Antioxidant and Antibacterial Activities of Total Polyphenols Isolated from Pigmented Sorghum (Sorghum bicolor) Lines

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ABSTRACT

Methanolic extracts from pigmented grains of ten sorghum lines (LKhs 1, LKhs 3, LKhs 5, LKhs 8, LKhs 10, LC-9, LC-13, L47, LIND and LDeib) were analyzed for total polyphenols, carotenoid contents, antioxidant capacity and antibacterial activity. Antioxidant activities were determined using a number of in vitro assays, including DPPH (2, 2-diphenyl-1-pycrilhydrazil hydrate) radical scavenging activity, ABTS (2,2’-azinobis3-ethylbenzothiazoline- 6-sulphonic acid) radical cation scavenging activity and FRAP (Ferric-reducing antioxidant power) assays. These various antioxidant activities were compared to standard antioxidants such as butylated hydroxyanisole (BHA), α-tocopherol, ascorbic acid and trolox. The yield of methanolic extracts obtained from the pigmented grains was in the range of 1.51 – 3.24%. The total polyphenols and carotenoids were in the range of 229 ± 11 – 787 ± 34 mg GAE/100 g and 8 ± 0.5 – 21 ± 2.3 μg β-carotene/100 g, respectively. The scavenging effects of all grain extracts on the DPPH radical were greater than that of BHA and α-tocopherol and less than that of ascorbic acid. The relative abilities of grain extracts to scavenge the ABTS radical (ABTS+) generated in the aqueous phase, were in the range of 32 – 74% compared to 82% for the trolox. Line LC-9 showed much higher ABTS radical scavenging activity (74%) than the other lines (32 – 63%). The reductive capabilities of grain extracts on ferric-ferricyanide complex, were extremely high (0.44 – 0.82 at 700 nm) compared to control (0.08 at 700 nm). Lines LC-9, LIND, L47, LC-13 and LDeib exhibited the highest antioxidant capacities and thus could be potential rich sources of natural antioxidants. The total polyphenol contents were highly correlated with the DPPH (R² = 0.915), ABTS (R² = 0.902) and FRAP (R² = 0.903) values. This indicated that polyphenols were the major contributors to antioxidant properties of sorghum grains. There were significant variations in the degrees of antibacterial activities of grain extracts on test bacteria. With the exception of extract from line LKhs 8, all other extracts strongly inhibited the growth of E. coli (14 – 30 mm). However, none of methanolic extracts showed antibacterial activity against Bacillus subtilis. These results provide evidence that some of the pigmented sorghum might indeed be potential sources of new antibacterial agents. Line LC-9 showed significantly higher antioxidant activity and yielded high amount of both polyphenol and carotenoid contents than the other lines. However, this line may provide a source of new antioxidant in diets as well as genes for new improved varieties for use in food and medicinal purposes.

Key Words: Antioxidant, antibacterial, polyphenols, pigmented sorghum.

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INTRODUCTION

Sorghum is recognized as an important crop throughout the arid tropical and sub-tropical regions of Africa, Asia and Central America. Given its natural tolerance to heat and drought stress, sorghum is a key crop in providing food security for millions of people in these regions (Tuinstra, 2008). In Africa, most of the grain is used to prepare foods and beverages for human consumption including traditional stiff or thin porridges, granulated foods and beer (Awika and Rooney, 2004 and Dicko et al., 2005). It is a very important crop in the Sudan serving as a primary source of food, beverage and total livelihood for millions of people in the country. The crop originated in the Northeast quadrant of Africa and the Sudan is widely recognized as a major centre of diversity (Grenier et al., 2004). It is the staff of life for all Sudanese. In many parts of the country the crop is wholly utilized (Ejeta, 1989).

Polyphenols are plant metabolites characterized by the presence of several phenol groups (i.e., aromatic rings with hydroxyls), which derive from L-phenylalanine (Knaggs, 2003 and Boudet, 2007). The most important polyphenol classes are phenolic acids, which include polymeric structures, such as hydrolyzable tannins, lignans, stilbenes and flavonoids. Flavonoids include flavonols (e.g., quercetin and kaempferol, the most ubiquitous flavonoids in foods), flavones, isoflavones, flavanones, anthocyanidins (pigments responsible for the colour of most fruits), flavanols (catechins-monomers and proanthocyanidins-polymers, known as condensed tannins) (Scalbert and Williamson, 2000 and Manach et al., 2004). Some polyphenol hydroxyls are very reactive in:
I. Neutralizing free radicals (-R') by donating a hydrogen atom (-RH) or an electron (-R') (Leopoldini et al., 2006).

II. Chelating metal ions in aqueous solutions (Leopoldini et al., 2006; Lavid et al., 2001 and Erdemoglu and Gucer, 2005).

III. Binding and precipitation of proteins, due to extensively coating of hydrophobic surfaces of peptides and then to cooperative bridge formation (Zhu et al., 1997 and Charlton et al., 2002).

Nowadays, phenolic compounds are generally regarded as desirable components of human food, because of their antioxidant activity. Therefore, they are considered to be of nutraceutical importance (Awika and Rooney, 2004; Parr and Bolwell, 2000, Santos-Buelga and Scalbert, 2000). Sorghum is rich in phytochemicals known to significantly affect human health, such as tannins, phenolic acids, anthocyanins, phytosterols and policosanols (Awika and Rooney, 2004). Recent studies have shown that sorghum has antioxidant activity (Choi et al., 2007), anticarcinogenic effects (Kwak et al., 2004) and cholesterol lowering effects (Ha et al., 1998) and can reduce the risk of cardiovascular disease (Cho et al., 2000). Furthermore, sorghum has been shown to possess DPPH radical-scavenging activity and direct antimutagenic effects (Kwak et al., 2004). However, little information is available concerning the antimicrobial effects of sorghum.

Recent epidemiological studies have suggested that increased consumption of whole grains, fruits and vegetables is associated with reduced risks of chronic diseases (Hu, 2002). This association may be attributed to the natural antioxidants from plant foods such as vitamin C, tocopherol, carotenoids, polyphenolics and flavonoids, which prevent free radical damage (Diplock et al., 1998). Sorghum varieties have unique compositions of 3-deoxyflavanones (Awika and Rooney, 2004, Hwang et al., 2004) and other components that are different from those found in other cereal grains. Evidence indicates that sorghum extracts and sorghum-based products have very powerful free radical scavenging properties in vitro (Awika et al., 2003). Limited data also suggest that the unique sorghum phytochemicals may have stronger biological activity than analogous compounds from other food plants (Carr et al., 2005 and Shih et al., 2007).

AIM OF THE STUDY

The objectives of this study were to determine antioxidant and antibacterial activities of methanolic extracts from pigmented grains of different sorghum lines and to explore relationship between antioxidant activity and antioxidant content in the samples.

MATERIALS AND METHODS

Sample preparation:
Grain samples of different sorghum lines (LKhS 1, LKhS 3, LKhS 5, LKhS 8, LKhS 10, LC-9, LC-13, L47, LIND and LDib) were kindly donated for use in this study by the Sorghum Breeding Programme (SBP), Faculty of Agriculture, University of Khartoum, Shambat, Sudan. Ten g of finely ground samples were extracted in 200 ml methanol on a shaker (Eyela Model MMS-300, Tokyo Rikakikai Co., Ltd., Japan) at room temperature for 24 h. Subsequently, the extracts were centrifuged at 8000 rpm for 15 min and the supernatants were filtered through a Whatman No. 2 filter paper. The combined filtrate was evaporated at 40°C. The dried extract was weighed and redissolved in methanol to a concentration of 2 mg/ml then stored at −20°C until analysis.

Determination of total polyphenol and carotenoid contents:
Total polyphenol contents in the extracts were determined using the Folin-Ciocalteu method (Dewanto et al., 2002) with some modifications; results were expressed as mg gallic acid equivalents per 100 g of grain. Total carotenoid contents in the extracts were determined by a spectrophotometric assay described by Lee and Castle (2001) with some modifications. Approximately, 5 ml of extract were mixed with equal volume of distilled water and 15 ml of hexane/acetone/methanol (50/25/25, v/v) solution. The mixture was homogenized then centrifuged at 3000 rpm for 10 min. The absorbance of the top layer of hexane was measured at 450 nm using a spectrophotometer. Total carotenoid contents of the samples were calculated as µg β-carotene per 100 g of sample.

Antioxidant activity determination:
Three methods, DPPH, ABTS and FRAP were used. These methods are based on reaction with electron-donating or hydrogen radicals (H) producing compounds/antioxidants according to the reaction R + Aox-H → RH + Aox.

DPPH radical scavenging activity:
The DPPH (2,2-diphenyl-1-pycrilhydrazile hydrate) radical scavenging activity of grains was estimated according to the method explained by Blois (1958). Briefly, 0.1 mM solution of DPPH in methyl alcohol was prepared and 1 ml of this solution was added to 3 ml of sample or standard. Discolorations were measured at 517 nm after incubation for 30 min at 30°C in the dark. Lower absorbance of the reaction mixture indicates higher free radical scavenging activity. The percentage of DPPH which was scavenged (%DPPH*sc) was calculated using:

%DPPH*sc = (Acont − Asamp) × 100/Acont

Where, Acont is the absorbance of the control and Asamp is the absorbance of the sample.

ABTS radical scavenging activity:
The scavenging activity of grains on ABTS (2,2’-azinobis (3-ethylbenzothiazoline- 6-sulfonic acid) radical cation scavenging activity was estimated according to the method of (Re et al., 1999). Briefly, ABTS radical cation was freshly prepared by mixing 14 mM ABTS with an equal volume of 4.95 mM potassium persulphate and kept for 24 h in dark at room temperature. This ABTS radical cation solution was used for the assay after dilution in phosphate buffer saline (PBS) appropriately. To 50 µl of sample or standard, 150 µl of ABTS radical solution was added. After one min incubation at room temperature, the absorbance was measured at 734 nm. Methanol was used
as a blank solution and ABTS solution without the sample served as a control. Trolox was used as a reference synthetic antioxidant compound. Reduction of ABTS radical in percent (R %) was calculated the same as described in DPPH radical assay.

Ferric-reducing antioxidant power (FRAP):
The FRAP (Ferric-reducing antioxidant power) of grain extracts was determined according to the method of Oyaizu (1986) with some modifications. One ml of each sample was mixed with phosphate buffer (2.5 ml, 0.2 M, pH 6.6) and 2.5 ml of 1% potassium ferricyanide (K₃Fe (CN)₆). The mixture was incubated at 50°C for 20 min and then 2.5 ml of trichloroacetic acid (10%) was added to the mixture, which was centrifuged at 1000 rpm for 10 min. The upper layer solution (2.5 ml) was mixed with distilled water (2.5 ml) and FeCl₃ (0.5 ml, 0.1%) and the absorbance was measured at 700 nm. A higher absorbance indicates a higher reductive capability.

Antibacterial activity:
Four bacterial species, namely, Bacillus subtilis (ATCC 25924), Pseudomonas aeruginosa (ATCC 27853), Escherichia coli (ATCC 25922) and Salmonella typhimurium (ATCC 14028) were used as test bacteria. Each bacterial species was suspended in 500 ml of nutrient broth and incubated overnight at 37°C. The culture was diluted 1/10 with sterile normal saline to produce the bacterial stock suspension (10⁸ - 10⁹ cfu/ml) were thoroughly mixed and its antibacterial activity of grain extracts. To 250 ml of the culture was adopted with some modifications to 1/10 with (ATCC 25922) and (ATCC 14028) were used as test bacteria. Each bacterial species was suspended in 500 ml of nutrient broth and incubated overnight at 37°C. The culture was diluted 1/10 with sterile normal saline to produce the bacterial stock suspension (10⁸ - 10⁹ cfu/ml).

The cup-plate agar diffusion method (Murray et al., 1995) was adopted with some modifications to assess the antibacterial activity of grain extracts. To 250 ml of the sterile Mueller-Hinton medium, 2 ml of bacterial stock suspension (10⁶ -10⁹ cfu/ml) were thoroughly mixed and its temperature was maintained at 45°C. Twenty five ml aliquots of inoculated medium were distributed into sterile Petri dishes to give a depth of about 4 mm. Wells were punched in the agar then filled with 0.1 ml of each extract. The extracts were allowed to diffuse at room temperature for two hours, after which the plates were incubated at 37°C overnight. Antibacterial activities were evaluated by measuring inhibition zone diameters. Methanol served as a control and was inactive against all test bacteria.

Statistical analysis:
The obtained data of the different tests were subjected to statistical analysis. The SPSS version 16.0 for Windows Statistical Package was used for the analysis. One-way analysis of variance (ANOVA) was used to test for significant differences between means of measured parameters. The Duncan’s Multiple Range test was used for further multiple comparisons among the means.

RESULTS AND DISCUSSION

Total polyphenol and carotenoid contents:
Phenolic compounds are secondary metabolites, which synthesize in plants. They have biological properties such as antioxidant, anti-apoptosis, anti-aging, anti-carcinogen, anti-inflammation, anti-atherosclerosis, cardiovascular protection, improvement of the endothelial function, as well as inhibition of angiogenesis and cell proliferation activity. Most of these biological actions have been attributed to their intrinsic reducing capabilities (Han et al., 2007). Recent studies (Juntunen et al., 2000 and Karppinen et al., 2003) have shown that cereal grains contain constituents that have demonstrated health benefits for humans, such as antioxidants and anti-disease factors. Among cereals, sorghum has the highest content of phenolic compounds reaching up to 6% (w/w) in some varieties (Deshpande et al., 1986; Beta et al., 1999 and Awika and Rooney, 2004). Hence, it is important to quantify polyphenolic contents in sorghum grains and to assess their contribution to antioxidant and antibacterial activities.

Antioxidants in grains are difficult to be extracted due to different solubility of active compounds (Miller et al., 2000). Previous studies reported that relatively higher antioxidant activities were observed for methanolic extracts of grains compared to the other solvents including n-hexane, diethyl ether, ethyl acetate, acetone and water (Oki et al., 2002). Therefore, methanol was selected as an extraction solvent in this study. Yields of methanolic extracts (as percentage w/w) obtained from sorghum grains are presented in (Table 1) and the grains gave a yield of 2.3 – 6.8%. Polyphenolic contents in methanolic extracts were expressed as mg gallic acid equivalents per 100 g of sample. There was a wide variation observed in the total polyphenol content among the sorghum varieties. The total polyphenol contents of the samples ranged from 229 ± 11 to 787 ± 34 mg GAE/100 g (Table 1). Among all samples studied, five sorghum lines (LC-9, LIND, L47, LC-13 and LDeib) displayed detectable amounts of total polyphenols. However, these lines could be novel sources of bioactive components. Reports on the levels of phenolic compounds in sorghum varieties show a high intervarietal difference of contents among varieties screened (Subramanian et al., 1992; Iwuoha and Aina, 1997; Bvochora et al., 1999; Dicko et al., 2002 and 2005). However, levels of total phenols of sorghum reported in the literature vary widely due to differences in extraction solvents, test methods and standards used. This makes it difficult to do direct comparisons (Sikwese and Duodu, 2007).

Total carotenoid contents in grains, expressed as μg β-carotene equivalents per 100 g of sample, were significantly lower in all the tested samples (8 ± 0.5 – 21 ± 2.3 μg β-carotene /100 g) than the polyphenolic contents (Table 1). Carotenoids may act as singlet oxygen quencher and can transfer one electron to the radicals, giving rise to a stable carotenoid radical cation regenerating the original molecule (Mortensen and Skiksted, 1997).

Antioxidant capacity:
The antioxidant capacities of plant extracts largely depend on the composition of the extracts and conditions of the test system. The antioxidant capacities are influenced by many factors, which cannot be fully described with one single method. Therefore, it is necessary to perform more than one type of antioxidant capacity measurement to take into account the various mechanisms of antioxidant action (Wong et al., 2006). In this study, the methanolic extracts of ten pigmented sorghum grains were evaluated for antioxidant capacities using DPPH, ABTS and FRAP assays.
Scavenging of DPPH radical:
The stable DPPH radical, which has a maximum absorption at 517 nm, is widely used to evaluate the free radical scavenging activity of hydrogen donating antioxidants in many plant extracts (Brand-Williams et al., 1995; Wettasinghe and Shahidi, 2000 and Amarowicz et al., 2004). The DPPH free radicals scavenging activities of grain extracts, BHA, α-tocopherol and ascorbic acid are presented in (Figure 1). Most of the extracts exhibited remarkable scavenging effect on the stable DPPH radical. All grain extracts showed higher radicals scavenging activities (14 – 56%) than BHA (11%) and α-tocopherol (13%) and lower activity than ascorbic acid (91%). Line LC-9 had the highest DPPH quenching activity (56%) followed by LIND (42%), while LKhs 1 (14%) and LKhs 8 (16%) had the lowest activity. (Dlamini et al., 2007) reported that tannin sorghums, Red Swazi, NS 5511 and Framida, had significantly higher ABTS and DPPH antioxidant activity when compared to sorghums without a pigmented testa layer, Macia and NK 283.

<table>
<thead>
<tr>
<th>Sorghum line</th>
<th>Total polyphenols (mg GAE/100 g)</th>
<th>Total carotenoids (μg β-carotene/100 g)</th>
<th>Yield (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LKhs 1</td>
<td>229 ± 11</td>
<td>08 ± 0.5</td>
<td>1.51</td>
</tr>
<tr>
<td>LKhs 3</td>
<td>305 ± 18</td>
<td>12 ± 1.2</td>
<td>1.82</td>
</tr>
<tr>
<td>LKhs 5</td>
<td>270 ± 13</td>
<td>12 ± 1.8</td>
<td>1.56</td>
</tr>
<tr>
<td>LKhs 8</td>
<td>233 ± 15</td>
<td>11 ± 0.9</td>
<td>1.52</td>
</tr>
<tr>
<td>LKhs 10</td>
<td>266 ± 22</td>
<td>14 ± 1.7</td>
<td>1.53</td>
</tr>
<tr>
<td>LC-9</td>
<td>787 ± 34</td>
<td>21 ± 2.3</td>
<td>3.24</td>
</tr>
<tr>
<td>LC-13</td>
<td>652 ± 25</td>
<td>18 ± 1.3</td>
<td>2.73</td>
</tr>
<tr>
<td>L47</td>
<td>670 ± 30</td>
<td>18 ± 1.7</td>
<td>2.35</td>
</tr>
<tr>
<td>LIND</td>
<td>691 ± 17</td>
<td>11 ± 1.5</td>
<td>2.86</td>
</tr>
<tr>
<td>LDeib</td>
<td>590 ± 24</td>
<td>17 ± 1.3</td>
<td>2.01</td>
</tr>
</tbody>
</table>

Values are means of three replicates ± SD.

Table 1: Total polyphenol and carotenoid contents in methanolic extracts from ten sorghum lines.

Scavenging of ABTS radical:
The ABTS method is widely employed for measuring the relative radical scavenging activity of hydrogen donating and chain breaking antioxidants in many plant extracts (Brand-Williams et al., 1995 and Netzel et al., 2003). It is recommended to be used for plant extracts because the long wavelength absorption maximum at 734 nm eliminates colour interference in plant extracts (Awika et al., 2004). The capability of the grain extracts and trolox (antioxidant standard) to scavenge ABTS radicals is shown in (Figure 2). The abilities of the tested samples to scavenge ABTS radicals were compared to trolox standard. All crude extracts exhibited good antioxidant activities (32–74%) compared to trolox (82%). The highest scavenging ability (74%) was exhibited by extract from line LC-9, while the lowest one (32%) was determined in the extract of line LKhs 1. However, the extensive investigations on antiradical and antioxidant activities of small phenolics including flavonoids and phenolic acids have been reported (Heim et al., 2002). Apart from these, (Hagerman et al., 1998) have reported that the high molecular weight phenolics (tannins) have more ability to quench free radicals (ABTS•+) and that effectiveness depends on the molecular weight, the number of aromatic rings and nature of hydroxyl groups’ substitution than the specific functional groups.

Reducing power activity:
The FRAP assay, which is a simple assay that gives fast and reproducible results (Benzie and Strain, 1996), is versatile and can be readily applied to both aqueous and alcohol extracts of different plants. In this method, ferric-ferricyanide complex is reduced to the ferrous form depending on the presence of antioxidants (Amarowicz et al., 2004). The reductive capacity of a compound may serve as a significant indicator for its potential antioxidant activity (Meir et al., 1995). The reducing power of methanolic extracts is presented in (Figure 3). All tested samples showed strong ferricion-reducing activities (0.44 – 0.82 at 700 nm) compared to control (0.08 at 700 nm). This indicated that polyphenolics in methanolic extracts of sorghum grains may play a role as electron and hydrogen donors. Extract of line LC-9 had relatively higher reducing power ($A_{700}=0.82$) than other extracts.

Figure 1: Antioxidant activity of methanolic extracts and standards using DPPH free radical-scavenging assay.

BHA: Butylated hydroxyanisole, α-T: α-Tocopherol, AA: Ascorbic acid.

Figure 2: Scavenging effect of grain extracts and Trolox (as standard) on ABTS radical cation.

Figure 3: Reducing power activity of methanolic extracts from ten sorghum lines.
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(A_{500} = 0.44 – 0.72). Miller et al. (2000) reported that the antioxidant capacities of cereals and cereal products are high, especially those of wheat, corn and sorghum. On a fresh matter basis, are even equal or higher than those of some fruits and vegetables (Miller et al., 2000 and Wu et al., 2004).

However, the antioxidant activity of putative antioxidants have been attributed to various mechanisms, among which are prevention of chain initiation, binding of transition metal ion catalysts, decomposition of peroxides, prevention of continued hydrogen abstraction, reductive capacity and radical scavenging (Gulcin et al., 2003 a and b).

![Graph](image)

**Figure 3:** Reducing power of methanolic extracts from sorghum grains.

**Correlation between antioxidant capacity and total polyphenols:**
The correlation coefficient (R²) between the antioxidant capacities and the total polyphenols of the methanolic extracts was determined (Figure 4). The R² between the antioxidant capacities obtained from DPPH, ABTS and FRAP assays, were 0.915, 0.902 and 0.903, respectively. It is clear that the total polyphenol contents of the sorghum grains correlated highly with their antioxidant activities measured by the three methods. Therefore, high phenolic content is an important factor in determining the antioxidant capacities of these grains. However, variable results have been reported on the relation between phenolic content and antioxidant activity of different plant materials. Whereas some authors found a correlation between the polyphenol content and the antioxidant activity, others found no such relationship. (Adom and Liu 2002) reported a direct correlation between total polyphenol content and antioxidant activity in extracts of corn, wheat, oats and rice.

**Antibacterial activity:**
The results of antibacterial activity of methanolic extracts obtained from the pigmented sorghum are presented in (Table 2). A wide magnitude of variation was detected among the grain extracts in their activities as well as among the tested bacteria in their sensitivities. All extracts exhibited remarkable antibacterial activity against *E. coli* (14 – 30 mm) except the extract of line LKhs 8. In contrast, none of the tested sorghum extracts inhibited the growth of *B. subtilis*. Among the ten lines, the methanol extract of LIND had the highest level of antibacterial activity (32 mm) against *P. aeruginosa*. *S. typhonium* was sensitive to methanolic extracts of lines LKhs 5, LKhs 10, LC-9, L47 and LDeib, while it did not show any sensitivity to the other extracts.

![Graph](image)

**Figure 4:** Correlating (R²) between total polyphenol content and DPPH (a), ABTS (b) and FRAP (c) assays. Values are means of three determinations ± SD.
Table 2: Antibacterial activity of methanolic extracts. The activity was determined by measuring the diameter of zone of inhibition (mm).

<table>
<thead>
<tr>
<th>Sorghum line</th>
<th>E. coli</th>
<th>B. subtilis</th>
<th>P. aeruginosa</th>
<th>S. typhimurium</th>
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<tr>
<td>LKhs 1</td>
<td>30</td>
<td>-</td>
<td>12</td>
<td>-</td>
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<tr>
<td>LKhs 3</td>
<td>18</td>
<td>-</td>
<td>10</td>
<td>12</td>
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<td>LKhs 5</td>
<td>24</td>
<td>-</td>
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<td>LKhs 8</td>
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<td>LKhs 10</td>
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<tr>
<td>LA7</td>
<td>24</td>
<td>-</td>
<td>10</td>
<td>-</td>
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<tr>
<td>LIND</td>
<td>20</td>
<td>-</td>
<td>32</td>
<td>-</td>
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<tr>
<td>LDeib</td>
<td>16</td>
<td>-</td>
<td>16</td>
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</tbody>
</table>

CONCLUSION

According to the results of this study, it can be concluded that the methanolic extracts of pigmented sorghums have significant antioxidant activities against various antioxidant systems in vitro. Moreover, the pigmented grains can be used as an easily accessible source of natural antioxidants and as a possible food supplement or in pharmaceutical industry. Polyphenol contents seem to be the main components responsible for the antioxidant activity of all grain extracts. Results suggest that these grains are not only interesting source for antioxidant activities but also potential sources of antibacterial agents.

REFERENCES


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