on seed quality in Sudan. The present study was conducted to investigate the effect of inoculation with four *Bradyrhizobium* strains on yield and seed quality of five guar cultivars.

2. Materials and methods

2.1. Cultivars and Bradyrhizobium strains

Seeds of the guar cultivars HFG-75, HFG-182, HFG-363, HFG-408 and WB-195 were supplied by the Ministry of Agriculture, Sudan. *Bradyrhizobium* spp. strains TAL 169 and TAL 1371 were supplied by NifTAL Project, Paia, Hawaii, USA, whereas, strains ENRRI 16A and ENRRI 16C were locally isolated. The strains were maintained at 4°C on yeast extract mannitol agar (YEMA) slopes.

2.2. Field experiment

The field experiment was carried out at the Demonstration Farm of the Faculty of Agriculture, Shambat, University of Khartoum (latitude 15°40′N, longitude 32°32′E), during 1996/97 in a factorial design with four replicates. The soil has the following composition: 17% sand, 20% silt, 63% clay, 0.02% N, 0.01% P, 0.4% O.C., 8.0 pH value, and cations (meq/l) 4.0 K, 29.6 Na,

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6.7 Ca, 9.3 Mg. The mean temperature, relative humidity and annual rainfall of the experimental site were 25–35°C, 14–45% and 50–200 mm, respectively. The land was prepared by deep ploughing, harrowing and levelling. Then the area was ridged and divided into 3×4 m plots. Each of the five guar cultivars was treated as follows:

1. Control (uninoculated).
2. Inoculated with *Bradyrhizobium* sp. strain TAL 169.
3. Inoculated with *Bradyrhizobium* sp. strain TAL 1371.
4. Inoculated with *Bradyrhizobium* sp. strain ENRRI 16A.
5. Inoculated with *Bradyrhizobium* sp. strain ENRRI 16C.

Plots were immediately irrigated after sowing and then, subsequently, irrigated at 7-day intervals.

2.3. Yield and 100-seed weight

At harvest, the total yield was estimated on a per hectare basis. The seeds were carefully cleaned and freed from dirt, stones, chips and other extraneous grain or dirt. From each sample, 100 seeds were counted randomly in triplicate and their weight was recorded.

2.4. Chemical analysis

Seeds were carefully cleaned then ground to pass through a 0.4 mm screen; for proximate analysis AOAC (1975) methods were followed in the determination of moisture (7.003), petroleum ether extracts (7.048), crude fibre (7.057), ash (14.006), and crude protein (7.016). Carbohydrate was calculated by difference. Calcium, magnesium, sodium, potassium, iron, manganese, copper and zinc content of the seeds were determined using an atomic absorption spectrophotometer, Perkin Elmer Model 2280.

2.5. Statistical analysis

Each sample was analyzed in triplicate and the figures were then averaged. Data were assessed by analysis of variance (ANOVA). The Duncan multiple range test was used to separate means. Significance was accepted at $P \leqslant 0.05$.

3. Results and discussion

3.1. 100-seed weight and yield

Bradyrhizobium inoculation had no significant effect on 100-seed weight (Table 1). There were no significant differences between guar cultivars. *Bradyrhizobium* inoculation significantly ($P \leqslant 0.05$) increased the yield of guar compared with the control treatments (Table 1). Cultivars WB-195, HFG-182, and HFG-75 produced significantly ($P \leqslant 0.05$) higher grain yield/ha than HFG-363 and HFG-408. There was a significant strain X cultivar interaction, for instance inoculation of cultivar HFG-182 with *Bradyrhizobium* strain ENRRI 16C increased the yield by 24.7% over the control. Weaver, Arayangkool, and Schomberg (1990) and Singh and Singh (1990) reported similar results for guar cultivars.

3.2. Crude protein content

Bradyrhizobium strains, TAL 1371 and TAL 169, significantly ($P \leqslant 0.05$) increased protein content by 19% and 8%, respectively, over the uninoculated treatment, whereas, strains ENRRI 16A and ENRRI 16C, increased the protein content by 8% and 14%, respectively, over the control (Table 2). There was a significant

Table 1
Effect of *Bradyrhizobium* inoculation on 100-seed weight and grain yield of five guar cultivars

Cultivar	Treatments					
	Control	TAL 169	TAL 1371	ENRRI 16A	ENRRI 16C	Mean
100-seed weight (g)						
HFG-75	3.30^{a}	3.40^{a}	3.40^{a}	3.60^{a}	3.50^{a}	3.44^{a}
HFG-182	3.30^{a}	3.30^{a}	3.40^{a}	3.40^{a}	3.50^{a}	3.38^{a}
HFG-363	3.40^{a}	3.40^{a}	3.30^{a}	3.30^{a}	3.40^{a}	3.36^{a}
HFG-408	3.60^{a}	3.60^{a}	3.50^{a}	3.50^{a}	3.50^{a}	3.54^{a}
WB-195	3.40^{a}	3.60^{a}	3.50^{a}	3.50^{a}	3.50^{a}	3.50^{a}
Mean	3.40	3.46	3.42	3.46	3.48	
Grain yield (kg/ha)						
HFG-75	880.8^{a}	916.4^{b}	930.7^{a}	1026.4^{b}	912.1^{a}	933.3^{b}
HFG-182	863.5^{a}	894.3^{ab}	856.9^{a}	1022.9^{b}	1077.1^{b}	942.9^{b}
HFG-363	772.9^{a}	772.9^{a}	930.0^{a}	834.3^{a}	882.3^{a}	838.5^{a}
HFG-408	772.3^{a}	875.0^{ab}	850.5^{a}	820.0^{a}	852.1^{a}	834.0^{a}
WB-195	890.4^{a}	982.3^{b}	1075.0^{b}	1034.0^{b}	919.7^{a}	980.3^{b}
Mean	836.0	888.2	928.6	947.5	928.7	

Values are means. Means not sharing a common superscript(s) in a column are significantly different at $P \leqslant 0.05$ as assessed by Duncan's multiple range test.

strain X cultivar interaction, for instance inoculation of cultivar HFG-363 with *Bradyrhizobium* strain TAL 1371 increased the protein content by 33.3% over the control. Singh and Singh (1990) reported that inoculation of *Bradyrhizobium* strains increased protein content of guar over uninoculated control by 28%. This could probably be attributed to the increase in the nitrogen-fixing efficiency of inoculated plants where more nitrogen is fixed and translocated to the seeds. Moreover, inoculation enhanced the symbiotic properties of guar plants and better growth and production were obtained by biofertilizers application. *Rhizobium* Inoculation has been reported to increase seed protein content of soybean (Regitano, Carpi, Camara, Baggio, & Marcos, 1995), faba bean (Babiker, Elsheikh, Osman, & El Tinay, 1995; Elsheikh, 1998) and fenugreek (Abdelgani, Elsheikh, & Mukhtar, 1998).

3.3. Carbohydrate content

Inoculation with all *Bradyrhizobium* strains significantly decreased the carbohydrate content (Table 2). This result is in line with that of the effect on fat, fibre, ash and protein contents where the increase in these constituents due to the inoculation was counteracted by the decrease in the carbohydrate content. The reduction in the carbohydrate component due to inoculation was also reported by Abdelgani, Elsheikh, and Mukhtar (1998) and Elsheikh, and Elzidany (1997a).

3.4. Moisture

The moisture content of guar seeds was affected neither by the strains of *Bradyrhizobium* nor by the cultivar (Table 2). The results obtained in this study are in agreement with those of Abdelgani, Elsheikh, and Mukhtar (1998) for fenugreek. In contrast, Elsheikh, and Elzidany (1997a) reported that the effect of *Rhizobium* inoculation, nitrogen, sulphur or chicken manure treatments on moisture content of faba bean varied from no response to a significant effect. Generally, the moisture content is affected by the cultivar, the relative humidity of surrounding atmosphere at harvest and storage.

3.5. Ash content

Ash content of guar cultivars was significantly ($P \leqslant 0.05$) increased with *Bradyrhizobium* strains (Table 3). However, according to Elsheikh, and Elzidany (1997a) the ash content of faba bean seeds was significantly increased with chicken manure and sulphur treatments but not with *Rhizobium* strains. The ranges of ash contents of chickpea, lentil, soybean and faba bean were 2.9–4.0%, 2.4–4.1%, 4.3–5.0% and 2.6–3.3%, respectively (El Tinay, Mahgoub, Mohammed, & Hamad, 1989). The ash content of foodstuffs represents the inorganic residue remaining after the organic matter has been burnt. The ash obtained is not necessarily of

Table 2
Effect of *Bradyrhizobium* inoculation on protein content (%), carbohydrate content (%) and moisture content (%) of seeds of five guar cultivars

	Treatments					
	Control	TAL 169	TAL 1371	ENRRI 16A	ENRRI 16C	Mean
Protein						
HFG-75	16.4 (±0.01)^{ab}	16.7 (±0.06)^{a}	20.5 (±0.08)^{b}	19.3 (±0.01)^{b}	19.3 (±0.02)^{b}	18.4^{b}
HFG-182	16.0 (±0.01)^{a}	17.8 (±0.06)^{b}	19.6 (±0.03)^{a}	18.4 (±0.01)^{a}	17.8 (±0.03)^{a}	17.9^{a}
HFG-363	16.2 (±0.08)^{a}	17.5 (±0.08)^{b}	21.6 (±0.05)^{c}	19.0 (±0.01)^{b}	20.2 (±0.03)^{c}	18.9^{c}
HFG-408	16.7 (±0.00)^{bc}	17.5 (±0.03)^{b}	19.9 (±0.01)^{a}	18.4 (±0.01)^{a}	19.3 (±0.07)^{b}	18.4^{b}
WB-195	17.0 (±0.03)^{c}	20.5 (±0.03)^{c}	20.5 (±0.01)^{b}	19.0 (±0.07)^{b}	19.9 (±0.06)^{c}	19.5^{d}
Mean	16.5	18.0	20.4	18.0	19.2	
Carbohydrates						
HFG-75	61.1 (±0.01)^{a}	58.5 (±0.08)^{a}	57.2 (±0.02)^{bc}	60.8 (±0.05)^{b}	51.5 (±0.06)^{a}	57.8^{a}
HFG-182	62.2 (±0.05)^{ab}	59.1 (±0.09)^{ab}	55.2 (±0.05)^{a}	60.2 (±0.03)^{ab}	58.3 (±0.06)^{bc}	59.0^{b}
HFG-363	62.8 (±0.01)^{b}	60.1 (±0.01)^{bc}	57.9 (±0.03)^{c}	60.3 (±0.06)^{ab}	57.6 (±0.01)^{b}	59.7^{b}
HFG-408	61.3 (±0.02)^{a}	60.7 (±0.03)^{c}	56.3 (±0.05)^{ab}	59.1 (±0.01)^{a}	57.4 (±0.08)^{b}	59.0^{b}
WB-195	62.9 (±0.06)^{b}	59.2 (±0.07)^{ab}	58.2 (±0.08)^{c}	59.8 (±0.08)^{a}	59.1 (±0.01)^{c}	59.7^{b}
Mean	62.1	59.5	57.0	59.9	56.8	
Moisture						
HFG-75	5.60 (±0.07)^{a}	5.70 (±0.02)^{a}	5.80 (±0.07)^{a}	5.50 (±0.07)^{a}	5.80 (±0.03)^{a}	5.72^{a}
HFG-182	5.90 (±0.07)^{a}	5.90 (±0.07)^{a}	5.80 (±0.06)^{a}	5.30 (±0.06)^{a}	5.60 (±0.06)^{a}	5.70^{a}
HFG-363	5.60 (±0.05)^{a}	5.80 (±0.02)^{a}	5.40 (±0.06)^{a}	5.80 (±0.07)^{a}	5.70 (±0.06)^{a}	5.66^{a}
HFG-408	5.70 (±0.03)^{a}	5.70 (±0.02)^{a}	5.90 (±0.01)^{a}	5.70 (±0.03)^{a}	5.80 (±0.02)^{a}	5.76^{a}
WB-195	5.70 (±0.03)^{a}	5.50 (±0.02)^{a}	5.70 (±0.02)^{a}	6.00 (±0.02)^{a}	5.80 (±0.02)^{a}	5.74^{a}
Mean	5.70	5.80	5.72	5.70	5.74	

Values are means (±SD). Means not sharing a common superscript(s) in a column for each parameter are significantly different at $P \leqslant 0.05$ as assessed by Duncan's multiple range test.

Table 3
Effect of *Bradyrhizobium* inoculation on ash content (%), fat (%) and crude fibre content (%) of seeds of five guar cultivars

	Treatments					
	Control	TAL 169	TAL 1371	ENRRI 16A	ENRRI 16C	Mean
Ash						
HFG-75	6.20 (±0.06) a	6.10 (±0.06) a	7.00 (±0.04) b	8.40 (±0.04) d	8.20 (±0.02) d	7.20 b
HFG-182	6.20 (±0.00) a	6.20 (±0.03) a	7.70 (±0.06) c	6.00 (±0.06) b	7.20 (±0.06) c	6.20 a
HFG-363	6.50 (±0.07) a	7.00 (±0.06) b	6.90 (±0.09) b	4.60 (±0.07) a	6.10 (±0.06) a	6.20 a
HFG-408	6.40 (±0.01) a	6.80 (±0.07) b	7.30 (±0.06) bc	6.90 (±0.06) c	6.50 (±0.03) ab	6.80 b
WB-195	6.30 (±0.01) a	7.30 (±0.06) b	5.00 (±0.07) a	5.10 (±0.07) a	6.90 (±0.03) bc	6.10 a
Mean	5.92	6.60	6.80	6.20	7.00	
Fat						
HFG-75	1.60 (±0.06) b	1.82 (±0.02) b	1.67 (±0.07) b	2.03 (±0.01) bc	1.80 (±0.07) b	1.78 b
HFG-182	1.43 (±0.04) a	2.18 (±0.03) c	1.45 (±0.07) a	2.10 (±0.01) c	1.37 (±0.05) a	1.71 b
HFG-363	1.50 (±0.07) ab	1.47 (±0.01) a	1.47 (±0.02) a	1.47 (±0.07) a	1.83 (±0.00) b	1.55 a
HFG-408	1.45 (±0.06) ab	1.83 (±0.03) b	1.70 (±0.04) b	1.92 (±0.03) b	1.78 (±0.06) b	1.74 b
WB-195	1.52 (±0.06) ab	1.47 (±0.01) a	1.57 (±0.02) ab	1.53 (±0.03) a	1.52 (±0.02) a	1.52 a
Mean	1.50	1.76	1.57	1.81	1.66	
Crude fibre						
HFG-75	8.47 (±1.03) c	8.95 (±0.02) c	8.63 (±0.02) b	8.40 (±0.07) ab	9.17 (±0.03) d	8.72 b
HFG-182	7.55 (±1.01) a	8.85 (±0.02) c	9.52 (±0.05) c	8.60 (±0.00) b	8.17 (±0.07) a	8.54 b
HFG-363	8.25 (±1.02) bc	8.03 (±0.05) b	7.82 (±0.08) a	8.50 (±0.07) b	8.80 (±0.03) bc	8.28 a
HFG-408	7.80 (±0.06) ab	7.47 (±0.09) a	8.70 (±0.04) b	8.30 (±0.05) ab	8.32 (±0.07) ab	8.12 a
WB-195	8.75 (±1.01) c	9.03 (±0.09) c	9.03 (±0.01) bc	7.90 (±0.09) a	8.85 (±0.05) cd	8.71 b
Mean	8.16	8.47	8.74	8.34	8.66	

Values are means (±SD). Means not sharing a common superscript(s) in a column for each parameter are significantly different at $P \leqslant 0.05$ as assessed by Duncan's multiple range test.

exactly the same composition as the mineral matter present in the original food as there may be losses due to volatilization or as a result of some interaction between constituents.

3.6. Fat content

Bradyrhizobium strains, ENRRI 16A, ENRRI 16C, TAL 169 and TAL 1371, significantly ($P \leqslant 0.05$) increased the fat content by 17%, 9.6%, 14.8% and 4.5%, respectively, over the control (Table 3). Guar cultivars varied greatly in their fat content. Generally, the results are in good agreement with those reported by Bhaty and Christison (1984) and Elsheikh (1998). Fats are important dietary constituents not only because of their high energy value, but also because of the vitamins and the essential fatty acids.

3.7. Crude fibre content

Guar cultivars varied greatly in their crude fibre content (Table 3). Inoculation with *Bradyrhizobium* strains, TAL 169, TAL 1371, ENRRI 16A and ENRRI 16C, increased the crude fibre content by 3.7%, 6.6%, 2.2% and 5.8%, respectively, over the uninoculated control (Table 3). There was a significant strain-cultivar interaction; for instance inoculation of cultivar HFG-182 with *Bradyrhizobium* strain TAL 1371 increased the crude fibre content by 26% over the control. Similarly, inoculation was found to increase seed crude fibre of guar cultivars by 10.4% (Khatta, Kumar, & Gupta, 1988). Crude fibre is the insoluble and combustible organic residue remaining from a food sample after boiling both in acid and then alkali. This treatment provides a crude fibre consisting largely of cellulose together with a proportion of the lignin and hemicellulose.

3.8. Mineral contents

Bradyrhizobium strains ENRRI 16A, ENRRI 16C, TAL 169 and TAL 1371 significantly increased Ca content of guar by 11.4%, 16.7%, 20.3%, and 14.2%, respectively, over the control (Table 4). The Ca contents of guar cultivars were generally similar. Inoculation also significantly increased the magnesium and potassium contents. The data reported here are in agreement with the magnesium and potassium contents of white bean, broad bean, chickpea and soybean cultivars reported by Khatta, Kumar, and Gupta (1988) and El Tinay, Mahgoub, Mohammed, and Hamad (1989). *Bradyrhizobium* strains had no significant effect on sodium, manganese, copper or iron contents of guar cultivars. However, *Bradyrhizobium* strains ENRRI 16A, TAL 169, significantly increased zinc content by 9.9%, respectively, over the uninoculated control. Guar cultivars showed no significant differences between each other in calcium, magnesium and sodium contents, and they varied significantly in their potassium, manganese, iron, zinc and

Table 4
Mean seed mineral content (mg/100 g) of five guar cultivars as affected by four different strains of *Bradyrhizobium*

Mineral	Strains				
	Control	TAL 169	TAL 1371	ENRRI 16A	ENRRI 16C
Calcium	279 (±0.17) ^{a}	350 (±0.12) ^{c}	325 (±0.17) ^{b}	315 (±0.17) ^{b}	335 (±0.30) ^{bc}
Magnesium	172 (±0.27) ^{a}	195 (±0.17) ^{b}	201 (±0.26) ^{b}	210 (±0.26) ^{b}	189 (±0.16) ^{ab}
Sodium	2.8 (±0.05) ^{a}	3.0 (±0.20) ^{a}	3.2 (±0.06) ^{a}	3.0 (±0.07) ^{a}	3.0 (±0.06) ^{a}
Potassium	172 (±0.13) ^{a}	187 (±0.20) ^{b}	195 (±0.21) ^{c}	187 (±0.23) ^{b}	191 (±0.20) ^{a}
Manganese	0.40 (±0.01) ^{a}	0.50 (±0.01) ^{a}	0.40 (±0.01) ^{a}	0.50 (±0.01) ^{a}	0.50 (±0.01) ^{a}
Iron	5.3 (±0.02) ^{a}	6.2 (±0.02) ^{a}	6.2 (±0.02) ^{a}	6.2 (±0.03) ^{a}	6.4 (±0.02) ^{a}
Zinc	0.30 (±0.03) ^{a}	0.33 (±0.03) ^{ab}	0.32 (±0.03) ^{a}	0.33 (±0.02) ^{ab}	0.35 (±0.03) ^{b}
Copper	0.32 (±0.03) ^{a}	0.32 (±0.02) ^{a}	0.32 (±0.02) ^{a}	0.32 (±0.03) ^{a}	0.38 (±0.01) ^{a}
Mineral	Cultivars				
	HFG-75	HFG-182	HFG-363	HFG-408	WB-195
Calcium	320 (±0.17) ^{a}	317 (±0.12) ^{a}	320 (±0.17) ^{a}	328 (±0.17) ^{a}	319 (±0.30) ^{a}
Magnesium	195 (±0.27) ^{a}	197 (±0.17) ^{a}	195 (±0.26) ^{a}	195 (±0.26) ^{a}	206 (±0.16) ^{a}
Sodium	3.2 (±0.05) ^{a}	2.5 (±0.02) ^{a}	3.5 (±0.06) ^{a}	3.0 (±0.07) ^{a}	2.8 (±0.06) ^{a}
Potassium	187 (±0.13) ^{b}	187 (±0.20) ^{b}	173 (±0.21) ^{c}	183 (±0.23) ^{ab}	179 (±0.20) ^{a}
Manganese	0.50 (±0.01) ^{a}	0.50 (±0.01) ^{a}	0.40 (±0.01) ^{a}	0.40 (±0.01) ^{a}	0.50 (±0.01) ^{a}
Iron	6.2 (±0.03) ^{ab}	5.9 (±0.02) ^{a}	5.6 (±0.02) ^{a}	6.2 (±0.03) ^{ab}	6.4 (±0.02) ^{b}
Zinc	0.33 (±0.02) ^{ab}	0.32 (±0.02) ^{a}	0.31 (±0.03) ^{a}	0.32 (±0.02) ^{a}	0.35 (±0.03) ^{b}
Copper	0.38 (±0.03) ^{d}	0.35 (±0.03) ^{c}	0.32 (±0.02) ^{b}	0.29 (±0.02) ^{a}	0.32 (±0.02) ^{b}

Values are means (±SD). Means not sharing a common superscript(s) in a raw for each treatment are significantly different at $P \leqslant 0.05$ as assessed by Duncan's multiple range test.

copper contents (Table 4). These results are, generally, lower than the data obtained by Augustin, Beck, Kalbtloish, Kagel, and Mathews (1981).

4. Conclusion

Inoculation with *Bradyrhizobium* strains significantly affected the chemical composition of guar cultivars. Selection of guar cultivars for carbohydrate content, should be undertaken, because, although strains increase the total seed yield, they decrease the carbohydrate content and consequently the gum content. However, when guar is grown for feed animals, efficient strains should be used to increase the seed yield and to improve seed protein content.

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