Nutrient, fatty acid and mineral composition of selected white food-grade sorghum hybrids grown in a Mediterranean area of Southern Italy

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Abstract

The nutrient composition, fatty acid content and mineral content of six white food-grade sorghum hybrids selected in either Argentina or Bolivia, and grown in a Mediterranean area of Southern Italy were studied. The six hybrids were analyzed for various attributes including moisture, protein, carbohydrate, dietary fiber, fat contents, fatty acid composition, and mineral content. Slight variations in both protein and in fiber contents were observed among hybrids. Linoleic, oleic and palmitic were the most abundant fatty acids in all samples with noticeable difference in their percentage content between both hybrids from Argentina and Bolivia. Slight variations in the content of the elements were found among the six white sorghum hybrids examined, and K, Fe, and Sb were, respectively, the most abundant macro-element, micro-element and trace element in all analyzed hybrids. These results are discussed in the context of the importance of the white food-grade sorghum in human nutrition, and of the opportunity to select the best varieties from the point of view of nutritional content.

Keywords: food-grade sorghum hybrid, nutrient composition, fatty acids, mineral, Mediterranean area

Introduction

Sorghum, a heat and drought tolerant C4 plant, is a widely consumed cereal staple in subtropical and semi-arid regions of Africa and Asia (Kresovich et al, 2005; Dicko et al, 2006; Reddy et al, 2009; Ashok-Kumar et al, 2010; Pontieri and Del Giudice, 2016). It ranks fifth in the world with respect to overall grain production (with the first four grains being maize, rice, wheat and barley), and accounted for 2.2% of total worldwide grain production in 2013 (Food and Agriculture Organization, 2014). With increasing world population and decreasing water supplies, it represents an important crop for future human use. Worldwide, more than 35% of sorghum is grown directly for human food. The rest is used primarily for animal feed, alcohol production and industrial products (FAO, 1995; Awika and Rooney, 2004). The United States is the largest producer and exporter of sorghum, accounting for 20% of world production and almost 80% of world sorghum exports in 2001-2003 (USDA-FAS, 2003; Awika and Rooney, 2004). In many developing countries sorghum has traditionally been used in food products and various food items (Pontieri and Del Giudice, 2016).

Sorghum is considered as a safe food for celiac patients suffering from symptoms associated with an immune reaction to gluten proteins found in all Triticum species and closely related cereals such as barley and rye (Kasarda, 2001; Ciacci et al, 2007). Recently, a report provide molecular evidence for the absence of toxic gliadin-like peptides in sorghum, confirming that sorghum can be definitively considered safe for consumption by people with celiac disease (Pontieri et al, 2013). Besides, in recent years farmers in USA have begun producing sorghum hybrids that produce white grain from a tan-color plant (often called «food-grade» sorghum) for production of wheat-free foods for persons with celiac-disease (Tuinstra, 2008). Moreover, new technologies aimed at enhancing the nutritional and functional values of sorghum proteins in industrial-scale processes have been developed (de Mesa-Stonestreet et al, 2010). Therefore, sorghum might provide a good basis for gluten-free foods for all people, either with or without celiac disease as an alternative to wheat foods.

Sorghum breeders have released numerous

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sorghum varieties and hybrid cultivars that exhibit improved performance in semi-arid and tropic environments (Tuinstra, 2008). Identification of sorghum varieties meeting specific food and industrial requirements is important for food security. In developing countries, particularly in West Africa, the demand for sorghum is increasing. This is due not only to the growing population, but also to country policies that promote its processing and industrial utilization (Dicko et al, 2006; Akintayo and Sedgo, 2001).

Genetic improvement and the expansion of production are two main ways of reaching higher production levels. The International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) manages one of the largest collections of sorghum in the world with nearly 38.000 accessions. Expanded testing programs are required to evaluate the agronomic performance of these genotypes and to determine their value with respect to food and grain quality traits.

Our research group is engaged in developing the cultivation of white, tan-plant, «food-grade» sorghum lines in Mediterranean area (Pontieri et al, 2010, 2011, 2012, 2016). Our attempt is to select hybrids with improved nutritional characteristics and high yielding capacity among white food-grade sorghum hybrids coming from either Argentina or Bolivia, and grown in Southern Italy.

Materials and Methods

Sorghum cultivars

The sorghum cultivars and seed sources employed in this study are listed in Table 1. Full field cultivation was carried out in San Bartolomeo in Galdo (BN) in an area called Fortore, in Campania Region, South of Italy, were soils are predominantly clay loam, deep and with a good water holding capacity.

Floor sample preparation

Approximately 1,000 g of grain samples were turned into flour with a two-roll mill (Chopin mod. Moulin CD1). Subsequently, the flours so obtained have been sieved with a planetary sieve (Buhler), through a 120 μm^2 sieve opening.

Humidity

Humidity was determined according to the AOAC (1995, 925.09) method and as described by Pontieri et al (2011).

Ash

For ash measurement, sorghum samples (ca 3g each) were weighed into shallow, relatively broad ashing dish that has been ignited at ~550°C, cooled in a desiccator, and weighed soon after reaching room temperature (AOAC, 1923).

Protein content

Nitrogen concentration was obtained by the Kjeldahl method (AOAC, 1920), and total protein content was estimated using a conversion factor of 6.25. Sorghum samples (2 g each) were analyzed using a Mineral Six Digester and an Auto Disteam semi-automatic distilling unit (International PBI, Milan, Italy).

Total lipid content

Lipid content in the sorghum grain samples was determined as described by Pontieri et al (2010). About 3 g each sample was grinded with liquid nitrogen in a mortar and lyophilized using an FTS-System Flex-DryTM instrument. The samples were extracted using a Soxhlet apparatus with chloroform ($CHCl_3$) for 4 h, then were dried using a rotary evaporator to obtain the crude extracts which were weighed to obtain the amount of extracted fat. Samples were analyzed in triplicate.

Gas Chromatography of Fatty Acids

Esterification of fatty acids from bulk populations, and gas chromatographic analysis of fatty acid methyl esters were carried out as described by Pontieri et al (2011).

Carbohydrates

Total carbohydrates were determined as described by Arienzo et al (2003).

Fiber

Fiber was determined according to the (AOAC, 1995, 962.09) method. In particular, fiber was considered to be the loss, after incineration, of a certain rate of the sample digested in acid environment by H_2SO_4 0.255 N, followed by an alkaline digestion by NaOH 0.223 N. Digestion was obtained with an automatic digestor (Velp Scientific mod. FIWE3).

Total minerals determination

The determination of the mineral elements of interest was performed according to Tenore et al (2012) as described by Pontieri et al (2014).

Results

Nutrient composition

The chemical composition of white food-grade sorghum hybrids coming from either Argentina or Bolivia, and grown in Southern Italy is shown in Table 2. With reference to Argentina hybrids their nutritional

Table 1 - List of sorghum hybrids.

Hybrid name	Source	Supplied by
RV03 = SASG03W	Semillas Hibrridas Gaiman s.r.l. Venado Tuerto (Santa Fè, Argentina)	Alberto L Chessa
RV05 = SASG05W	Semillas Hibrridas Gaiman s.r.l. Venado Tuerto (Santa Fè, Argentina)	Alberto L Chessa
RV05 = SASG06W	Semillas Hibrridas Gaiman s.r.l. Venado Tuerto (Santa Fè, Argentina)	Alberto L Chessa
RV05 = SASG07W	Semillas Hibrridas Gaiman s.r.l. Venado Tuerto (Santa Fè, Argentina)	Alberto L Chessa
RV05 = SASG08W	Semillas Hibrridas Gaiman s.r.l. Venado Tuerto (Santa Fè, Argentina)	Alberto L Chessa
B01 = SW6129W	Sem West s.r.l. (Santa Cruz de la Sierra, Bolivia)	Alberto L Chessa

Table 2 - Sorghum samples nutritional values.

	RV03	RV05	RV06	RV07	RV08	B01
Humidity (%)	12.8 ± 1.02	15.4 ± 0.62	13.3 ± 1.06	18.1 ± 1.45	12.6 ± 0.63	12.8 ± 0.90
Ashes (%)	2.1 ± 0.17	2.5 ± 0.18	2.1 ± 0.15	1.9 ± 0.15	2.1 ± 0.13	2.2 ± 0.13
Total proteins (%)	5.9 ± 0.35	8.4 ± 0.34	5.1 ± 0.15	9.3 ± 0.74	8.9 ± 0.27	7.6 ± 0.23
Total fats (%)	2.25 ± 0.11	2.93 ± 0.18	2.38 ± 0.07	2.66 ± 0.21	2.58 ± 0.21	3.57 ± 0.14
Saturated fats (g per 100 g raw fat)	0.4 ± 0.03	0.5 ± 0.03	0.3 ± 0.02	0.4 ± 0.01	0.4 ± 0.02	1.2 ± 0.08
Total carbohydrates (%)	74.06 ± 5.18	67.66 ± 3.38	68.64 ± 2.75	64.25 ± 2.57	69.48 ± 5.56	70.07 ± 2.80
Sugars (%)	0.9 ± 0.03	0.9 ± 0.05	0.7 ± 0.03	0.5 ± 0.02	0.6 ± 0.02	0.7 ± 0.02
Fiber (%)	2.89 ± 0.23	3.11 ± 0.12	8.48 ± 0.34	3.79 ± 0.15	4.34 ± 0.35	3.76 ± 0.23
Monounsaturated fats (g per 100 g raw fat)	0.7 ± 0.06	1.3 ± 0.05	1.0 ± 0.06	1.1 ± 0.06	0.9 ± 0.04	1.7 ± 0.12
Polyunsaturated fats (g per 100 g raw fat)	1.2 ± 0.06	1.1 ± 0.07	1.11 ± 0.04	1.2 ± 0.05	1.3 ± 0.05	0.7 ± 0.05

profiles were nearly similar with a slight variation in total protein percentage of RV07 hybrid, which was higher in comparison with those of the other Argentina hybrids, while the RV06 hybrid had a higher percentage in fibers in comparison with the other Argentina hybrids. Moreover, the nutritional values of the B01 hybrid from Bolivia were almost similar to those of the Argentina hybrids except a higher fatty acids percentage.

Fatty acid composition of total lipids

Fatty acid composition of total lipids of sorghum cultivars analyzed is presented in Table 3. Linoleic was the predominant fatty acid in all extracts, followed by oleic acid and palmitic acid, which agree with the results previously reported (Osagie, 1987; Serna-Saldivar and Rooney, 1995; Pontieri et al, 2011). The percentage of linoleic acid of the RV03 Argentina hybrid was higher in comparison with both the other Argentina hybrids and the B01 Bolivia hybrid, while the percentage of oleic acid of the B01 Bolivia hybrid was higher in comparison with that of all Argentina hybrids analyzed. The results in Table 3 have been also illustrated by bar graph (Figure 1).

Minerals content

Results of macro-element, micro-element, and trace element analyses of the six sorghum hybrids are reported in Table 4 and in Figure 2. The content of macro-elements followed the sequence K > Mg > Ca > Na in the analyzed samples. The content of micro-elements followed the sequence Fe > Zn > Al > Mn > Cu > Ni > Cr > Ba > Pb > Mo > As > Sn > Ag > Co > Se > Be > V > Tl. The content of trace elements followed the sequence Sb > Hg > U > Cd. Slight variations in the content of the elements were found among the six white sorghum hybrids examined, and K, Fe and Sb were, respectively, the most abundant macro-element, micro element and trace element in all analyzed hybrids. Besides, potassium and sodium contents of the samples varied from 26.98 to 33.14 g kg^{-1} and 0.21 to 0.69 g kg^{-1}, respectively. The potassium content of the hybrid samples ranged from about 42-fold to 123-fold higher than that of sodium. Therefore, the K:Na ratio was similar or higher than the recommended ratio 5.0 (Szentmihalyi et al, 1998) for human diet.

Discussion

The main purpose of the present study was to analyze the white food-grade sorghum hybrids coming from Argentina and Bolivia to select the most suitable for the growth and production of high-quality grain in the Mediterranean area of Southern Italy. Indeed, it

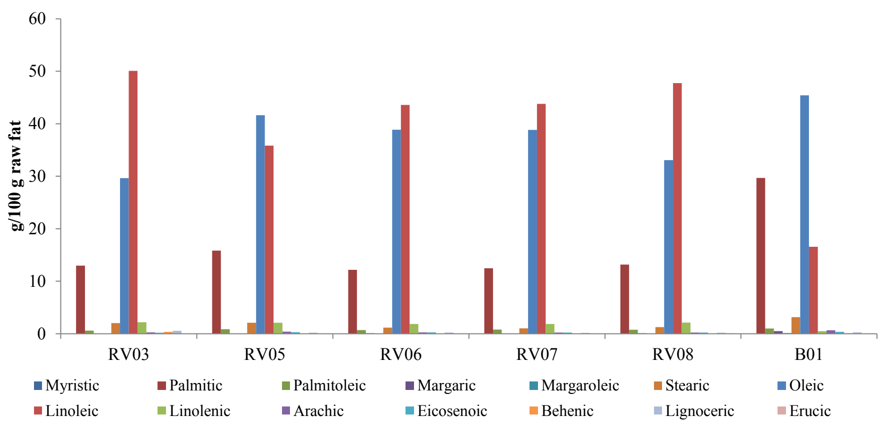

Figure 1 - Bar graph of fatty acids contents of sorghum hybrids.

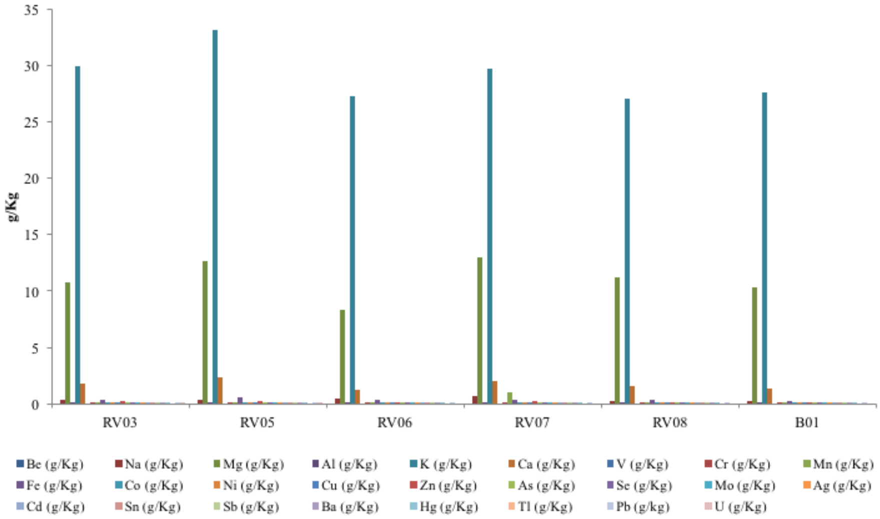

Figure 2 - Bar graph of macro-elements, micro-elements, and trace elements content of sorghum hybrids.

was reported that sorghum composition could vary significantly due to genetics and environment (Serna-Saldivar and Rooney, 1995).

As shown in Table 2, the percentages of components in all analyzed sorghum hybrids were comparable among them. An exception is the total protein content of RV07 hybrid, which was higher in comparison with those of the other hybrids analyzed, while the fatty acids content of the B01 hybrid from Bolivia was higher than the other analyzed sorghum hybrids.

As shown in Table 3 and Figure 1, linoleic was the predominant fatty acid in all extracts, followed by oleic acid and palmitic acid, which agree with the results previously reported (Osagie, 1987; Serna-Saldivar and Rooney, 1995; Pontieri et al, 2011). The fatty acid composition for all sorghum cultivars was qualitatively and quantitatively similar with slight variation among them. In fact, the percentage of linoleic acid of the RV03 Argentina hybrid was higher in comparison with both the other Argentina hybrids and the B01 Bolivia hybrid, while the percentage of oleic acid of the B01 Bolivia hybrid was higher in comparison with that of all Argentina hybrids analyzed. From these data, it is noted that the monounsaturated fatty acid rate is 37% on average and essentially composed of oleic acid, while the polyunsaturated fat rate is about 40% and essentially composed of linoleic acid. Unsaturated fatty acids are of great importance to diet, because they are significant components of the biological membranes and play the role of fluidity modulators in them. Moreover, unsaturated fatty acids are not cholesterogenic (unlike saturated fatty acids), and lower the risk of thrombosis, due to their anti-aggregating activity on blood lipoprotein particles. These two features make them strongly recommended to lower the risk of atherosclerosis (Dicko et al, 2006; Taylor et al, 2006; Stefoska-Needham et al, 2015).

Both Table 4 and Figure 2 show the concentrations of macro-elements K, Na, Mg, Ca and P. The content of each macro-element followed the sequence K > Mg > Ca > Na in all six sorghum hybrids analyzed. The most abundant mineral was K, followed by Mg, a fact that is consistent with the literature data (Afify et al, 2012; Pontieri et al, 2014). Both

Table 3 - Fatty acid content (g per 100 g raw fat) of food-grade sorghum hybrids.

	RV03	RV05	RV06	RV07	RV08	B01
Myristic	0.018±0.001	0.012±0.001	0.035±0.002	0.010±0.001	0.019±0.001	0.014±0.001
Palmitic	12.970±1.038	15.828±0.475	12.156±0.729	12.462±0.498	13.162±1.053	29.688±0.891
Palmitoleic	0.575±0.046	0.870±0.035	0.697±0.042	0.778±0.054	0.751±0.045	0.988±0.069
Margaric	0.068±0.003	0.069±0.006	0.106±0.005	0.067±0.005	0.088±0.006	0.498±0.040
Margaroleic	0.073±0.004	0.055±0.002	0.073±0.005	0.073±0.004	0.064±0.003	0.137±0.005
Stearic	2.030±0.081	2.095±0.126	1.161±0.058	1.030±0.041	1.260±0.038	3.146±0.094
Oleic	29.658±2.076	41.631±2.082	38.878±2.333	38.846±2.719	33.064±1.323	45.433±3.635
Linoleic	50.071±2.003	35.840±1.792	43.601±1.744	43.803±2.628	47.763±1.433	16.576±0.663
Linolenic	2.175±0.109	2.103±0.063	1.870±0.075	1.846±0.055	2.121±0.170	0.498±0.040
Arachic	0.262±0.010	0.394±0.032	0.240±0.010	0.213±0.006	0.211±0.013	0.664±0.046
Eicosenoic	0.190±0.008	0.283±0.023	0.240±0.012	0.229±0.011	0.215±0.015	0.345±0.010
Behenic	0.354±0.011	0.058±0.005	0.028±0.002	0.073±0.005	0.031±0.002	0.087±0.005
Lignoceric	0.557±0.022	0.185±0.015	0.218±0.007	0.157±0.008	0.198±0.010	0.254±0.013
Erucic	0.031±0.022	0.018±0.001	0.064±0.004	0.011±0.001	0.080±0.005	0.066±0.005

Table 4 - Elements content in sorghum hybrids.

	RV03	RV05	RV06	RV07	RV08	B01
Be (mg kg^{-1})	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Na (g kg^{-1})	0.34±0.02	0.41±0.02	0.45±0.03	0.69±0.04	0.21±.0.01	0.26±0.01
Mg (g kg^{-1})	10.75±0.64	12.61±0.38	8.34±0.42	12.99±0.39	11.24±0.67	10.29±0.51
Al (mg kg^{-1})	101.67±4.07	161.66±4.85	49.59±3.97	57.56±4.60	75.39±3.77	57.45±4.02
K (g kg^{-1})	29.89±0.90	33.14±1.33	27.26±1.36	29.70±2.08	26.98±1.62	27.58±1.93
Ca (g kg^{-1})	1.83±0.07	2.41±0.14	1.25±0.06	1.97±0.08	1.55±0.05	1.35±0.09
V (mg kg^{-1})	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cr (mg kg^{-1})	15.70±1.10	33.85±2.03	31.48±1.26	16.22±0.65	15.04±0.60	8.06±0.56
Mn (mg kg^{-1})	62.92±3.78	87.51±4.38	52.74±2.11	97.52±4.88	74.12±5.93	60.33±1.81
Fe (mg kg^{-1})	366.59±22.00	552.66±38.69	353.99±28.32	358.93±28.71	317.40±19.04	245.73±12.29
Co (mg kg^{-1})	0.40±0.02	0.92±0.06	0.55±0.03	0.47±0.03	0.35±0.03	0.22±0.01
Ni (mg kg^{-1})	18.07±1.45	41.06±2.05	28.76±0.86	19.06±1.52	26.72±1.34	12.20±0.85
Cu (mg kg^{-1})	23.69±1.18	40.15±1.20	23.88±1.19	33.15±2.32	37.73±2.64	28.85±1.15
Zn (mg kg^{-1})	238.15±14.29	269.95±18.90	171.63±10.30	235.17±18.81	190.40±9.52	192.11±5.76
As (mg kg^{-1})	1.14±0.06	0.24±0.01	0.56±0.04	0.31±0.02	0.28±0.01	0.63±0.04
Se (mg kg^{-1})	0.10±0.01	0.06±0.00	0.08±0.00	0.05±0.00	0.06±0.01	0.08±0.00
Mo (mg kg^{-1})	1.30±0.06	1.63±0.05	1.23±0.09	1.94±0.16	1.29±0.08	1.91±0.15
Ag (mg kg^{-1})	0.73±0.04	0.30±0.02	0.18±0.01	0.14±0.01	0.13±.0.01	0.11±0.01
Cd (μg kg^{-1})	11.50±0.58	34.50±2.07	12.50±1.00	27.50±1.93	38.50±1.93	20.50±0.82
Sn (mg kg^{-1})	0.81±0.03	0.29±0.01	0.19±0.01	0.15±0.01	0.16±0.01	0..13±0.01
Sb (μg kg^{-1})	85.00±3.40	61.00±1.83	38.00±1.52	28.50±1.71	36.00±2.88	15.00±0.75
Ba (mg kg^{-1})	6.72±0.34	2.29±0.25	4.42±0.31	6.33±0.19	6.43±0.26	6.01±0.42
Hg (μg kg^{-1})	65.00±4.55	55.00±1.65	57.00±3.42	49.50±3.96	48.00±3.84	49.00±2.45
Tl (mg kg^{-1})	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Pb (mg kg^{-1})	2.05±0.12	1.42±0.11	0.61±0.02	2.50±0.10	1.20±0.05	0.69±0.02
U (μg kg^{-1})	21.50±1.29	6.18±0.31	2.96±0.21	3.77±0.30	2.54±0.08	3.37±0.27

Table 4 and Figure 2 also show the concentrations of micro-elements Fe, Zn, Al, Mn, and others. The content of each micro-element followed the sequence Fe > Zn > Al > Mn > Cu > Ni > Cr > Ba > Pb > Mo > As > Sn > Ag > Co > Se > Be > V > Tl in all six sorghum hybrids analyzed. The most abundant micro-element was Fe, confirming the data reported in the literature (Jambunathan, 1980; Afify et al, 2012; Pontieri et al, 2014). Finally, Table 4 and Figure 2 show the concentrations of trace elements whose content followed the sequence Sb > Hg > U > Cd.

With reference to the macro-elements content, the present study shows a K:Na ratio higher than the recommended ratio for the human diet in all seven sorghum hybrids analyzed (Szentmihalyi et al, 1998). In fact, it is well known that an improved K:Na ratio in the diet may benefit bone health, reduce muscle loss, as well as mitigate other chronic diseases such as hypertension and stroke (Arbeit et al, 1992). Moreover, the magnesium content in all hybrids was higher than those in corn flour (on average, 0.47 g kg^{-1}) and wheat flour (on average, 0.25 g kg^{-1}) as reported in Danish Food Composition Databank (Saxholt et al, 2008). Since the six sorghum hybrids have higher magnesium contents, they could be considered as sources of magnesium, which is required for the function of many enzyme systems in human metabolism (Saxholt et al, 2008).

Regarding the micro-elements content, the results reported in the present study show high content of both Fe and Zn in all sorghum hybrids. The latter two elements are essential micro-elements in human nutrition, and their deficiencies are major public health threats worldwide (Ashok-Kumar et al, 2010).

With reference to the trace elements such as Sb, Hg, U, Cd, they could be toxic to human health at concentrations higher than a certain limit. However, the concentrations of trace elements in the seven sorghum hybrids analyzed in this study do not exceed the maximum permitted by Regulation (CE) n. 1881/2006 that fixes a limit of some contaminants in food.

Moreover, in this work, the sorghum hybrids coming from Argentina and Bolivia were also analyzed by immunochemical point of view to measure the concentration of gliadin. The results indicated that the gluten levels in all sorghum cultivars were less than 5 ppm (data not shown). Those values are well below the 20 ppm threshold that has been proposed to be safe for celiac patients (Valdés et al, 2003).

Sorghum has considerable further potential to be used as a human food and beverage source. Particularly in the developed countries, there is today a growing demand for gluten-free food and beverages from people with celiac disease and other intolerances to wheat, who cannot eat products from wheat, barley, or rye (Taylor et al, 2006). The future promise of sorghum in the developed world is for wheat substitution for people with celiac disease or allergies to gluten (Fenster, 2003; Ciacci et al, 2007). The present study verified an acceptable strategy of testing white food-grade sorghum hybrids from different parts of the world and growing them in the Mediterranean region, and demonstrated the validity of additional testing to select the best white sorghum varieties from the point of view of the content of nutrients and high yield capacity. The results also confirmed previous works (Pontieri et al, 2010, 2011, 2012, 2014, 2016) on the possibility of expanding sorghum cultivation in the Mediterranean for human use.

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